The Journal of
Economic Perspectives

A journal of the
American Economic Association

Celebrating 30 Years

Fall 2016

The Journal of
Economic Perspectives

A journal of the American Economic Association

Editorial offices:
Journal of Economic Perspectives
American Economic Association Publications
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Pittsburgh, PA 15203
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The *Journal of Economic Perspectives* gratefully acknowledges the support of Macalester College.
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Composed by American Economic Association Publications, Pittsburgh, Pennsylvania, USA.
Printed by R. R. Donnelley Company, Jefferson City, Missouri, 65109, USA.
No responsibility for the views expressed by the authors in this journal is assumed by the editors or by the American Economic Association.
THE JOURNAL OF ECONOMIC PERSPECTIVES (ISSN 0895-3309), Fall 2016, Vol. 30, No. 4. The *JEP* is published quarterly (February, May, August, November) by the American Economic Association, 2014 Broadway, Suite 305, Nashville, TN 37203-2418. Annual dues for regular membership are $20.00, $30.00, or $40.00 depending on income; for an additional $15.00, you can receive this journal in print. E-reader versions are free. For details and further information on the AEA go to https://www.aeaweb.org/. Periodicals postage paid at Nashville, TN, and at additional mailing offices.
POSTMASTER: Send address changes to the *Journal of Economic Perspectives*, 2014 Broadway, Suite 305, Nashville, TN 37203. Printed in the U.S.A.

The Journal of
Economic Perspectives

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Volume 30 • Number 4 • Fall 2016

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Immigrants, Productivity, and Labor Markets

Giovanni Peri

Although news reports often make international migration sound like a succession of unprecedented crises, immigration from lower-income to higher-income countries has actually been a steady force operating at a roughly constant rate during the last 50 years. There have certainly been year-to-year fluctuations and the combination of sending and receiving countries has changed somewhat over time, but a sustained and common trend is clear over the long run.

Figure 1 shows the evolution of foreign-born individuals as share of the total population in the main receiving rich countries. The United States is represented by the solid line. Europe (as summarized by 13 countries that were members of the European Union before the 2004 expansion, plus Switzerland and Norway) is shown by the dashed line. The combination of Canada and Australia is shown by the dotted line. The three country groups show a similar growth of foreign-born as share of the population: that is, an increase by 8–9 percentage points of the population over the period from 1960 to 2015, or about 0.2 percent per year.

Of course, the timing of the increase in immigration isn't identical, and year-to-year fluctuations are omitted from the graph, which connects census-year points. But as a whole, Europe experienced acceleration in the growth of the foreign-born population share since 1990 with the opening of Eastern Europe and larger migrations from North Africa. Individual European countries had a variety of immigration experiences, and Table 1 provides some of the most recent figures. Some countries, such as Austria, Luxembourg, Switzerland, Sweden, and Ireland, reached

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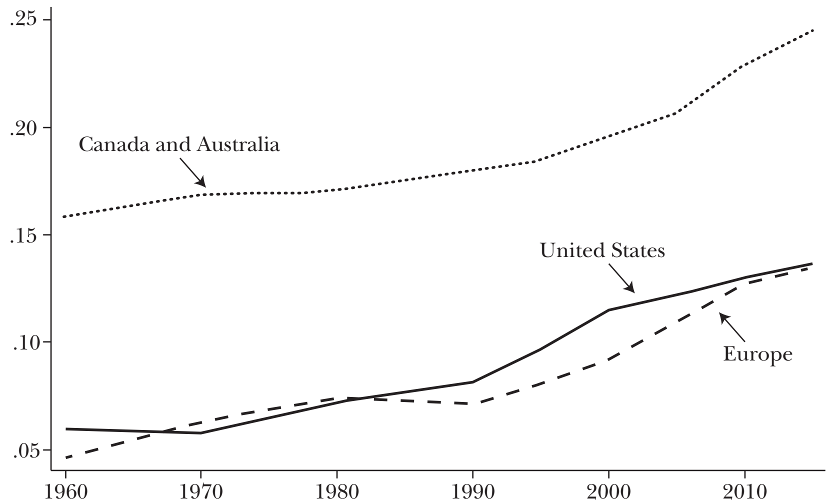
† For supplementary materials such as appendices, datasets, and author disclosure statements, see the article page at
http://dx.doi.org/10.1257/jep.30.4.3 doi=10.1257/jep.30.4.3

Figure 1
Foreign-Born as Share of the Population



Sources: Original data sources are the National Censuses and other National Population surveys. For the period 1960–1980, we use the aggregation of immigrants reported in World Bank (2012), while for the period 1990–2015, we used United Nations (2015). Total Population data are from the World Bank.
Notes: The figure shows total foreign-born as share of the total population in the United States, Europe, and Canada-Australia. The countries included in what we call Europe are 13 countries of Western Europe that first joined the European Union before 2004 (Austria, Denmark, Finland, France, Germany, Greece, Ireland, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom—excluding Belgium and Italy for which data are not available) plus Switzerland and Norway.

shares of immigrants above 15 percent in 2015, with fast growth during the previous two decades. In some cases, such as Spain and Ireland, the last 20 years marked the only period of significant immigration, beginning with a very small foreign-born population in 1995. For other countries, such as Finland and Portugal, immigrants as percentage of population are still in the single digit. Looking again at Figure 1, we see that, relative to Europe, the United States has been on a roughly steady immigration trajectory since 1970, with a faster rate in the 1990s (a period of large immigration from Mexico). Canada–Australia experienced an acceleration during the ten years since 2005. In 2015, about 13 percent of the population in the United States and Europe and about 25 percent of the population in Canada and Australia was foreign-born.

The presence of foreign-born in Europe, the United States, Canada, and Australia increased significantly over the last four decades, despite the fact that immigration policy did not become significantly more open in these countries over the same period. For example, in the United States, the Immigration and Naturalization Act of 1965 established the prevailing principles and rules that still govern immigration policies. Although all of these nations have seen some changes to

Table 1
Immigration in European Countries

Country in Europe	*Share of immigrants in population 2015*	*Change in immigrant share 1995–2015*	*Country of origin of the largest groups of immigrants*		
			Largest	*2nd largest*	*3rd largest*
Austria	0.17	0.06	Germany	Serbia	Turkey
Denmark	0.10	0.04	Germany	Turkey	Poland
Finland	0.06	0.04	Estonia	Sweden	Russian Federation
France	0.12	0.02	Algeria	Morocco	Portugal
Germany	0.15	0.06	Poland	Turkey	Russian Federation
Greece	0.11	0.03	Albania	Germany	Georgia
Ireland	0.16	0.10	United Kingdom	Poland	Lithuania
Luxembourg	0.45	0.14	Portugal	France	Italy
Netherlands	0.12	0.03	Turkey	Suriname	Morocco
Norway	0.14	0.09	Poland	Sweden	Lithuania
Portugal	0.08	0.03	Angola	Brazil	France
Spain	0.13	0.10	Morocco	Romania	Ecuador
Sweden	0.17	0.06	Finland	Iraq	Poland
Switzerland	0.29	0.09	Germany	Italy	Portugal
United Kingdom	0.13	0.06	India	Poland	Pakistan

Sources: The original data sources are from National Censuses and other National Population surveys. We include the 15 countries of Western Europe for which United Nations (2015) reports data on foreign-born population by country of origin consistently for the last two decades. Data on total population are from the World Bank.

immigration policies over time, those changes have not consistently reduced the entry barriers to immigrants (Ortega and Peri 2013).[1] Thus, the continuing growth in the share of foreign-born residents in these countries has been primarily driven by persistent economic and demographic forces, rather than by a policy shift aimed at opening the borders.

In this essay, I will describe the key facts about immigration to high-income countries. I will also discuss the evolution of the framework that economists use in

[1] The United States has seen two important changes in the last half-century that, although they did not alter immigration policy in a fundamental way, are worth mentioning. First, the Immigration Reform and Control Act of 1986 regularized the status of a large number of undocumented immigrants. It was followed by a high level of tolerance for the inflow and the employment of low-skilled undocumented workers during the 1990s. Second, the H-1B temporary visa program established in 1990 has subsequently become the main channel of entry for work-related high-skilled immigrants, many of whom have eventually become US residents.

thinking about its economic effects. Twenty years ago, economists typically framed their analysis of immigration as an increase in the supply of labor within a model of homogeneous workers and a downward-sloping labor demand, which was determined by the complementarity between labor and physical capital.[2] This approach tended to focus the attention of the researcher on how immigrants competed with other homogeneous workers in the labor force while keeping everything else fixed, in a "partial" view of the labor market. More recent analyses offer greater flexibility. Researchers now distinguish different types of workers by their education and other important skill dimensions (such as ability in performing manual or analytical tasks). Moreover, immigration is now analyzed in a framework that looks at its total effects and accounts for many responses to immigrants: from native workers, in terms of possible complementarities and degrees of specialization; from firms, in terms of choices about capital and technology; and even from consumers, in terms of the mix of goods and services they choose to purchase. Unsurprisingly, this framework has produced a richer set of possible effects of immigrants on wages and employment of natives. Indeed, not only economists studying labor markets but economists studying regions, firms, trade, and investments have begun analyzing the multifaceted impact of immigration.

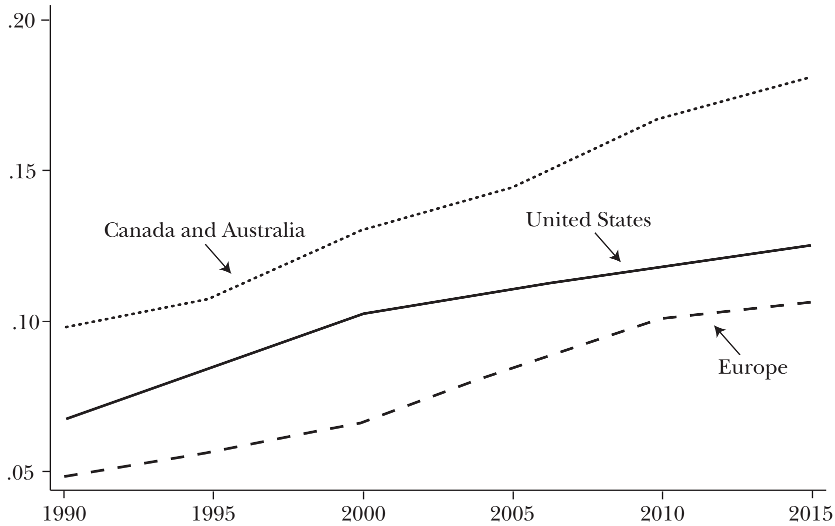
Trends in Origins and Skill Levels of Immigrants

Up until about 1990, immigrants from other high-income countries represented a significant share of total immigrants, especially in inter-European migration and in Canada and Australia (which received a large share of migrants from Europe). However, the growth of the foreign-born population during the last 25 years has been mostly fueled by the growth in immigrants from nonrich countries. In the United States, immigrants from nonrich countries, especially from Asia and Latin America, were the largest part of the foreign-born population already in the 1970s, and the whole increase since 1990s has been due to their growth. In Europe, however, immigration from Asia, Africa, and Latin America was much less prevalent before 1990. Figure 2 shows for the United States (solid line), Europe (dashed line), and Canada–Australia (dotted line), the immigrants from nonrich countries (that is, originating outside of this group itself) as share of the population since 1990. The growth of that group accounts for the whole growth of foreign-born, expressed in terms of population share, experienced in those country groups during the period considered (compare with Figure 1).

Two qualifications of this phenomenon are important. First, the "nonrich" countries with largest emigration rates to high-income countries are those at intermediate levels of economic development, like countries in Latin America (for

[2] As an example of discussions based on this approach, this journal published a three-paper "Symposium on Immigration" in the Spring 1995 issue, assessing the labor market impact of immigrants in 1995. Borjas (1995) and Friedberg and Hunt (1995) are two very highly cited essays from that issue.

Figure 2
Foreign-Born from Nonrich Countries as Share of the Population

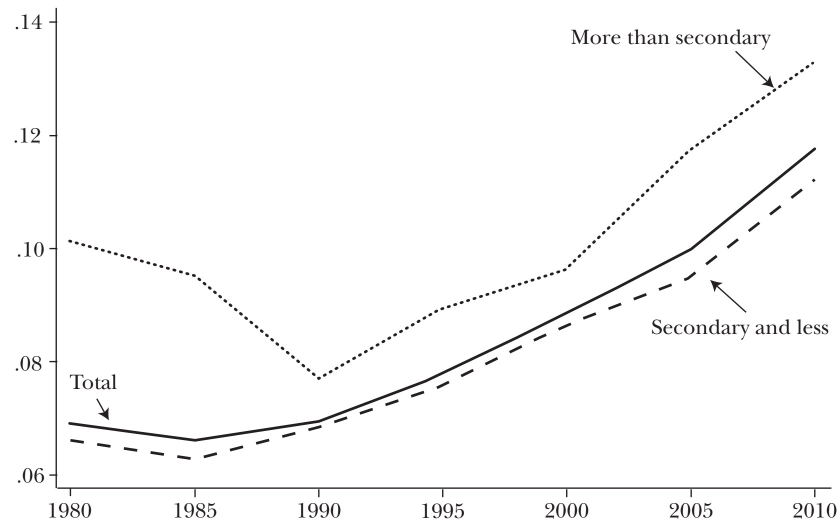


Sources: The data source for immigrant counts is United Nations (2015), and data on total population are from the World Bank.
Notes: The figure shows foreign-born from outside of Europe, the United States, Canada, and Australia as percentage of the population. The solid line represents the figures for the United States, the dashed line for Europe (as defined in Figure 1), and the dotted line is the aggregation of Canada and Australia. The period covered is 1990–2015.

example, Mexico), East Asia (for example, the Philippines), or North Africa–Middle East (for example, Algeria or Morocco), but not the poorest part of the world like the countries of sub-Saharan Africa. Since 1990, about 50 percent of immigrants to the United States, Europe, Canada, and Australia were from Asia, 30 percent from Latin America, and only 20 percent from Africa. Emigration is generally low from very poor countries; indeed, growth in income and education in very poor countries is frequently associated with increased emigration rates because migration becomes more affordable and economic returns to emigration grow. Emigration to high-income countries is better described (as in Clemens 2014) as a phase in the economic development of a country rather than an escape valve for countries most deeply mired in poverty.

A second important qualification is that, while immigration from nonrich countries often conjures images of large masses of unskilled laborers, in reality it has been quite skill-intensive. The composition of immigrants into high-income countries, even if they originate from countries with lower income per person, tends to be more concentrated among highly educated than among less educated, relative to the population of the country of destination. Grogger and Hanson (2011) show that highly educated people are much more likely to migrate and obtain the largest economic gains from migration. Figure 3 shows the trends over time for

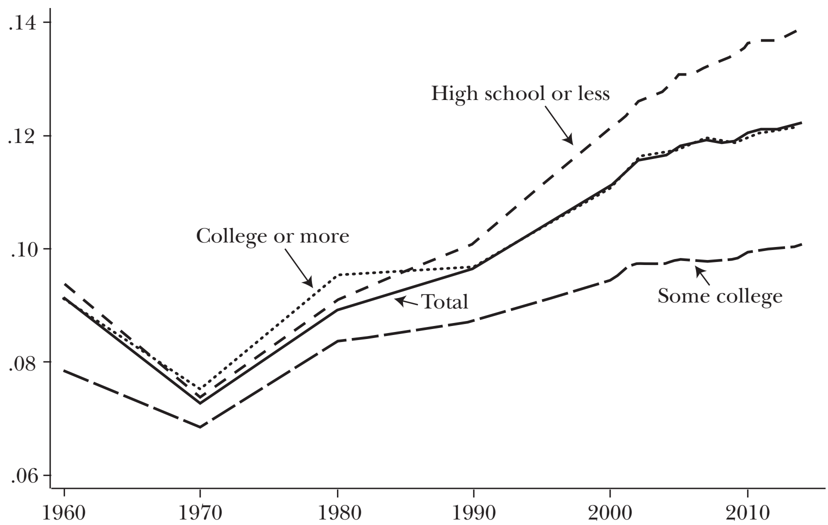
Figure 3
Foreign-Born Share in Europe, by Schooling Group



Sources: The data source is Brücker, Capuano, and Marfouk (2013) for the number of immigrants by education group and Barro and Lee (2013) for the number of natives by education group.
Notes: The figure aggregates the 15 countries included in our definition of Europe. It shows the foreign-born share of the population (thick bold line), the foreign-born share for the population with a secondary education or less (dashed line), and the foreign-born share for the population with more than secondary education (dotted line). The period covered is 1980–2010.

migrants to Europe: the thick line shows the foreign-born share of the population; the dashed line shows the foreign-born share for the population with secondary education or less; and the dotted line shows the foreign-born share for the population with more than secondary education. A qualitatively similar pattern appears in the data for Canada and Australia (not shown): that is, the foreign-born were overrepresented in the higher education group vis-à-vis natives. If we consider that natives in the receiving countries increased significantly their level of schooling during the considered period, and also that the average schooling in countries of origin of immigrants was usually lower than in the receiving countries, we realize that immigrants were very positively and increasingly selected along the education dimension. Thus, migrants from nonrich countries were highly educated not just relative to other people in their countries of origin (Docquier and Marfouk 2004; Docquier, Lohest, and Marfouk 2005; among others) but, usually, also relative to the country of destination (Docquier, Ozden, and Peri 2014). This strong selection can be rationalized by the fact that highly educated individuals are those for which absolute returns to migration are largest, because rich–poor country wage differentials between skilled workers are larger than the differentials between low-skilled workers.

Figure 4
Foreign-Born Share in the United States by Schooling Group

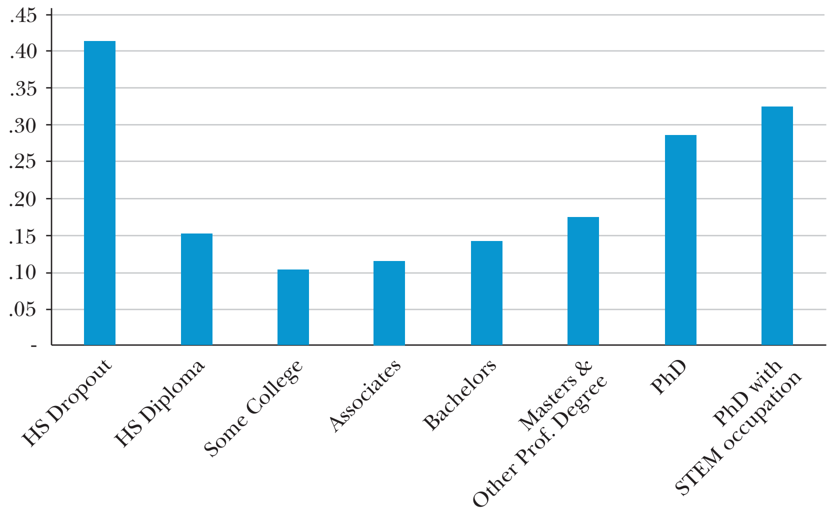


Notes: The figure is relative to the United States. The solid line represents foreign-born as share of the resident population, 18 years and older. The short-dashed line represents foreign-born with high school degree or less as share of residents with high school degree or less. The long dashed line represents immigrants with some college education but no degree as share of the residents with some college but no degree. The dotted line represents the college-educated foreign-born as share of college-educated residents. The source of data is the US Census 1960, 1970, 1980, 1990, 2000, and, yearly, American Community Survey, 2000–2014.

Figure 4 shows these patterns for the United States since 1960. The solid line shows the foreign-born share of the US population, and then the US population (older than 18) is divided into three groups: those with high school diploma or less, those with some college education, and those with a college degree or more. US immigrants were underrepresented at intermediate levels of "some college" education, shown by the long-dashed line. However, they were overrepresented both among less-educated (short-dashed line) and among college-educated-or-more, shown by the dotted line. Figure 5 illustrates this point more vividly. It presents the share of foreign-born as of 2014 divided into eight education groups, showing that US immigrants are overrepresented at the two extremes of this skill distribution. One-third of US workers with a PhD and a job in a STEM (science, technology, engineering, and mathematics) field were foreign-born in 2014, as well as 40 percent of workers with no high school diploma. We will discuss the implications of this distribution in the next section.

An additional fact about the distribution of foreign-born in the United States is that the immigrant population tends to be much more spatially concentrated than the native population (as discussed in Lewis and Peri 2015). Only

Figure 5
Foreign-Born Share of Employment by Schooling Group, United States, 2014



Source: The data include US residents 18 years and older from the ACS 2014.
Notes: The groups are defined as follows: "HS Dropout" is the group with no high school diploma. "HS Diploma" is the group that has a high school diploma as highest degree and no further education. "Some College" is the group with a diploma and some college attendance but no degree. "Associates" is the group with an associate degree. Bachelors" is the group with a Bachelor degree. "Master and Other Professional Degree" is the group with a Master degree or a professional (law, medical) degree. "PhD" is the group of people with a PhD. "PhD with STEM occupation" is the group with PHD employed in STEM occupations as defined in Peri, Shih, and Sparber (2015).

5 percent of the US rural population is foreign-born. However, that share grows to 8 percent in urban areas that are not in the top 100 in terms of population, to 12 percent among the top 100 metro areas by population, to 30 percent in the top ten metro areas by population, and 39 percent in the top two metropolitan areas of New York and Los Angeles. This tendency to agglomerate in large urban areas as well as the large college share of immigrants (and even more, the large share of immigrants among those with science, technology, engineering, and mathematics degrees) implies that immigrants could be contributing to human capital agglomeration and density externalities. Faster learning, better employer-employee matches, lower transportation costs, cross-fertilization of ideas, and similar productivity-enhancing externalities—of the type identified in Ciccone and Hall 1996; Moretti 2004a and b; Greenstone, Hornbeck, and Moretti 2010; and Iranzo and Peri 2009—could be strengthened by the described features of US immigrants. The next section explores economic frameworks that lay out the channels for these effects and, in general, for the effects of immigrants on labor productivity and wages.

Canonical and More Recent Economic Frameworks

When analyzing the labor market impact of immigrants on wages during the 1980s and 1990s, economists usually started within a basic framework sometimes called the "canonical" model. This approach considers immigration as a change in supply of homogeneous aggregate labor. It assumes that the most relevant factor determining labor demand (that is, marginal productivity of labor) is the amount of physical capital, which is considered fixed in the short run and adjustable in the long run. Hence the only predicted effect of increased immigration in this model is an increase of labor supply along a downward-sloping demand curve in the short run and then a movement along a horizontal demand curve in the long run, when capital adjusts (as long as we assume constant returns to scale to capital and labor). When using this model, economists asked: "What is the elasticity of labor demand in the short run?" The answer would determine the extent of the negative effect of immigration on native wages in the short run.

The last 20 years of research have shown that this canonical model excessively constrains our understanding of the effects of immigration. More recent frameworks have offered several variations and typically have incorporated four features that are absent or undeveloped in the canonical model: 1) immigrants are analyzed as a change in the supply of heterogeneous workers[3] in a general equilibrium context; 2) there is significant variety and differentiation between the kinds of tasks that immigrants and natives are more likely to perform; 3) native workers and firms can shift their choices in response to immigration; and 4) immigrants may affect the total factor productivity at the local (city, region) level.

Skills of Immigrants and Skills of Natives

A first aspect of the new framework is that it moves away from analyzing immigration as a partial equilibrium change in the quantity of homogeneous labor supply. Instead it considers immigration within the framework of general equilibrium changes of heterogeneous labor supply. Specifically, it views immigrant workers, as providing differentiated inputs in production, where a key aspect differentiating the inputs of workers is their level of education. Moreover, as the inflow of immigrants has been a continuous phenomenon, protracted across the decades (albeit with yearly fluctuations), this framework recognizes that physical capital has adjusted at comparable speed requiring a general equilibrium approach.

[3] As many readers will recognize, other fields of economics have evolved along roughly similar lines. For example, international trade economists have learned the advantages of analyzing trade between heterogeneous firms with different productivity (Melitz 2003) while allowing for the possibility of trading and offshoring productive tasks (Grossman and Rossi-Hansberg 2008). Labor economists have learned the importance of thinking within a framework where heterogeneous workers and machines perform productive tasks with different degrees of complementarity and substitutability (see the excellent review in this journal by Autor 2015). The framework here achieves similar progress in thinking of the effects of immigrants on labor market outcomes and productivity of natives.

The choice of how to partition workers of different education levels into different and complementary (rather than easily substitutable) production skills has been a debated topic. It is an important choice because the partition of skill groups and their degree of complementarity has implications for how changes in relative demand and relative supply translate into wage changes. A group of studies (such as the seminal paper by Card and Lemieux 2001, and then Card 2009; Goldin and Katz 2008; and Ottaviano and Peri 2012) has argued that the most relevant partition across workers by education groups is between people with at least some college education and people with a high school degree or less. We will call these two groups "college-educated" and "non-college-educated." These two groups of workers tend to be employed in different occupations. They use different technologies and are characterized by different productive abilities. More importantly, the relative wage of college-educated has grown relative to non-college-educated during the last 40 years, driven by technological and structural change, and it has also been negatively affected by their relative supply, revealing a significant degree of complementarity between these two groups (Autor, Katz, and Kearny 2008).

Another line of research, however, emphasizes that further partitioning along the schooling dimension is needed to understand the impact of immigrants (for example, Borjas, Grogger, and Hanson 2012). In particular, workers with no high school degree and workers with just a high school degree should be considered as differentiated and complementary rather than as substitutes. This choice would imply a more concentrated competition effect of immigrants among workers with no degree (where supply of immigrants is larger) and positive complementary effect on workers with just a high school degree. We do not think that the balance of empirical evidence supports this assumption, as relative wages of high school dropouts and graduates do not seem to respond to changes in their relative supply, either at the national (Ottaviano and Peri 2012) or the local level (Card 2009).

We recognize, however, that the estimate of elasticity of substitution across education groups is sensitive to the empirical specification and to the identification assumptions (a point made in Borjas, Grogger, and Hanson 2012), and hence there is room for disagreement on this issue. Other subpartitions of immigrant skill levels according to experience or age have been used, but workers' productive skills seem significantly more interchangeable (substitutable) across ages, and we will not focus on this dimension here.[4]

Considering "college-educated" and "non-college-educated" as the two relevant labor inputs has two consequences. First, the inflow of immigrants to the United States was quite balanced, nationally, between these two education groups: In 2014, the percentage of foreign-born among US workers with less than a college degree

[4] The age structure of immigrants could be relevant in affecting relative wages of young and old workers, but the literature has not focused much on this issue. Potentially more relevant is the fact that, as immigrants are younger than natives, they can reduce the dependency ratio and help fund social security in rich countries. This point has been made in several policy reports and anecdotally, but we do not know of academic papers that analyze this effect in detail.

was 16.9 percent, and among those with college or more it was 16.1 percent. Thus, the effect of immigration on the relative supply of these two types of labor was limited. Hence, purely through forces of substitution or complementarity, US immigration would not have much effect on relative wages of college and non-college workers at the national level. Second, as US immigration was a continued and fairly steady phenomenon during the last 40 years, capital could adjust (as argued in Ottaviano and Peri 2012), so also the absolute wage of each group should have remained rather stable in response to immigration. These considerations suggest that if we limit the focus to relative skill supply and physical capital adjustment, and if we emphasize the college/non-college division as the most relevant skill partition, the general equilibrium effects of immigration on wages of natives during the last decades should have been quite small.

Differentiation among Productive Tasks

The second aspect of the new framework is that within the group of college- and non-college-educated, it can be useful to consider workers as differentiated in their supply of productive "tasks." For the group of non-college-educated, it makes sense to separate the supply of manual tasks, which are more commonly performed by immigrants, and nonmanual tasks—mainly communication-interaction tasks—more commonly performed by natives. For example, if we rank occupations by their manual content (defined as intensity of use of eye-hand-foot coordination measured by the Dictionary of Occupational Titles produced by the US Department of Labor), we find that in 2014 the foreign-born made up about 18 percent of noncollege workers doing jobs with little manual content, but about 32 percent of the jobs with the highest level of manual content (based on our own calculations using US Department of Labor information on occupation skill content and American Community survey data). For the group of college-educated, on the other hand, it makes sense to separate what are often called the math-analytical tasks from the rest, which can be broadly classified as managerial-communication tasks. Immigrants with college education are more likely to have jobs that focus on tasks in the math-analytical category. With immigrants changing the relative supply of manual and math-analytical abilities within the two education groups, this could generate depressing effects on wages in manual tasks (within non-college-educated) and in math-analytical tasks (within college-educated). Through complementarity, it would also generate an increase in the wage of nonmanual and nonmath-analytical occupations, which would disproportionately benefit native workers.[5]

[5] If one is not interested in analyzing the mechanism at work with regard to the tasks and occupational specialization of immigrants and natives, but only the wage effects of immigration on natives of different education levels, then one can simply consider the college- and non-college-educated to be imperfectly substitutable inputs, and immigrants and natives to be imperfectly substitutable subgroups within each of those. Because of specific skills, abilities, and preferences, these two groups are imperfect substitutes, and one can estimate the degree of complementarity with natives and the implied relative wage effects from an inflow of immigrants with given skill distribution. This has typically been done in a nested constant elasticity of substitution production function framework (Ottaviano and Peri 2012; Manacorda,

The principle of comparative advantage can help explain why US migrants are especially prevalent in physical-manual and math-analytical types of tasks. Manual abilities are transferrable across countries but communication abilities (especially if native languages are different) are much harder to transfer. Hence, non-college-educated immigrants working in the US have comparative advantages in manual tasks. For college-educated immigrants, math-analytical skills are more easily transferred across countries than managerial and communication skills, which are more culture and country specific. Moreover, college-educated immigrants are a selected group with high ability levels.

Margins of Adjustment

A third important aspect of the new and more general framework is that it considers workers' and firms' responses to the changes in relative supply of productive skills brought by immigrants. In general, native workers will tend to move away from task/skills supplied by immigrants and towards tasks/skills complemented by them.

Task and skill supply will respond, slowly, to relative wages. This adjustment may occur, in part, through changes in the educational choice of natives (within college or noncollege groups) by adding a few years of schooling; for example, Hunt (2012) finds that in areas with a large inflow of noncollege immigrants, natives tend to complete high school at higher rates. The shift can also take place by choosing different areas of study. However, it mostly takes place as native workers move towards occupations that specialize in abilities complementary to those of immigrants. Hence, as immigrants are absorbed in manual jobs (such as construction workers, food industry workers, housekeepers, cleaning crews, and waiters), less-educated natives move to more communication-intensive jobs (construction site supervisors, restaurant managers, farm managers, sale representatives, and similar occupations), whose relative demand increases. This response, together with the change in relative wages, will enhance the complementarity and reduce competition between immigrants and natives of similar educational levels (Peri and Sparber 2009). As for the college-educated group, while foreign scientists and engineers are hired in US companies, native highly-skilled workers pursue more managerial-organizational careers attracted by the premium paid by those jobs, again spurred by complementarity and limited competition with the math-analytical immigrant workers (Peri and Sparber 2011). The idea of individuals adjusting their occupational choice in response to relative compensation is at the base of the Roy (1951) model. The current framework considers it as a task-intensity choice.

Native workers might respond with geographic mobility, too: for instance, native workers can move out of a local economy, like a city or region, if their skills

Manning, and Wadsworth 2012). The results for the US economy as an aggregate imply zero to small positive wage effects of immigrants on natives, which arise as a direct consequence of the balanced college–non-college distribution of immigrants and their small degree of imperfect substitutability with natives. The task framework, however, allows us to "open the box" and study in greater detail one important mechanism through which immigrants and native are different, and it introduces further testable predictions of the impact of immigrants on natives.

are substitutes (or move in if their skills are complements) with those of immigrants. While there is some debate on the geographical mobility of natives in response to immigrants, most studies do not seem to find a very significant role for it (for example, Peri 2012; Peri and Sparber 2009), potentially because other mechanisms already reduce wage impacts and because of moving costs.

A different type of adjustment may also occur at the firm level. Firms choose technology, often associated with a specific type of capital equipment, also responding to the skill supply in the labor force (as illustrated in Acemoglu 2002). For instance, facing a larger supply of manual skills, firms will choose more manual-intensive techniques (possibly reducing mechanization of some processes, as shown in Lewis 2011), or in some locations in which immigration is non-college-intensive, firms can use technology that makes more intensive use of such workers (as shown in Peri 2012). Both adjustments will attenuate any downward effect of skill supply on wages by increasing the productivity of the abundant factor. Moreover, such adjustments may come with efficiency gains and thus some overall boost in average wages of both native and immigrant workers.

Externalities of Immigration

The fourth important aspect of the new framework is that immigrants may generate productive externalities. Several mechanisms are potentially important here.

First, because of the overrepresentation of immigrants among college-educated and science and engineering jobs, immigrants may improve learning and promote innovation at the local level (as illustrated by Kerr and Lincoln 2010; Hunt and Gauthier-Loiselle 2010). A series of papers has argued for positive productivity effects of college-educated in US cities (Moretti 2004a, b; Iranzo and Peri 2009). More recently, local productive externalities of scientists and engineers have been specifically measured (Peri, Shih, and Sparber 2015), and the local multiplier effects of high human capital jobs have been found (Moretti and Thulin 2013).

Second, given the tendency of immigrants to concentrate in urban and particularly in higher-population areas, immigrants may enhance agglomeration externalities by increasing the density of economic activity (as in Ciccone and Hall 1996) based on co-location, reduction of transport costs, increases in local learning, and thicker and more efficient labor markets (Ellison, Glaeser, and Kerr 2010; Greenstone, Hornbeck, and Moretti 2010; Chassamboulli and Palivos 2014).

Yet another channel of positive local productivity effects, potentially important but harder to measure, is that productive benefits may arise from "place of birth" variety in workers, which in turn may generate a greater variety of ideas and increase the variety of goods and services supplied locally (as in di Giovanni, Levchenko, and Ortega 2015) or enhance productivity (Ottaviano and Peri 2006; Ortega and Peri 2014; Trax, Brunow, and Suedekum 2012). In some local services like restaurants and entertainment, the variety brought by foreign-born workers may enhance the amenity value of a location, and make it more attractive to (some) natives. Similarly immigrants may increase the supply and lower the price of some local nontradable services, such as housekeeping, gardening, and child care (Cortés 2008; Cortés and Tessada 2011). This may increase the real income of native residents who consume those services at lower cost and, at the local level it may act as a positive productivity boost.

Finally, if immigrants increase the price of fixed local factors such as land, they may have a negative externality effect on real wages. Land is not a very relevant factor in production in the US economy, but its value can be an important component of housing prices and rental services. Hence, economists have analyzed how immigrants impact the price of housing across US metropolitan areas. Saiz (2007) finds a significant positive effect of immigration on housing costs, which can be due to a constrained supply of housing and represents a crowding externality. However, if accompanied by growth in wages and employment (as in Ottaviano and Peri 2006), it may also in part reflect the higher willingness-to-pay of individuals due to the amenity value of local goods and service variety brought by immigrants, especially by the highly skilled among them.[6]

Overall, this broader framework for assessing the effects of immigration has important implications. It brings to center stage the analysis of general equilibrium effects of immigration, rather than focusing on partial effects only. Combining the college/non-college framework, physical capital adjustment, and the skill-supply and technology response to the manual and math-analytical changes in skills brought by immigrants, it implies that immigration may not have a strong impact on native relative or absolute wages. Several margins of adjustment will work to reduce the impact of immigrants. The framework also predicts a change in specialization of natives in response to immigration, and it opens the possibility for a positive long-run effect on productivity through local externalities and local price and variety effects. Within this rich set of possibilities, we now turn to the empirical analysis.

Empirical Evidence

The recent empirical literature has made progress in estimating some important parameters that determine the intensity of relative wage effects across skills, as well as parameters that capture the margin of response of native specialization and productivity.

We begin here with the so-called "national approach," which focuses on immigration changing the relative skill supply in labor markets, largely leaving aside other considerations. Those studies consider different skill groups within the whole US as separate labor markets whose demand are connected by their relative substitutability or complementarity in production (such as Borjas 2003; Ottaviano and Peri 2012). This approach focuses on the analysis of complementarity across skills, but it ignores the margins of change in native supply/specialization and the

[6]Diamond (2016) finds that the share of college-educated in a metropolitan area represents a very important amenity and that people, especially the highly educated, are willing to pay for it in the form of higher house price and rents.

technological adjustment, discussed above. We then turn to the studies focused on the margins of adjustment of native labor supply, and on technology adoption and on externality effects of immigrants. Because these effects are more likely to be localized, researchers have mainly used area-level data, especially analyzing metropolitan areas or states. Finally, we turn to quasi-experiments, which study the effects of an exogenous and sudden shift that affects immigration.

All of these approaches are useful and informative. We will discuss what we can learn from each, as well as potential limitations and how economists have improved identification strategies and their understanding of the general equilibrium effects of immigrants using each approach.

National Approach: Focus on Skill and Structure

In the national approach, the researcher first divides workers into education-age cells (or more generally skill cells), which are combined in a production function at the aggregate US level. This approach then estimates the elasticity of substitution across these cells, using the relative wage response to inflows of immigrants that produced changes in relative skill supply. Borjas (2003) pioneered this approach, building on Card and Lemieux (2001). In Ottaviano and Peri (2012), we extended it, focusing on certain details and assumptions that matter in terms of results. Let's first sketch the methodology of this approach and then consider some findings.

The methodology of this approach begins by partitioning the population by education, age, and US or foreign place of birth. These characteristics are the main determinants of people's skills. Using several observations from the national data over time, it is possible to estimate the elasticity of substitution across those skill cells. However, to have enough statistical power, one has to impose a specific structure of skill complementarity that reduces the number of possible elasticity parameters. The most-used framework, for its tractability and robustness, is the nested constant elasticity of substitution (CES) structure. One common "nesting" structure divides workers into education groups to determine the first partition, and then into experience groups within education groups, and then distinguishes native and immigrant groups within experience groups.

Once elasticities are estimated using regressions, the researcher then needs to "simulate" the general equilibrium effects of immigration to account for direct competition effects (from immigrants in the same cell) and indirect complementarity effects (from immigrants in other cells). The strength of each effect is determined by the elasticity estimates, the structure of the production function, and the inflow of immigrants in each group. This approach makes clear that looking only at the reduced form regression of wages of native workers on the inflow of immigrants in that skill cell (controlling for fixed effects that capture the cross-skill complementarity effects), does not provide information on the general equilibrium effect of immigrants on wages of that group. That regression estimates a partial, relative effect, which needs to be combined with other elasticities and with the supply of immigrants by skill to obtain the wage effect on each skill group.

What are the assumptions behind this approach for identifying causality? This approach often seeks to address issues of omitted variables, like unobserved shocks in the demand for skill groups, by including fixed effects for skill (as proxied by education or experience) and time. Thus, the identifying assumption behind this approach is that, after controlling for unobserved demand changes using fixed effects, the remaining variation of immigrants by skill cell is driven by changes in their supply. The national growth of some industries or occupations that increases the demand for workers in specific skill cells (by age and education level) can threaten the identification assumption of this approach, by affecting wages and the inflow of immigrants in a cell.

Several relevant results emerge from this approach (for more discussion, see Ottaviano and Peri 2012). First, college and noncollege workers appear harder to substitute with each other than any other subgroup by age and/or finer gradations of education. The evidence suggests that it is a reasonable approximation to consider the other education and age subgroups within college and noncollege as perfectly substitutable when evaluating the general equilibrium effects of immigrants.[7] Second, considering immigrants and natives as two different groups, one finds a small but significant degree of imperfect substitution between them: immigrants in a skill group do not affect demand for native workers in the same group as negatively as they affect demand for other similar immigrants. Third, as the national capital–output ratio is rather insensitive to the yearly inflow of immigrants, it is reasonable to assume full adjustment of capital to immigration over a decade, which leads to keeping the capital intensity relatively stable during the last 40 years.

Taking these estimates, together with the relatively balanced college–noncollege distribution of immigrants during the last decades, produces small estimated wage effects of immigrants on any group of natives through the relative supply channel. One mostly obtains zero or slightly positive general equilibrium effects of immigration on wages of college and non-college native workers nationally between 1980 and 2010. In Ottaviano and Peri (2012), we analyze the effect for 1990–2006, finding in our preferred specification (table 2, column 6) an impact between (positive) 0.3 and 0.6 percent on wages of native noncollege workers and ranging from 0.3 to 1.3 percent for college-educated workers.[8] The simulated standard errors for those values are around 0.3–0.4 percent. Overall, focusing on the education-experience structure of immigrant labor supply at the national level and estimating substitutability-complementarity across skills, without accounting for adjustments in total and relative productivity and task specialization, one is left with small overall effects of immigrants on native wages of any education group.

[7] We have mentioned above the disagreement by Borjas, Grogger, and Hanson (2012) on this point. They argue for finer partition of schooling groups, and emphasize that the elasticity of substitution among them is imprecisely estimated in the literature and that it can vary over a large range.

[8] If one assumes instead the complementarity between high school graduate and high school dropouts preferred by Borjas (2003), immigration 1990–2006 would have a negative effect on native dropout wages (-2.0 percent) but positive on native high school graduates (+1.5 percent).

Area-Level Approach: Focus on Adjustments and Identification

Researchers have used area-level analysis to study margins of adjustment other than just wages, assuming, importantly, that native workers are not fully mobile and some of the productivity impact of immigrants remains more local. Metropolitan areas or states, and more recently "commuting zones," which are places within which people work and live, have been considered as the relevant units to analyze these effects.

Two issues need to be addressed if we want to estimate causal effects of immigration on local economies. First, the variation of immigrants across specific areas in the United States is partly driven by area-specific labor demand changes, which are imperfectly observable and can be correlated with native wage and employment growth. Indeed, there is a strong, positive, and very significant correlation between immigration and changes in native wages across local areas in the United States (as discussed in detail in Basso and Peri 2015). But even if no causal relationship exists, labor response to "booming areas" will often generate a positive correlation between wage/employment growth of natives and net immigration across areas. Thus, one needs a way to control for changes in local labor market demand, and a common approach is to use instrumental variable estimation, as will be explained below. Second, cities and regions are not closed economies and hence inflows and outflows of native workers and of firms and physical capital in response to immigration need to be considered as important margins of adjustment. These two issues do not invalidate the area analysis, which is extremely useful and informative, but have to be addressed.

The so-called "shift-share" (or enclave) instrument has become prevalent in this empirical literature, following an early intuition by Altonji and Card (1991) later developed in Card (2001). This strategy tries to isolate supply-driven changes of immigrants in local areas. It relies on the fact that, due to early circumstances related to distance from port of entry, historical accident, and preference of migrants, some areas in the United States were settled by groups of immigrants from specific countries before the surge in foreign-born that started in the 1970s. In the 1960s, for instance, Philadelphia had a large historical community of Italian immigrants, Boston was home to a large share of Irish immigrants, Los Angeles had a significant Mexican population, and San Francisco had a large Chinese community. Because of the role of immigrant networks in channeling information and assisting new arrivals, people immigrating after the 1970s were more likely to locate where a large community of co-nationals already existed. The prior distribution of immigrants in the 1960s, combined with the fact that, immigration rates boomed since the 1980s for some nationalities, such as Mexicans and Chinese, while they remained low for other groups, such as the Italians and Irish, imply very different inflows of immigrants across metropolitan areas.

The "shift-share" approach allocates total immigrants from each country proportionally to their 1970 share across US states (or metropolitan areas). In this way, researchers can exploit the aggregate surge in emigration from some countries (and not from others) and their unequal prevalence across areas in 1970 to obtain supply-driven differential growth of immigrant labor across US areas. The variation of this shift-share instrument is driven by aggregate national and international factors that affected emigration from different countries. Hence, these factors are plausibly independent of local labor demand changes in US areas. In the first stage of this two-stage least squares approach, this instrument is used to predict immigration in US areas, hence isolating supply-driven inflows. In the second stage, using only the variation predicted for the supply-driven component, we estimate immigration's effect on native wages and employment.

It is important that the initial distribution of immigrants from each specific country is not correlated with strongly persistent area-specific demand changes; for this reason, it is often desirable to use the distribution of immigrants several years before the beginning of the period analyzed, which ideally should correspond with an immigration surge.

Using a shift-share instrument for the measurement of changes in immigration across US metropolitan areas, in Ottaviano and Peri (2006), we estimated a significant positive effect from increased immigration on labor productivity, especially if immigrants are from a variety of countries of origin. In Peri and Sparber (2009), we show that high immigration in US states produced a significant shift of native non-college-educated workers towards nonmanual occupations, complementary to immigrant specialization, with marginally positive effects on their wages. In Peri (2012), I show, and Lewis (2011) also shows, that large inflows of less-educated immigrants (usually Mexican) produced a choice of production techniques at the state or metro area level that tended to be more intensive in the use of unskilled and less-educated workers. As a consequence, the local wage of noncollege natives did not change much in response to larger immigrant supply. Taken as a group, these studies show how a combination of complementarity, productivity effects, and margins of adjustment, combined to attenuate negative effects on less-educated workers and contributed to potentially positive average wage effects on natives. These studies also found small to no significant response of employment and outward mobility of natives to an increase in immigrant supply. The adjustment to increased immigrant supply took place mainly within the area, rather than spilling over to other areas, with little impact on wages and productivity of non-college-educated.[9]

Several empirical studies of European countries that have received substantial immigration flows—such as the United Kingdom, Germany, Spain, and Italy—have also applied the area approach using shift-share instruments. Overall, the evidence

[9] The measure of change in labor supply due to immigration is a very important detail in calculating correlations between the growth of immigrant population and the change of native average wages (and employment) across US labor markets. The measure that should be used is the change in foreign-born workers (or hours worked) divided by the total *initial* labor force (or total hours worked). This variable captures the labor supply change in a local market due to immigrants in percentage points of the baseline labor force. The existing literature, on the contrary, often uses the *change* in *the immigrant share* of the labor force. That measure combines changes in immigrant and in native employment, building into the explanatory variable potentially spurious correlations with native wage and native employment changes. This point was discussed in Peri and Sparber (2011) and more recently in Card and Peri (forthcoming), which show that the specification with immigrants as share of labor force can be strongly biased and should be avoided.

points to small wage effects and possibly some negative employment effects on natives and a somewhat smaller response of native specialization (for example, D'Amuri and Peri 2014; Glitz 2012). Two papers, Angrist and Kugler (2003) and D'Amuri and Peri (2014), find smaller adjustment of natives and larger displacement effects of immigrants in European markets. They connect these findings with the lower labor market flexibility and higher costs of hiring and lay-offs that characterize several European countries. The interaction of the labor market impact of immigration with labor market institutions is an important area that deserves further attention.

Two other issues have been studied with particular emphasis in European countries, as they appear to be more relevant there. First, immigrants often have lower labor-market participation than natives and new immigrants seem to displace previous immigrants who are not fully integrated in the labor market (for example, Brücker and Jahn 2011). Hence their costs in terms of nonemployment may be higher than in the United States. Second, especially in Germany and in the United Kingdom, there seems to be a certain amount of "skill downgrading" of immigrants so that workers with relatively high schooling level perform jobs comparable to less-skilled natives. This is likely due to barriers created by language, licensing, and legal requirements. This phenomenon, as pointed out by Dustmann, Frattini, and Preston (2013), implies that immigrants are stronger competitors of natives whose education is lower than theirs than they are of similarly educated natives.

Two potentially important variations in the implementation of the shift-share method have recently been explored. A first variation is that rather than simply using variations in the national inflow of immigrants by country of origin, the construction of supply-driven immigrant changes has used variation in US immigration policies as source of change in immigrant flows. For example, the maximum allowed number (quota) for H-1B temporary visas issued by the United States sharply increased in 1999 and again in 2001 and then dropped in 2004. This visa program, established in 1990, has subsequently become the main channel of entry for work-related high-skilled immigrants. By interacting the aggregate H-1B visa quota, changing over years, with pre-existing distribution of foreign scientists and engineers across US metropolitan areas, Kerr and Lincoln (2010) identify a positive impact of increasing the quota on the amount of US patenting, especially for firms and cities highly dependent on foreign scientists. In Peri, Shih, and Sparber (2015), using similar variation, we identify a positive effect of skilled immigrants on wages of native college-educated workers across US metropolitan areas. We attribute this finding to local productivity growth driven by science and technology workers, who are key inputs in the invention and adoption of productivity-enhancing technologies and are largely overrepresented among skilled immigrants. The advantage of using policy variation such as the H-1B quota and its changes is that the estimates of these effects are more directly translated into policy evaluations. The main identifying assumption of this approach is that no metropolitan area is large enough to drive national policies: to the extent that the aggregate variation in immigration policies is independent of specific productivity changes of metropolitan areas, the estimates of local effects can be viewed as causal.

The second recent variation is that when using the shift-share instrument, researchers increasingly perform a validity check. This is aimed at establishing that, in the initial year, the distribution of country-specific foreign-born people across US areas, and hence the instrument itself is not correlated with pre-period economic trends in those areas.[10] That is, in the year chosen as the initial year, the share of foreign-born should not predict the change in native wages and employment before the analyzed period. For instance, in the United States, the year 1970 might be chosen as the initial year, as the immigration reform of 1965 started a long-trend increase in immigration (and census data are available for 1970). Hence, one should ascertain that a shift-share instrument constructed starting in 1970 for US labor markets (as measured by commuting zones or metropolitan statistical areas) is not correlated to the pre-1970 growth of wages and employment. In some European countries such as Spain, where immigration surged in the 2000s, the year 2000 might be chosen as the initial year. This validity test has only been applied fairly recently, in part because it can be tricky in some cases. One needs a clear period of immigration growth (or growth in a specific group of immigrants) considered as the "event period" that follows little or no immigration (the pre-event period). In decades of steady growth of foreign-born, or when there is no clear starting point for the phenomenon, it may be hard to identify such a pre-immigration period.

In Peri, Shih, and Sparber (2015), we show that the share of foreign-born workers in science, technology, engineering, and mathematics jobs across US metro areas in 1980 was not related to pre-1980 wage growth, but it was strongly related to growth in these jobs in the 1990s and 2000s after the H-1B visa program (which started in 1990) allowed larger inflow of these science and technology workers. In this case, the identified "high-skilled immigration period" is the 1990–2010 period, beginning with the introduction of the H-1B visa program. This finding is consistent with the idea that the shift-share instrument proxies for a supply-driven shock and is not correlated with persistent and pre-existing demand trends.

Analyzing Quasi-Experiments: What Do We Learn from Sudden Inflows?

In some circumstances, usually driven by sudden eruption of wars or abrupt changes in policies or regimes, a large and sudden flow of migrants—often refugees—arrive at a specific destination in a short window of time. In these situations, the arrival of these migrants was not the consequence of changes in economic conditions in the receiving country and often immigrants did not choose the area of settlement based on economic considerations.

Thus, these episodes approximate sudden shifts in immigrant labor supply and can be used to identify a short-run causal impact of increased immigrant supply. The econometric approach to studying these quasi-experiments typically applies a difference-in-differences method, considering the "treatment" to be the sudden

[10] The concern that past and persistent area-specific trends may affect past inflow of immigrants as well as local economic performance was first formulated in Borjas, Katz, and Freeman (1997) as they cautioned against the risks of the area approach in assessing labor market effects of immigrants.

inflow of immigrants (or refugees) into one or more local areas and choosing an appropriate control group to evaluate the impact of the treatment relative to outcomes in such a control group.

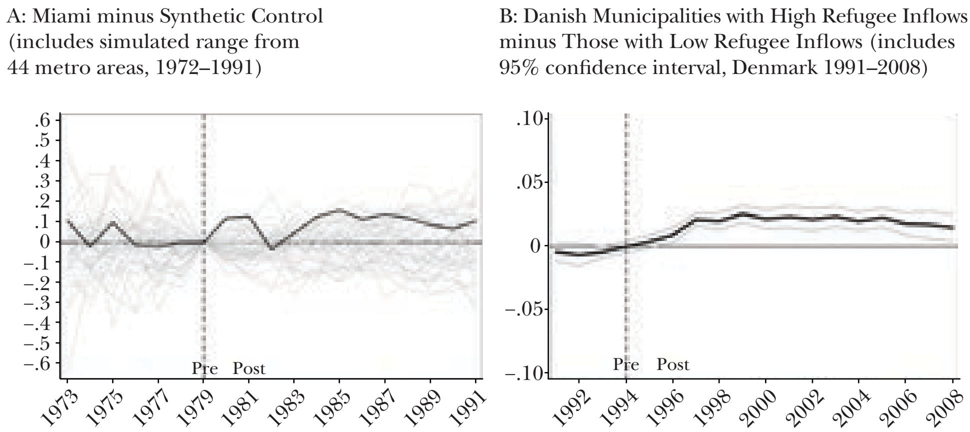
Between May and September 1980, about 120,000 Cubans left from the port of Mariel to reach the United States, as consequence of a sudden and temporary lift of the travel ban by the Castro regime in Cuba. About half of them arrived in Miami. The event was sudden, very limited in time, and not accompanied by economic crises in Cuba. Hence the Miami economy was receiving many refugees because of its pre-existing Cuban community but was unaffected by the other forces related to the Cuban outflow. This episode was first analyzed by Card (1990), who compared Miami to four control cities chosen as roughly similar to Miami in terms of black and Hispanic employment percentages and pre-1979 labor market trends. He found negligible effects on average wages and on wage dispersion in Miami relative to the control cities after 1980.

In Peri and Yasenov (2015), we revisited the Mariel boatlift episode, using the "synthetic control" method. For this method, the control group is the combination of metropolitan areas (among 44 whose data are available) that minimize the difference in some labor market variables over the 1972–1979 (pre-event) period between this control group and Miami. Because the refugees were mainly unskilled, we focus on the group of non-Cuban high school dropouts aged 19–65, the group more likely to compete with the new immigrants. While the imprecision of the estimates is large, the treatment-control difference after the Mariel boatlift actually shows a positive effect on the wages of native unskilled labor one, two, and three years after the event. However, as Figure 6A shows, the results are well within the range of simulated treatment-control differences, which capture the idiosyncratic variation in the sample, and hence no clear evidence of any wage effect is shown in the analysis.[11]

In another example of quasi-experimental variation, in Foged and Peri (2016), we analyzed the impact of the surge in refugees to Denmark from the war zones of Bosnia, Somalia, Afghanistan, and Iraq (in turn) during the period from the Bosnian crisis of 1994 to the Great Recession of 2008. The approach is to compare municipalities that were refugee-receiving (treated) and not refugee-receiving (control). The identification strategy is particularly clean in this case, because under Denmark's refugee-dispersal policy between 1986 and 1998, all refugees were dispersed without knowledge of their characteristics and quasi-randomly across municipalities; hence some municipalities happened to receive more Bosnians or Afghans or Somalis or Iraqis than others. The inflows of refugees were modest up to 1994. But, beginning in 1994, a large flow of refugees from Bosnia began (driven by the Balkan war), and

[11] Work on the Mariel boatlift is ongoing. For example, Borjas (2015) shows larger negative effects on wages after the boatlift in some subgroups (white, males, and non-young). However, this work uses different data: specifically, it uses the March Current Population Survey, while in Peri and Yasenov (2015), we use the Outgoing Rotation Group of the Current Population Survey. The March CPS sample is much smaller than the ORG-CPS, and thus statistically less reliable. It shows large imprecision, sensitivity to sample selection, huge year-to-year variation, and extremely large standard errors.

Figure 6
Treatment-Control Differences in Native Low-Skilled Logarithm of Hourly Wages in Two Quasi-Experiments



Source: Figure 6A represents author's adjustment of a figure in Peri and Yasenov (2015). Figure 6B uses the author's elaboration on estimates from Foged and Peri (2016).
Notes: Each graph shows differences in treatment-control log(wages) before and after the event, marked with a vertical line. In panel A, the thick line represents the wage difference between Miami and Control and the other lines represent the simulated differences for 44 other cities, providing the range of possible variation for the constructed statistic. In Panel B, the thick line represents the estimated difference and the two thinner lines delimit the 95 percent confidence interval.

the dispersal policy was revoked after few years. As a result, refugees from different nationalities started clustering where an existing community of co-nationals already existed, generating differential flows. These flows are quasi-randomly distributed, as they follow the initial dispersal pattern. Moreover, Denmark has administrative longitudinal data of the full population. Thus, we can track the wage and occupation for every single Danish individual over time; for example, we can track workers who lived as of 1994 in municipalities highly impacted by refugees even if they moved elsewhere. For the pre-1994 period, there was no significant difference or trend differential in the hourly wage of native workers between treated and control Danish municipalities. After 1994, a positive difference slowly emerged and persisted for native less-educated workers in the municipalities that had received more immigrants. This treatment-control difference in wages of the less educated between 1991 and 2008 is shown in Figure 6B. The explanation for this wage increase is that native low-skilled workers made a transition towards less manual and more complex (communication- and cognitive-intensive) occupations in response to the inflow of refugees, who specialized in manual jobs, and this increased their wages.

Of course, like all quasi-experiments, the Danish event analyzed here can only be generalized with caution. The larger refugee inflow starting in 1994 was distributed over time and not excessively large at any single moment (overall it increased the labor force of the treated municipalities by 2 percentage points relative to the control). It was smaller and not as sudden relative to the Mariel boatlift, allowing for the operation of adjustment on the margin. But on the other side, the sample size of the Danish data is vastly larger than the Mariel data. Moreover, the Danish data is of high quality and it follows the universe of Danish workers for 18 years, which allows an assessment of the long-run impact of low-skilled immigration through adjustment and transitions of less-educated native workers.

Studies using quasi-experimental data seem quite worthwhile, but broader lessons must be drawn with care because these sudden episodes may miss important parts of the medium- and long-run effects of immigration. In particular, five important features limit what we can learn from sudden flows of refugees. First, these episodes are rare and not representative of typical patterns of migration to high-income countries, which occur at slower and more predictable rates and are largely driven by economic motivations. As a consequence, these unexpected episodes often allow less time for adjustment on the margins, and their short-run effect may be larger than for expected episodes. Second, the type of immigrants in these episodes may be significantly less "labor market ready" than the average immigrant because they are more likely to be coming from wars and from refugee camps. Third, the suddenness of the episodes does not necessarily guarantee exogeneity of the distribution of immigrants, in which case identification of causal effects may be problematic. For instance, Hunt (1992) studied repatriates from African colonies to France, and Carrington and de Lima (1996) studied repatriates to Portugal, but those returnees could choose their destination region and hence omitted variable bias can be significant. Fourth, proximity to a crisis or to a war-ridden country of origin may affect local labor markets in the receiving country through other channels, including disruption of trade, reduced capital movements, and fear of conflict, which would in turn affect labor markets in receiving countries for reasons not directly related to the arrival of immigrants. As an example, a recent study of Syrian refugees in Turkey may suffer from this issue (Ceritoglu, Gurcihan Yuncular, Torun, and Tumen 2015). Finally, these quasi-experimental episodes often involve only a handful of regions or cities receiving a large and sudden inflow of immigrants—the Mariel boatlift was focused on immigrant arrivals in a single city—and hence broader and precise inference can be problematic.

Discussion and Conclusions: Promising Research Avenues

Research on immigration continues to grow, including areas of research not discussed in this study involving the economic determinants of migration and the impact on countries of origin. Limiting the discussion to immigration's effect on labor markets and on productivity, I see three important and promising areas of research that may become increasingly relevant.

First, closer attention to the details of immigration policies and to their variations should be combined with the availability of longitudinal data on individual workers and firms. Some research on US immigration involving the timing of changes in the total number of H-1B visa was mentioned earlier. Other US policy changes that seem worthy of investigation include the regularization of undocumented immigrants that followed the Immigration Reform and Control Act 1986, or changes in the rules allocating permits to hire some type of foreign workers (such as lotteries held in 2008 and 2009 to allocate H-1B visas to employers). Many European countries have rules, which change from time to time, about foreign workers and refugees and how they will be distributed and how the undocumented obtain legal status. Focusing on the specific nature and timing of policy changes and relying on administrative data that are increasingly available for European countries and the United States, we can significantly improve our understanding of the consequences of specific immigration policies on the labor market outcomes of natives and immigrants over the short and long runs.

Second, the effects of immigration on labor markets and on outcomes for native workers seem likely to interact with the flexibility and openness of labor market policies in a country, including rules about unionization and collective bargaining, protections for incumbent workers, and policies that seek to smooth labor market adjustment costs. While the United States has relatively pro-competitive and flexible labor markets, European countries vary substantially among themselves both in the presence of immigrants and in terms of their labor market policies and institutions. Thus, European countries seem to offer an interesting laboratory to study how labor market policies affect the impact and the absorption of immigrants.

Developing this point a step further, the general equilibrium analysis of immigration can be advanced also using models with frictions in labor markets (including search models) and ultimately embedding them into macroeconomic models. It seems plausible that immigration policies can have meaningful macro effects on labor and productivity, as well as on consumption and perhaps also redistribution. For instance, Chassamboulli and Palivos (2014) introduce immigration effects on the margin of job creation by firms, which generates a complementarity between immigrants and job creation. In Chassamboulli and Peri (2015), we use a general equilibrium model with search in labor markets to analyze the employment consequences of policies reducing the number of undocumented immigrants. Battisti, Felbermayr, Peri, and Poutvaara (2014) extend the search model of labor markets with immigrants to an economy with unemployment benefits and fiscal redistribution. One can readily imagine micro-based estimates of specific parameters used as building blocks in macroeconomic models that produce aggregate predictions for immigration policies going beyond the simple aggregate production function.

Third, there is a growing interest in the analysis of foreign students because they are the fastest-growing group of foreign-born. Tertiary education seems likely to be a sector of significant growth for jobs, value-added, and (service) exports for the US economy. Foreign students increase the demand for these services and, once they graduate with a US degree, they are often well-positioned to be productive workers and professionals. Hence US tertiary education services can be a sector in which foreign-born boost demand (as students) and supply (as researchers/professors) with potentially important contributions to US human capital and to local economies.

Related to this theme, immigration of scientists and engineers, especially at the very top of the ability distribution, also deserves more specific attention. Among the US-based Nobel laureates in Medicine, Physics, and Chemistry during the last 10 years, 17 out of 33 were foreign-born. Top science institutions have potentially large effects on innovation and growth for the whole world, which in turn implies that the mobility of top-skilled workers towards the poles of innovation (most of them in the United States) could be contributing to global science and global growth. The connection between high-skilled immigrants, and technological and scientific progress, as it affects the demand for more-skilled immigration, is not well understood but is likely to be a very important engine of growth in the long run.

■ *I am grateful to Gaetano Basso and Vasil Yasenov for outstanding research assistance. I thank Mette Foged, Gaetano Basso, and Vasil Yasenov for allowing me to use data and results from our joint projects in this article.*

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Journal of Economic Perspectives—Volume 30, Number 4—Fall 2016—Pages 31–56

The Impact of Immigration: Why Do Studies Reach Such Different Results?

Christian Dustmann, Uta Schönberg, and Jan Stuhler

The canonical model for studying the impact of immigration is a partial equilibrium model that combines one or various types of labor with capital in a constant-returns-to-scale production function (for an early example, see Altonji and Card 1991). The implications of this model for how immigration affects wages and employment are straightforward and intuitive. An expansion of a certain type of labor will lead to a decrease in the wage of native labor of the same type, in absolute terms and relative to other types of labor—as well as an increase in the marginal productivity of capital. This model has led to the common view of immigration being potentially harmful for individuals whose skills are most similar to those of immigrants, but possibly beneficial for those whose skills are different. However, when this canonical model is implemented through empirical models, some studies using this approach find a sizeable effect of immigration on wages of native workers, while others do not. For instance, while Card (2009) finds that immigration to the United States has only a minor effect on native wages, Borjas (2003) provides evidence for wages of natives being harmed by immigration, and Ottaviani and Peri (2012) report positive wage effects on natives. One reaction to these apparently contradictory findings has been to expand the theoretical framework in various ways. For example, one

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http://dx.doi.org/10.1257/jep.30.4.31 doi=10.1257/jep.30.42.31

approach is to acknowledge the multiple output nature of an economy, thus adding possibilities of adjustment to immigration along the product mix and technology margins (for example, Card and Lewis 2007; Lewis 2011; Dustmann and Glitz 2015). Another theoretical alternative is to allow the price of the output good to vary, rather than being fixed (for example, Özden and Wagner 2015).

Such alternative theories are worth exploring for their own sake, but we do not believe that they are necessary for explaining the differing findings from empirical studies of how immigration affects wages. We argue here that the often contradictory results in the empirical literature have two important sources. First, despite being derived from the same canonical model, different empirical specifications measure different parameters. Second, two assumptions that are commonly and tacitly made when bringing this framework to the data may be invalid: 1) that the labor supply elasticity is homogenous across different groups of natives; and 2) that we can place immigrants and natives into education-experience cells within which they compete in the labor market, based on their reported education and age.

In the next section, we classify existing empirical specifications into three groups. One specification, as for example in Borjas (2003), exploits variation in immigrant inflows across education-experience cells on a national level (or a "national skill-cell approach"). Another specification, as for example in Altonji and Card (1991), uses variation in the total immigrant flow across regions (a "pure spatial approach"). A third specification, as for example in Card (2001), uses variation in immigrant inflows both across education groups and across regions (a "mixture approach"). As we illustrate in Table 1, the national skill-cell approach tends to produce more negative wage effects for natives in response to immigration than the mixture approach, while estimates obtained from the pure spatial approach vary widely depending on which skill group is studied. However, as we argue below, estimates obtained from the different models are not comparable, answer different questions, and have different interpretations. While the national skill-cell and the mixture approach identify a *relative* wage effect of immigration—of one experience group versus another within education groups and of one education group versus another—the pure spatial approach recovers the *total* wage effect of immigration on a particular native skill group that takes into account complementarities across skill cells and across labor and capital. We illustrate that the different specifications are motivated by variants of the *same* canonical model but estimate *different structural* parameters.

We then turn to two extensions. First, research in this area typically assumes that the elasticity of labor supply is homogenous across different groups of natives (with many papers implicitly postulating a vertical labor supply curve). This assumption allows focusing the analysis on wages and ignoring employment responses. However, if the employment of natives responds to immigration, part of its overall impact on the labor market will be absorbed by employment as opposed to wage responses. Moreover, not only is labor supply likely to be elastic, but it is also likely to differ across groups of native workers (such as skilled and unskilled, or younger and older workers). We illustrate that with group-specific labor supply elasticities, the national skill-cell approach may produce estimates that are hard to interpret, while approaches that estimate *total* effects still produce estimates that have a clear interpretation. Furthermore, the degree to which the labor supply response of natives differs across groups, as well as its overall level, depend on the variation the chosen approach uses for identification. When using variation across skill-experience cells on the national level, employment adjusts only at the un- and non-employment margin. In contrast, when using variation across local labor markets, as in the pure spatial or mixture approach, the labor supply of natives may respond more elastically, due to the regional migration of workers.

Second, the national skill-cell and the mixture approach rely on the assumption that an immigrant and a native with the same *measured* education and experience compete against each other. However, there is strong empirical evidence that immigrants "downgrade" upon arrival, and we demonstrate the downgrading of immigrants for three countries: the United States, United Kingdom, and Germany. Consequently, assigning immigrants to skill groups according to their measured skills may lead to misclassification, and seriously impair the estimates of wage responses of natives to immigration. Although the bias cannot be unambiguously signed, we provide evidence suggesting that in the US context, downgrading may overstate the negative impact of immigration in both the national skill-cell and the mixture approach, but particularly so in the national skill-cell approach. Downgrading may therefore be one reason why the national skill-cell approach tends to produce more negative native wage effects than the mixture approach. In contrast, approaches that estimate *total* effects of immigration are robust to downgrading as they do not require the allocation of immigrants into skill groups.

In a final step, we turn to approaches that explicitly estimate the underlying parameters of the canonical model above and then use that model to predict the wage effects of immigration, as in for example Ottaviano and Peri (2012) and Manacorda, Manning, and Wadsworth (2012). We contend that downgrading may seriously impair the estimation of a key parameter in this approach, the elasticity of substitution between immigrants and natives, which may help to explain why studies using this approach find often positive wage effects of immigration for natives.

In summary, we argue that differences in coefficients estimated by the different specifications, and the assumptions being made about native labor supply responses and downgrading may explain many of the apparent contradictions among the empirical findings reported in the literature. We advocate investigating the effects of the *overall* (as opposed to the group-specific) immigration shock on wages and employment of various native groups. This procedure avoids the pre-classification of workers into groups and is therefore immune to the misclassification of immigrants that arises due to the "downgrading" phenomenon. Further, it estimates a parameter that is of direct policy relevance and easily interpretable, even if labor supply elasticities differ across groups of native workers.

We should emphasize that this paper is about the correct *specification* of empirical models and the interpretation of the estimated parameters, not about empirical *identification.* Any of the approaches we discuss slices the labor market into different sub-labor-markets and uses variation in the inflow of immigrants into

Table 1

Selected Studies on the Wage Impact of Immigration

Skill-Cell Approach	*Country*	*Sample*	*Specification*	*Group*	*Coefficient*	*S.E.*
Borjas (2003)	United States	Census and CPS, 1960–2001	OLS, weighted, decadal	natives, men	−0.57	(0.16)
Aydemir and Borjas (2007)	Canada	Census 1971–2001	OLS, weighted, decadal	natives, men	−0.51	(0.20)
	United States	Census 1960–2000	OLS, weighted, decadal	natives, men	−0.49	(0.22)
Llull (2014)	Canada, United States	Census 1960–2000	IV, weighted, decadal	natives, men	−1.66	(0.66)
Borjas (2014)	United States	Census and ACS 1960–2011	OLS, weighted, decadal	natives, men	−0.53	(0.10)
Card and Peri (2016)	United States	Census and ACS 1960–2011	OLS, weighted, decadal	natives, men	−0.12	(0.13)
Spatial Approach	*Country*	*Sample*	*Specification*	*Group*	*Coefficient*	*S.E.*
Card (1990)	United States	Census and CPS, 1979–1985, 4 MSAs	OLS, 3-year difference	natives, white[a]	−0.14	–
Altonji and Card (1991)	United States	Census, 1970–1980, 120 MSAs	IV, weighted decadal	natives, low education	−1.21	(0.34)
				natives, white dropouts	−1.10	(0.64)
Dustmann, Fabbri, and Preston (2005)	United Kingdom	LFS, 1992–2000, 17 regions	IV, weighted, yearly	natives	0.91	(0.58)
Card (2007)	United States	Census, 1980–2000, 100 MSAs	IV, weighted, cross-section	natives	0.06	(0.01)
Boustan, Fishback, and Kantor (2010)	United States	Census, 1940, 69 MSAs	IV, weighted, cross-section	men	0.01	(0.54)
Dustmann, Frattini, and Preston (2013)	United Kingdom	Census and LFS, 1997–2005, 17 regions	IV, yearly	natives	0.40	(0.11)
				natives, 10th pct.[b]	−0.52	(0.18)
				natives, 90th pct.[b]	0.41	(0.19)
Borjas (2015)	United States	Census and CPS, 1977–1992, 44 MSAs	OLS, weighted, 3-year difference	natives, dropouts[c]	−2.63	(1.08)
Dustmann, Schönberg and Stuhler (2016)	Germany	IAB, 1986–1996, 1,550 municipalities	IV, weighted, 3-year difference	natives	−0.13	(0.05)
				natives, young, low education	−0.56	(0.11)
Peri and Yasenov (2016)	United States	Census and CPS, 1977–1992, 44 MSAs	OLS, weighted, 3-year difference	natives, dropouts[d]	0.56	(0.73)
Foged and Peri (2016)	Denmark	IDA, 1995–2008, 97 municipalities	IV, weighted, yearly	natives, low education	1.80	(0.64)

(Continued on next page)

Table 1

Selected Studies on the Wage Impact of Immigration *(Continued)*

Mixed Approach	*Country*	*Sample*	*Specification*	*Group*	*Coefficient*	*S.E.*
LaLonde and Topel (1991)	United States	Census, 1970 and 1980, MSA × arrival cohort	OLS, weighted, decadal	immigrants, recent (≤5 yrs.) arrivals	−0.09	(0.03)
Card (2001)	United States	Census, 1990, MSA × occupation	IV, weighted, cross-section	natives, men	−0.10	(0.03)
Borjas (2006)	United States	Census, 1960–2000, MSA × education × experience	OLS, weighted, decadal	natives	−0.06	(0.02)
Card and Lewis (2007)	United States	Census, 1980–2000, MSA × education	IV, weighted, decadal	natives, men	−0.04	(0.06)
Card (2009)	United States	Census and ACS, 1980–2006, MSA × education	IV, weighted, decadal	natives, men	−0.42	(0.28)
Lewis (2011)	United States	Census, 1980–2000, MSA × education	IV, weighted, decadal	natives, manufacturing	−0.14	(0.04)
Glitz (2012)	Germany	IAB Subsample, 1996–2001, region × education	IV, weighted, yearly	natives	−0.26	(0.19)
Dustmann and Glitz (2015)	Germany	IAB Subsample, 1985–1995, region × education	IV, weighted, decadal	natives, manufacturing	−0.10	(0.06)
Özden and Wagner (2015)	Malaysia	LFS, 2000–2010, region × industry	IV, weighted, yearly	natives	0.02	(0.01)
Structural Approach	*Country*	*Sample*	*Group and Specification*[e]	*Elasticities of Substitution*[f]	*Simulated Impact*[g]	
Ottaviano and Peri (2012)	United States	Census and ACS, 1960–2006	natives, long run immigrants, long run	**σ**(X)=6.25, **σ**(E)=3.3, **σ**(MN)=20	0.05 −0.60	
Manacorda, Manning, and Wadsworth (2012)	United Kingdom	UK LFS and GHS, 1975–2005	natives, low education, long run natives, high education, long run	**σ**(X)=5.2, **σ**(E)=4.9, **σ**(MN)=6.9	0.08 −0.23	

Source: Authors.

Note: The table reports coefficient estimates from a regression of (changes in) log wages or earnings for the indicated group on a measure of the immigrant supply shock (for example, change in immigrant share or inflow rate). Standard errors are in parentheses. Estimates are not directly comparable as sample, specification, conditioning variables and definitions of the supply shock differ across studies. Only main data sources are listed (ACS = American Community Survey, CPS = Current Population Survey, GHS = General Household Survey, IAB = IAB Employment Subsample, IDA = Danish Integrated Database for Labor Market Research, LFS = Labor Force Survey). A specification is classified as weighted if estimation is on the individual level or if regression weights are used on aggregate statistics. MSAs = Metropolitan Statistical Areas. OLS = Ordinary Least Squares. IV = Instrumental Variable. [a]1979 versus 1982 difference-in-differences estimate, scaled by the immigration-induced 7 percent increase in labor force. [b]Natives at the indicated percentile of the native wage distribution. [c]1977–1979 versus 1981–1983 synthetic control estimate, scaled by immigration-induced 8 percent increase in labor force. [d]1979 vs. 1980–1982 synthetic control estimate, scaled by the immigration-induced 8 percent increase in labor force. [e]Capital is assumed inelastic in short run and perfectly elastic in long run. [f]Estimated elasticities of substitution across education group ($\sigma(X)$), experience groups ($\sigma(E)$), or between immigrants and natives ($\sigma(MN)$). [g]Simulated wage impact normalized by overall migration shock over period.

these sub-labor-markets as an identification device. We assume here that the allocation of immigrants to these sub-labor-markets is (conditionally) independent of shocks to wages or employment of native workers (which could be achieved either through random allocation of immigrants, or by use of an appropriate instrument), and that some, but not other sub-labor-markets are exposed to an inflow of immigrants.[1] Throughout the paper, we explain our arguments informally and verbally. We have prepared a self-contained companion appendix to this paper, available online with this paper at http://e-jep.org, which provides formal derivations and technical discussion.

Estimation Approaches Used in the Literature

The existing empirical literature has derived three conceptually different effects of immigration on wages, estimated using different types of variation for identification: 1) estimation at the national level exploiting variation in the skill-cell-specific inflow of immigrants, as pioneered by Borjas (2003); 2) estimation at the regional level exploiting variation in the total inflow of immigrants, as pioneered by Altonji and Card (1991); and 3) estimation at the regional level exploiting variation in the inflow of immigrants both across areas and skill cells, as for instance in Card (2001). These different empirical approaches identify conceptually different parameters that are not directly comparable—even if the estimation regressions are motivated by the same canonical model (or versions of that model).

The National Skill-Cell Approach: Variation in the Immigration Shock across Skill Cells

Borjas (2003) estimates the wage effects of immigration at the national level by categorizing immigrants and natives into education-experience cells using data from various census waves. This method identifies the *relative* wage effect of immigration by experience. To see this, we rewrite his baseline estimation equation (see equation 3 in his paper) as a first difference equation to obtain:[2]

$$\Delta \log w_{gat} = \theta^{skill} \Delta p_{gat} + \Delta \pi_t + \left(s_g \times \Delta \pi_t\right) + \left(x_a \times \Delta \pi_t\right) + \Delta \varphi_{gat}$$

[1] The identification of empirical models is a key problem in the literature. Studies that slice the labor market into spatial units typically rely on using past settlement of immigrants as an instrumental variable, as used in Altonji and Card (1991) and further developed in Card (2001). Studies that slice the labor market into skill groups instead typically assume that immigrant inflows are exogenous, an assumption that may be violated (Llull 2014). A number of studies exploit natural quasi-experiments that lead to a sharp rise or fall in immigration for identification purposes, such as Card (1990), Hunt (1992), Carrington and De Lima (1996), Friedberg (2001), Glitz (2012), Dustmann, Schönberg, and Stuhler (2016), and Foged and Peri (2016). Moreover, "push factors" that generate out-migration can be combined with the past settlement instrument (for example, Boustan, Fishback, and Kantor 2010; Ganguli 2015; Aydemir and Kirdar 2013; Monras 2015a).

[2] We have swapped the sub-indices i and j used by Borjas to denote education and experience cells with the sub-indices g and a used by us in the next section.

where $\Delta \log w_{gat}$ denotes the change in native wage (in logs) in education group *g*, experience group *a* at time *t*, and Δp_{gat} denotes the education-experience specific immigration shock, defined as the difference in the ratio of immigrants to all labor in each education-experience group *ga* between two time periods. The variables s_g, x_a, and π_t are vectors of education, experience, and time fixed effects. In the case of two education and experience groups, the parameter θ^{skill} may be thought of as a triple difference estimator where differences are taken over time, experience groups, and education groups. The inclusion of time fixed effects in first differences absorbs the overall immigration shock—any effects of immigration common to all education and experience groups are therefore differenced out. The education-time fixed effects capture, in addition to differential time trends by education unrelated to immigration, differences in immigration shocks across education groups. Any effects of immigration common to all experience groups within education groups are therefore likewise differenced out. The inclusion of experience-time fixed effects, in turn, soaks up the experience-specific immigration shock, in addition to allowing for differential time trends by experience unrelated to immigration. The parameter θ^{skill} therefore identifies the relative effect of immigration by experience and answers the question: "How does immigration affect native wages of experienced relative to inexperienced workers in the same education group?" Since the effects of immigration that are common to the education group are differenced out, this parameter is not informative about the distributional effects between education groups, nor about its absolute effects. The upper panel of Table 1 provides an overview of some of the papers adopting the national skill-cell approach. Typical wage estimates for native men are around –0.5 (for example, Borjas 2003; Aydemir and Borjas 2007; Borjas 2014). Estimates turn substantially more negative when using instrumental variables to adjust for the potential endogeneity of the immigration shock across education-experience cells (Llull 2014). In contrast, using an alternative measure for the education-experience specific immigration shock, Card and Peri (2016) report a smaller estimate of –0.1.

The Pure Spatial Approach: Variation in the Total Immigration Shock across Regions

In many studies that exploit spatial variation in immigrant inflows, the log wage changes of natives in education group *g* and experience group *a* in region *r* are related to the *total* region-specific immigration shock (defined as the ratio of all immigrants entering the region and all natives in that region), controlling for nation-wide education-experience specific time trends ($s_{ga} \times \Delta \pi_t$):

$$\Delta \log w_{gart} = \theta_{ga}^{spatial} \Delta p_{rt} + s_{ga} \times \Delta \pi_t + \Delta \varphi_{gart} .$$

In the case of two time periods and two regions *A* and *B*, the parameter $\theta_{ga}^{spatial}$ equals a difference-in-difference estimator where differences are taken over time and across regions. Provided that region *B*, otherwise identical to region *A*, did not experience an inflow of immigrants and is not indirectly affected by the immigration shock in region *A* (for example, through outmigration of natives), this parameter identifies the total effect of immigration on wages of a particular skill group. It answers the question "What is the overall effect of immigration on native wages of a particular education-experience group?" It is informative about the distributional effects of immigration both between education and experience groups, as well as about its absolute effects. The second panel of Table 1 provides an overview of some papers that adopt the pure spatial approach. For example, Altonji and Card (1991) report total wage estimates for white male high school dropouts of about –1.1, while Dustmann, Frattini, and Preston (2013) find negative total wage effects of about –0.5 at the 10th percentile, and positive wage effects of 0.4 at the 90th of the earnings distribution. Card (2007) finds small positive total wage effects (0.06) for natives on average.

The Mixture Approach: Variation in the Immigration Shock across Both Skill-Cells and Regions

A third set of papers exploits variation in the immigration shock across both skill-cells and regions, and are therefore a mixture of the pure skill-cell approach and the pure spatial approach. Most papers that fall into this category distinguish only between education (or occupation) cells. These papers then relate the wage change of natives in education group g and region r to the education-specific immigration shock in that region (Δp_{grt}), controlling for education- and region-specific time trends ($s_g \times \Delta \pi_t$ and $s_r \times \Delta \pi_t$):

$$\Delta \log w_{grt} = \theta^{spatial,skill} \Delta p_{grt} + (s_r \times \Delta \pi_t) + (s_g \times \Delta \pi_t) + \Delta \varphi_{grt}.$$

In the simple case of two regions A and B, two time periods, and two education groups, the parameter $\theta^{spatial,skill}$ can be expressed as a triple difference estimator where differences are taken over time, across regions, and across education groups. By conditioning on region-specific time effects and thus absorbing the total region-specific immigration shock, $\theta^{spatial,skill}$ identifies the relative effect of immigration by education and answers the question: "How does immigration affect native wages of low-skilled relative to high-skilled workers?" Since the effects of immigration common to all education-experience groups are differenced out, the mixture approach is informative about the distributional effects of immigration between education groups, but not about its absolute effects. The third panel of Table 1 provides an overview of some of the papers that adopt the mixture approach. Estimates are generally less negative than those obtained from the national skill-cell approach. For example, Card (2001), who uses just one cross-section and distinguishes between occupations rather than education groups, reports a wage estimate of –0.1 for native men. Dustmann and Glitz (2015) find a more negative response in nontradable industries (not shown), but little response in tradable or manufacturing industries.

In sum, depending on the definition of the immigration-induced labor supply shock (skill group specific or overall) and the variation in immigration shocks used (across skill cells, across regions, or both), the level of the analysis (for example, education groups versus education-experience groups), and the control variables used in the estimation regressions, different approaches identify conceptually different parameters. Although these parameters are not directly comparable, it is possible to transform total effects into relative effects of immigration by experience and education. In contrast, since total effects of immigration contain additional information in comparison to relative effects, the latter cannot be transformed into the former.

Interpretation of Relative and Total Effects of Immigration through the Lens of the Canonical Model

To aid the interpretation of the parameters estimated by the three main empirical approaches, we now present a simple version of the canonical model that motivates the empirical specifications outlined above.

Set-Up

Production Function. We assume a simple Cobb–Douglas production function that combines capital K and labor L into a single output good Y, where $Y = AL^{1-\alpha}K^{\alpha}$. Labor is assumed to be a constant-elasticity-of-substitution aggregate of different education types, and we distinguish here between low- (L_L) and high-skilled (L_H) labor only, so that $L = \left[\theta_L L_L^{\beta} + \theta_H L_H^{\beta}\right]^{1/\beta}$. The elasticity of substitution between low- and high-skilled workers is given by $1/(1-\beta)$, and measures the percentage change in the ratio of low-skilled workers to high-skilled workers in response to a given percentage change in the wages of low-skilled to high-skilled workers. The higher this elasticity, the more substitutable the two groups are. The two skill types are perfect substitutes (implying an infinite substitution elasticity) if $\beta = 1$.

Within each education group, we allow, similar to Card and Lemieux (2001), inexperienced (L_I) and experienced (L_E) workers to be imperfect substitutes, so that $L_g = \left[\theta_{gI} L_{gI}^{\gamma} + \theta_{gE} L_{gE}^{\gamma}\right]^{1/\gamma}$, and where $1/(1-\gamma)$ is the elasticity of substitution between inexperienced and experienced workers within an education group. If $\gamma = 1$, the two groups are perfect substitutes. We assume here that immigrants can be correctly classified to education and experience groups and that within an education-experience group, immigrants and natives are perfect substitutes. We turn to the possibility of misclassification and imperfect substitutability between immigrants and natives below.

Firms choose capital and labor by maximizing profits, taking wage rates and the price of capital as given. Output prices are assumed to be determined in the world market and are normalized to 1.

Capital and Labor Supply. Capital is supplied to the labor market according to $r = K^{\lambda}$, where r denotes the price of capital and $1/\lambda$ is the elasticity of capital supply. We assume that the labor supply of immigrants who enter the country is inelastic. In contrast, native employment in an education-experience group depends on the wage in that education-experience group. Let η_{ga} denote the labor supply elasticity for a particular education-experience group. It measures the percentage change in the supply of native labor in the education-experience group in response to a given percentage change in the wage of that group. The degree to which native labor supply responds to an immigration-induced labor supply shock (and the heterogeneity across groups) depends on the alternatives an individual has when wages in the current (or desired) job decline. If wages decline in the local economy, workers may respond by moving away (or no longer moving into the area). However, if wages decrease in all firms in the national economy, workers can respond only by moving from and into unemployment or by entering or exiting the labor force. Thus, when using spatial variation in immigrant inflows (as in the pure spatial and the mixture approach), estimated labor supply elasticities of natives are likely larger than when using variation across skill cells in the national labor market (as in the national skill-cell approach).

Labor supply elasticities on the national level may differ between different groups of workers. For instance, Altonji and Blank (1999) find that married women have the largest labor supply elasticities on the national level, while Ljungqvist and Sargent (2007) and Rogerson and Wallenius (2009) emphasize that individuals near retirement or those with low wage rates exhibit particularly large extensive margin responses. Groups that have the weakest attachment to the labor force, such as single mothers, appear more elastic on the extensive margin (for example, Meyer and Rosenbaum 2001, Gruber and Wise 1999, Heckman 1993, Keane and Rogerson 2015, and Chetty, Guren, Manoli, and Weber 2012 for a summary).

The labor supply elasticity at the local level captures in addition the internal migration of workers between areas and may thus depend on additional factors such as the supply of housing (Moretti 2011) and the size of the labor market that is considered (for example, Borjas 2006). This adjustment margin may have different importance for different types of workers. For example, geographic mobility may be a more important adjustment margin for skilled workers, as migration rates rise with education (Greenwood 1975; Molloy, Smith, and Wozniak 2011). Indeed, Bound and Holzer (2000) find that skilled workers are more likely to move in response to a local shock, as do Wozniak (2010), Notowidigdo (2011), Amior and Manning (2015), and ourselves in Dustmann, Schönberg, and Stuhler (2016). Similarly, Cadena and Kovak (2016) note that location choices respond more strongly to demand shocks for Mexican-born immigrants than for natives. Such patterns affect the incidence of local shocks. For example, Hornbeck and Moretti (2015) find that because college graduates move in greater numbers in response to a local productivity shock, its incidence is reduced for skilled workers. Both the overall size of the elasticity and the relative importance of the underlying adjustment margins may vary across groups. For example, in Dustmann, Schönberg, and Stuhler (2016), we find that young workers respond more strongly at the geographic margin than older workers.

Interpretation of Relative and Total Wage Effects of Immigration if Labor Supply is Inelastic

A common assumption in the literature is that native employment does not respond to wage changes (for example, Borjas 2003; Ottaviano and Peri 2012). With inelastic native labor supply, the only reason that total education- and education-experience-specific employment change is because of immigration. In this case, the equilibrium native wage response due to immigration equals:

$$\Delta \log w_{ga} = -\frac{\alpha\lambda}{1-\alpha+\lambda}\Delta\tilde{I} + (\beta-1)(\Delta\tilde{I}_g - \Delta\tilde{I}) + (\gamma-1)(\Delta I_{ga} - \Delta\tilde{I}_g),$$

where $\Delta\tilde{I}$ and $\Delta\tilde{I}_g$ are the overall and education-specific immigration shocks, measured as percentage change in efficiency units, and ΔI_{ga} is the education-experience specific immigration shock. Consider first the third term on the right side of the equation, and suppose that, within each education group, immigration is relatively inexperienced. This term is then negative for inexperienced natives, and positive for experienced natives. Thus, ceteris paribus, immigration will lower wages of inexperienced natives and raise wages of experienced natives within each education group.

The second term on the right side of the equation looks at how changes in immigration disproportionately affect education levels. The second term will be negative for the education group that is exposed to the larger inflow of immigrants and positive for the other education group, implying wage declines for the former and wage increases for the latter group (holding the other terms constant). Thus, the second and third terms summarize the key insight of the simple competitive model: Immigration will decrease the marginal product and hence wages of native workers most similar to immigrant workers, and may increase the marginal product and wages of native workers most dissimilar to immigrant workers.

Finally, the first term on the right captures the wage effects of immigration common to all education and experience groups and can, at an intuitive level, be understood as the slope of the aggregate demand curve. If capital supply is fully elastic ($\lambda = 0$), this term disappears and on *average*, wages do not change in response to immigration. If, in contrast, capital supply is not fully elastic, the direct overall immigration shock pulls down wages of all skill groups in the same way, and an immigration-induced labor supply shock has a negative effect on average wages—as immigration will lead to increases in the rent of capital and redistribute a share of output from labor to capital. The literature often denotes the case of inelastic capital supply as the *short-run* effect of immigration, and the case of perfectly elastic labor supply as the *long-run* effect.

Based on this equation, it is now straightforward to provide a structural interpretation of the relative and total effects of immigration identified by the three empirical approaches described in the previous section.

National Skill-Cell Approach. As explained above, the national skill-cell approach pioneered by Borjas (2003) identifies the relative wage effect of immigration by experience, while any effects of immigration common to all education and experience groups as well as any effects of immigration common to all experience groups within education groups are differenced out. Put differently, in the empirical specification underlying the national skill-cell approach, the total and the education-specific immigration shocks are held constant through the inclusion of general and education-specific time fixed effects. The parameter θ^{skill} estimated by the spatial skill-cell approach may therefore be thought of as the direct partial effect of immigration, holding the total and the education-specific immigration shock constant. From the previous equation, θ^{skill} identifies $(\gamma - 1)$, the inverse of the elasticity of substitution between experienced and inexperienced workers within education groups. It is unambiguously negative (as $\gamma < 1$), the more so the less substitutable experienced and inexperienced workers are within education groups.

Mixture Approach. Studies that exploit variation in the immigration shock across both skill-cells and regions (for example, LaLonde and Topel 1991; Card 2009) identify the relative wage effect of immigration by education, as any effects of immigration common to all education groups are differenced out. The parameter $\theta^{spatial,skill}$ estimated by the mixture approach may thus be thought of as the direct partial effect of immigration holding the total immigration shock constant. From an earlier equation, $\theta^{spatial,skill}$ identifies $(\beta - 1)$, the inverse of the elasticity of substitution between unskilled and skilled workers. This parameter is unambiguously negative, the more so the less substitutable low- and high-skilled workers are.

Pure Spatial Approach. The pure spatial approach adopted by, for example, Altonji and Card (1991) identifies the total wage effect of immigration for workers in education and experience group *ga*. The parameter $\theta_{ga}^{spatial}$ in the empirical equation for this approach given in the previous section corresponds to the change in log wages of skill group *ga* as response to the total immigration shock in head counts.

In addition to the elasticities of substitution between inexperienced and experienced workers and low- and high-skilled workers, the parameter depends on the elasticity of capital supply and the share of capital in production. This total effect measures not only the direct partial effects of an immigration-induced labor supply shock on native workers in a particular education-experience or education group, but also the indirect effects through complementarities across skill cells and across capital and labor and is, for this reason, in our view the most policy-relevant parameter. If capital supply is fully elastic, the total wage effect of immigration will be zero on average, while negative for some skill groups—those experiencing the stronger inflow of immigrants—and positive for other skill groups. If capital supply is fully inelastic, the total wage effect may be negative for all skill groups.

Interpretation if Labor Supply is Elastic but Constant across Skill Groups

So far, we have discussed the interpretation of the relative and total wage effects of immigration under the assumption that native labor does not respond to wage changes. Next, we turn to the case in which native labor supply does adjust to wage changes, but the labor supply elasticity is constant across skill groups. In this case, the labor market effects of immigration are not only absorbed through wage changes, but also through employment changes. Therefore, to obtain a complete picture of both the relative and total effects of immigration, wage and employment responses need to be studied jointly. As the labor supply elasticity increases, both the relative and the total wage effects become more muted, whereas the respective employment effects increase. If labor supply is infinitely elastic, the relative and total wage effects of immigration approach zero, whereas the respective employment effects approach −1, implying that each immigrant displaces one native worker. As discussed, the labor supply elasticity is likely to be smaller at the national level than at the local level—which, as emphasized by Borjas (2003), may help to explain why the national skill-cell approach tends to produce more negative wage effects than the mixture approach.

Our discussion so far has assumed that wages are fully downward flexible. However, in practice, wages may be partially downward rigid at least in the short-run, for example because of institutional constraints or contractual agreements. The degree of downward wage rigidity plays a similar role in determining the wage and employment impacts of immigration as the labor supply elasticity; the higher the degree of rigidity, the smaller the wage and the larger the employment response to immigration. Wage rigidity therefore provides an additional reason why native wage and employment responses need to be studied jointly to obtain an accurate picture of the labor market impacts of immigration.

Under the assumption that wages are fully downward flexible, estimates of the labor supply elasticities can be obtained by dividing the total or relative employment response by the respective native wage response. It is important to emphasize that the ratio of wage and employment effects obtained from the pure spatial or the mixture approach identifies the *local* labor supply elasticity, while estimates obtained from the skill-cell approach identify a *national* supply elasticity. Ebert and Stone (1992) estimates the local labor supply elasticity to be about 5 on the US metropolitan statistical area level, while Bartik (1991), Lettau (1994), Smith (2012), and Notowidigdo (2011) provide somewhat smaller estimates in the range of 1.5 to 4. Because of differences in specifications, such as the time frame and size of the local area considered, these estimates are not fully comparable. Estimates for the national labor supply elasticity at the extensive margin, typically estimated using tax changes, tend to be smaller: the meta-analysis in Chetty et al. (2012) points to an extensive margin elasticity of around 0.25. Longitudinal data, which trace workers over time across regions, make it possible to decompose the local employment response into inflows from and outflows to nonemployment, and inflows from and outflows to employment in other regions. For instance, in Dustmann, Schönberg, and Stuhler (2016), we show that in the particular context, movements across regions account for roughly one-third of the overall local native employment response, which adjusts predominantly because inflows into employment in the affected region decline (for similar evidence, see also Filer 1992; Monras 2015b).

Interpretation if Labor Supply Elasticities Vary across Skill Groups

So far, we have assumed that the elasticity of labor supply is constant across education-experience groups. It is likely, however, that labor supply elasticities differ between different groups of workers, both on national and local levels (see our discussion above). Alternatively, the degree of wage rigidity may differ across groups of workers. For example, in Dustmann, Schönberg, and Stuhler (2016), we argue that older workers' wages may be more "protected" than those of younger workers and, unlike wages of younger workers, less likely to adjust downward. Next, we highlight the implications of heterogeneity in labor supply elasticities or in the degree of wage rigidities across groups of workers for the interpretation of the relative and total effects of immigration.

Mixture Approach. Consider first the relative effect of immigration by education identified by the mixture approach. A key implication of the canonical model is that natives who suffer the largest inflow of immigrations (for example, low-skilled workers if immigration is relatively low-skilled) suffer the largest decline in wages as well as employment. With heterogeneous labor supply elasticities, however, this may no longer hold—a phenomenon we refer to as "perverse" effects (see also Dustmann, Schönberg, and Stuhler 2016). To grasp the intuition for the possibility of perverse effects, suppose that immigration is relatively low skilled and that, in line with the empirical evidence that low-skilled workers respond more elastically to wage changes along the un- or nonemployment margin, low-skilled natives have a higher labor supply elasticity than high-skilled natives. In equilibrium, low-skilled natives' employment will then have responded strongly relative to high-skilled natives' employment, while their wages adjust less, and may even increase relative to those of high-skilled natives. In the presence of heterogeneous labor supply elasticities, the relative wage and employment effect of immigration may therefore be of opposite sign. While the mixture approach continues to be informative about how immigration affects wages and employment of one education group relative to the other, focusing solely on native wage responses may yield a misleading picture of the overall relative effects of immigration. The possibility of perverse effects therefore reinforces our conclusion that wage and employment responses need to be studied jointly to obtain an accurate picture of the labor market impacts of immigration.

National Skill-Cell Approach. Consider next the wage and employment effects estimated by the national skill-cell approach (θ^{skill}), which compares wage changes between inexperienced and experienced low-skilled workers with those of inexperienced and experienced high-skilled workers. When labor supply elasticities (or the degrees of wage rigidity) vary across groups, estimates obtained from this approach are difficult to interpret and may no longer be informative about the effects of immigration on experienced natives relative to inexperienced natives within education groups. This is because the relative wage effect of one experience group versus the other among low-skilled workers is likely to differ from that among high-skilled workers. It can be shown that the triple difference estimator of θ^{skill} implied by the first equation in the paper describing this approach aggregates the two relative wage effects by experience in a nonmeaningful way, as it assigns a negative weight to the relative effect in one education group and a weight greater than 1 to the relative effect in the other education group.

Pure Spatial Approach. In contrast, the total effect of immigration estimated by the pure spatial approach remains a meaningful and policy-relevant parameter even in the presence of heterogeneous labor supply elasticities, addressing the same question as in the case of homogenous (or inelastic) labor supply responses: "How does the overall immigration shock affect wages and employment of a particular native education-experience group?" Estimates for the education-experience-specific labor supply elasticities can then be obtained by dividing the estimates for the total native employment effect in a particular education-experience group by the respective estimate of the total wage effect.

Downgrading and Misclassification

Empirical Evidence of Downgrading

"Downgrading" occurs when the position of immigrants in the labor market, which is typically measured by wage or occupation, is systematically lower than the position of natives with the same observed education and experience levels. Downgrading means that immigrants receive lower returns to the same measured skills than natives when these skills are acquired in their country of origin.

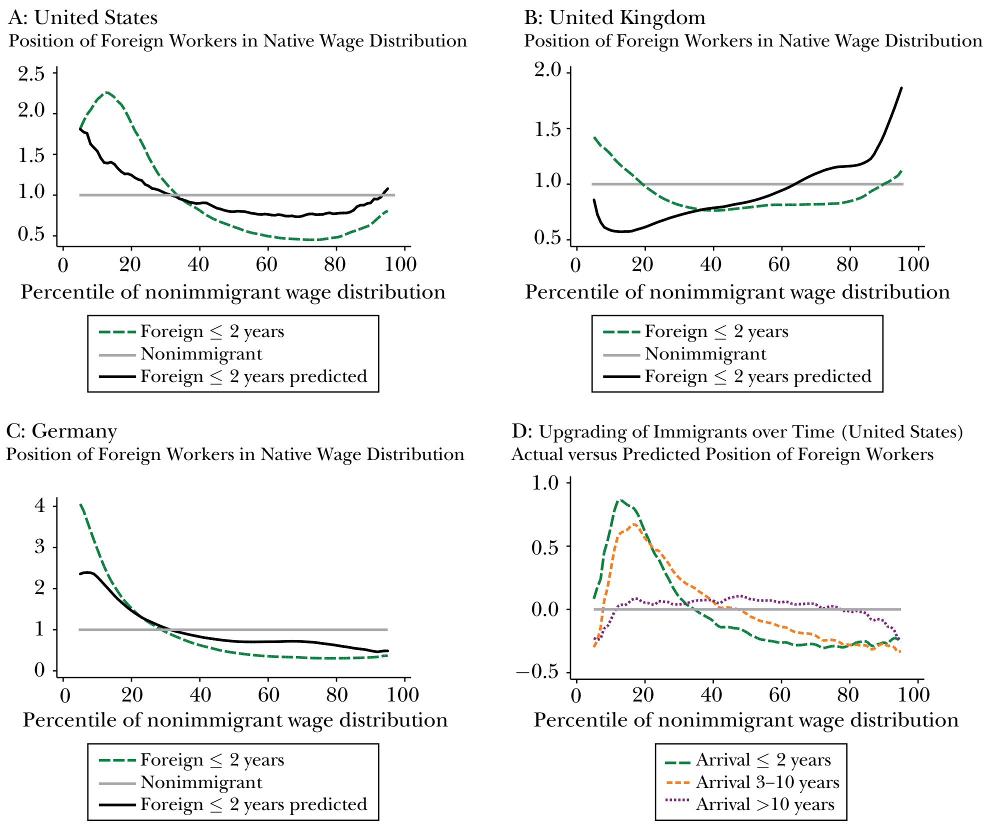
The research literature provides ample evidence on the initial downgrading of immigrant arrivals and their subsequent economic assimilation. As one example, for the case of immigration from Russia to Israel in the 1990s, the returns immigrants receive for their schooling and experience are initially zero or even negative, but rise with time spent in the host country, while immigrants with high education climb up the occupational ladder to move into high-skill occupations (Eckstein and Weiss 2004). Estimates of earnings equations such as those by Chiswick (1978), Borjas (1985), or Dustmann (1993), among others, have long shown that immigrants' earnings profiles are comparatively flat with respect to labor market experience or schooling acquired at home. Dustmann, Frattini, and Preston (2013) present evidence on immigrant downgrading for the United Kingdom, and Dustmann and Preston (2012) for the UK and the US economies.[3]

In the presence of downgrading, placement of immigrants into education or education-experience cells within which they compete with natives—a prerequisite of the skill-cell approach and the mixture approach—becomes difficult. For instance, a Polish surgeon who arrives in the United Kingdom may lack formal requirements or complementary skills such as the English language and might end up working as a nurse, at least initially. However, based on observed education, the researcher would allocate this surgeon to a skill cell further up the skill distribution.

To illustrate the degree of downgrading of immigrants, we offer some evidence from the United States, the United Kingdom, and Germany. We use data from the 2000 US Census and the German IAB Employment subsample, and from the UK

[3] Indirect evidence on initial downgrading follows also from the occupational upgrading of immigrants upon legalization (Kossoudji and Cobb-Clark 2000) and the relation between changes in immigration status and native wages (Orrenius and Zavodny 2007). The issue of downgrading has also been acknowledged in various papers that use the skill-cell approach, such as Borjas, Freeman, and Katz (1997, p. 42) and Borjas (2003).

Figure 1
Downgrading of Immigrants



Source: Panel A: US Census 2000; panel B: UK Labor Force Survey 1995–2005; and panel C: IAB Employment Subsample 2000, year 2000.
Note: Panels A–C show where recent immigrants (whom we define as immigrants who arrived over the past two years) are actually situated in the native wage distribution (the dashed lines in panels A–C), and where we would assign them if they received the same return to their experience and education as natives (the solid lines in panels A–C). These panels show kernel estimates of the actual (dashed lines) and predicted (solid lines) density of immigrants in the native wage distribution. Panel D shows the difference between the actual and predicted density of immigrants. The horizontal line shows as a reference the native wage distribution. The kernel estimates are above the horizontal line at wages where immigrants are more concentrated than natives, and below the horizontal line at wages where immigrants are less concentrated than natives.

labor force survey for the period between 1995 and 2005. In Figure 1, we show where recent immigrants (whom we define as immigrants who arrived over the past two years) are actually situated in the native wage distribution (the dashed lines in panels A–C), and where we would assign them if they received the same return to their experience and education as natives (the solid lines in panels A–C). The x-axis measures the percentiles of the wage distribution. The y-axis is the density of a particular group relative to natives (horizontal line at 1). For instance, a point (2, 20) means that members of the group are twice as likely as natives to be located at the 20th percentile of the native wage distribution. The figures first illustrate that in all three countries, immigrants are, relative to natives with the same formal measurements of experience and education, overrepresented at the bottom of the wage distribution, and underrepresented in the middle or upper ends of the wage distribution. For all three countries, the dashed line (showing where immigrants are actually located) lies above the solid line (showing where immigrants should be located based on their education and experience) at low percentiles of the wage distribution, but it tends to be underneath the solid line further up the wage distribution.[4] Overall, for the three countries of Germany, the United States, and the United Kingdom, recent immigrants have wages that are on average 17.9 percent, 15.5 percent, and 12.9 percent below those native workers would receive after controlling for sex, age, education groups, and age-by-education interactions. The degree of downgrading may change over time and differ across groups. In the United Kingdom, our own calculations (not shown here) show that cohorts that arrived in the mid or late 1990s downgrade less strongly than those that entered in the mid 2000s. In Germany, immigrants arriving in 2000 from other EU countries do not downgrade on average, while the degree of downgrading is substantial for arrivals from other source countries.

Downgrading is most severe in the years after immigrants arrive, as immigrants then proceed to upgrade their skills and acquire complementary skills in the host county. But the first years after arrival are exactly the years that matter when estimating the labor market impacts of immigration. For instance, when annual data is used, the change in the share of immigrants is driven by those who arrived over the past year. We illustrate "upgrading" in Figure 1D, where we plot the difference between the actual position of immigrants in the native wage distribution and their predicted position based on observable characteristics (the dashed lines), for immigrants with different durations in the United States. If immigrants and natives with similar characteristics have similar wages, then the actual and predicted positions should coincide (solid line). The panel shows that these profiles indeed become more similar the longer immigrants are in the country.

In the companion appendix to this paper, we propose a simple procedure to impute the degree of immigrant downgrading upon arrival in each

[4] More specifically, the allocation of where immigrants should be located according to their observable human capital characteristics (and where the skill-cell approach as well as the structural approach we discuss below would allocate them) is based on a flexible log wage regression model estimated for natives. It includes five age categories (18–25, 26–35, 36–45, 46–55, 56–65), four educational categories (three for Germany), and interactions between the two. We fit separate models for men and women and for different years, compute fitted values for immigrants, and add a normally distributed error term (based on the category-specific residual variance for natives) to compute their predicted rank within the native wage distribution. As the income rank is bounded, conventional kernel estimation with fixed window width would give misleading estimates at the extremes. The kernel estimates are therefore calculated on the log of the odds of the position in the non-immigrant distribution, as in Dustmann, Frattini, and Preston (2013).

Table 2
The Observed and Effective Skills of Immigrant Arrivals

A: United States (Census, year 2000)

Observed

Education (Potential Experience)	1–20 yrs	21–40 yrs	Total
Low	44.1%	13.4%	57.6%
High	36.3%	6.2%	42.5%
Total	80.4%	19.6%	

Effective

Education (Potential Experience)	1–20 yrs	21–40 yrs	Total
Low	56.2%	4.0%	60.3%
High	34.1%	5.6%	39.7%
Total	90.3%	9.7%	

B: United Kingdom (UK LFS, years 2003-2005)

Observed

Education (Potential Experience)	1–20 yrs	21–40 yrs	Total
Low	24.1%	6.2%	30.3%
High	62.7%	7.0%	69.7%
Total	86.8%	13.2%	

Effective

Education (Potential Experience)	1–20 yrs	21–40 yrs	Total
Low	71.3%	4.1%	75.4%
High	21.7%	2.9%	24.6%
Total	93.0%	7.0%	

C: Germany (IABS, year 2000)

Observed

Education (Potential Experience)	1–20 yrs	21–40 yrs	Total
Low	36.3%	6.2%	42.5%
High	51.4%	6.1%	57.5%
Total	87.7%	12.3%	

Effective

Education (Potential Experience)	1–20 yrs	21–40 yrs	Total
Low	61.9%	0.0%	61.9%
High	35.8%	2.3%	38.1%
Total	97.7%	2.3%	

Source: US Census 2000, UK Labor Force Survey 2003–2005, and IABS 2000.
Note: The table reports the observed distribution of recent immigrants (those who arrived within the last two years) across education-experience cells, as well as their imputed distribution based on effective skills. The imputation of effective skills is based on the distribution of workers across wage centiles and 2-digit occupations, as described in section 4.1 of the online Appendix.

education-experience cell under the assumption that immigrants and natives of the same *effective* education-experience type are equally likely to work in a particular occupation-wage group. We apply this procedure to immigrant cohorts that entered the United States, United Kingdom, and Germany around the year 2000. Table 2 contrasts their observed education-experience distribution with their effective one. In all three countries, there is considerable downgrading by experience: in the United States and Germany, the share of immigrants who are observed to be experienced is more than twice as high as the share of immigrants who are effectively experienced. Downgrading by education is particularly striking in the United Kingdom: Whereas 69.7 percent of immigrant arrivals to the United Kingdom would be classified as high skilled based on their reported education, only 24.6 percent are effectively high skilled, suggesting that far from a supply shock for high-skilled workers, immigrant arrivals to the United Kingdom were a supply shock in the market for low-skilled workers.

Interpretation of Relative and Total Effects of Immigration when Immigrants Downgrade

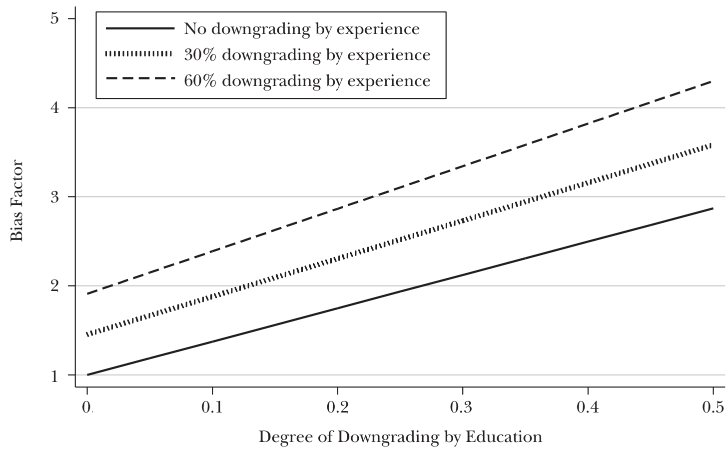
Downgrading may seriously bias the assessment of the wage and employment effects of immigration in the national skill-cell and in the mixture approaches, which rely on the pre-assignment of immigrants to education and experience cells, and then exploit variation in the relative density of immigrants across those skill groups. In contrast, the total effects of immigration obtained from the pure spatial approach is robust to the downgrading of immigrants and remains a policy-relevant parameter, addressing the question of how the overall immigration shock affects wages and employment of a particular skill group. Dustmann, Frattini, and Preston (2013) emphasize that with this approach, the actual position of immigrants in the distribution of native skills is part of the estimated parameter.

Mixture Approach. Downgrading leads to an overestimate of the true immigration shock to high-skilled natives and an underestimate of the true immigration shock to low-skilled natives. In the mixture approach, the direction of the bias due to downgrading is ambiguous in principle, and depends on whether the observed immigration shock is relatively low skilled or relatively high skilled. If, as it is the case in the US context, observed immigration is relatively low skilled, then downgrading will lead to an overstatement of the negative relative wage effect by education. In the US context, this type of bias is likely to be relatively small, since downgrading by education is, in contrast to downgrading by experience, small.

National skill-cell approach. Downgrading also leads to a bias in the estimates obtained from the national skill-cell approach. The direction of the bias is ambiguous in principle, and depends on the relative importance of the observed education-experience immigration shocks. In Figure 2, we plot the bias factor from downgrading against the degree of downgrading by education, where 0 refers to no downgrading and 0.5 refers to the case where 50 percent of high-skilled immigrants actually work in low-skilled jobs. In the figure, we assume for simplicity that the degree of downgrading by experience is the same for high- and low-skilled immigrants, and depict the bias factor for varying degrees of downgrading by experience (no downgrading, 30 percent downgrading, and 60 percent downgrading). The observed education-experience immigration shocks are computed from the 2000 US Census based on immigrants who entered the United States in the past two years.[5] The figure illustrates that over this time period in the United States, the bias factor exceeds one—implying an overstatement of the negative relative wage effect—and, depending on the degrees of downgrading, the bias factor can be very large. In the companion appendix to the paper, we show that based on the 2000 US Census data, reasonable estimates for the degree of downgrading by education

[5] In this time period, the observed education-experience specific immigration shock ΔI_{ga} was at 0.0225 largest for low-skilled inexperienced natives (workers with 20 or less years of potential experience who did not attend college), and at 0.0026 smallest for high-skilled experienced natives. High-skilled inexperienced natives experienced a somewhat larger immigration shock than low-skilled experienced natives ($\Delta I_{HI} = 0.0113$ and $\Delta I_{LE} = 0.0073$).

Figure 2
Illustration of the Bias in the National Skill Cell Approach when Immigrants Downgrade



Source: Authors using data from the 2000 US Census.
Note: The figure illustrates the bias that may arise in estimates of the relative wage effect by experience of immigration obtained by the national skill cell approach when immigrants downgrade. The figure plots the bias factor against the degree of downgrading by education, for three degrees of downgrading by experience (0, 30 percent and 60 percent). For example, a bias factor of 2 implies that the estimated effect based on the observed skill-specific immigration shock is twice as large as the true effect that we would obtain if we could correctly assign immigrants to skill cells. The observed shocks to each education and experience group are drawn from the 2000 US Census. See section 4.2 of the online appendix for details.

and by experience are 0.09 and 0.54, respectively. Such degrees of downgrading suggest a bias factor of more than 2—implying that the "true" relative effect by experience, were we able to correctly assign immigrants to skill cells, is less than half of the estimated effect. Because in the US context, downgrading by experience exceeds downgrading by education, the bias from downgrading will be larger in the skill cell than in the mixture approach. Downgrading therefore provides an alternative explanation as to why the national skill-cell approach typically produces more negative wages effects of immigration than the mixture approach. Furthermore, as the degree of downgrading declines with time in the host country, any bias from downgrading will be larger when annual rather than decadal Census data are used for estimation.

Structural Models and Substitutability between Immigrants and Natives

A more structural approach is to estimate the underlying parameters of the canonical model above and to use that model to predict the wage effects of immigration. Using this approach, resulting estimates obviously rely on strong structural assumptions that are far more stringent than those imposed by the empirical literature discussed so far. Borjas, Freeman, and Katz (1997) offer an early application of this approach. More recently, Ottaviano and Peri (2012) and Manacorda, Manning, and Wadsworth (2012) extend this approach to more flexible production functions but maintain the assumption of inelastic labor supply. Llull (2013) and Piyapromdee (2015) relax this assumption and model labor supply choices.

Here, we will focus on Ottaviano and Peri (2012) and Manacorda, Manning, and Wadsworth (2012). These two studies report *positive* wage effects of immigration for natives. For example, Ottaviano and Peri (2012) predict the long-run total wage effect (assuming fully elastic capital) of immigration on native workers to be 0.6 percent over the period 1990 to 2006 in the United States. Scaled by its impact on total labor supply (an increase of 11.4 percent), this estimate suggest that a one-percent increase in labor supply by immigration increases the wage of native workers by 0.05 percent (see bottom panel of Table 1). By contrast, previous immigrants suffer a substantial wage loss (–0.6 percent).

Both studies impose a production technology similar to the one described above, but allow immigrants and natives to be imperfect substitutes within each education-experience cell. If immigrants and natives are imperfect substitutes within education-experience groups, and mostly low-skilled inexperienced immigrants enter the labor market, then the incumbent low-skilled inexperienced immigrants will bear most of the burden of increased immigration—the more so the less substitutable immigrants and natives are within skill cells. In contrast, wages of not only high-skilled experienced natives, but also of low-skilled inexperienced natives may increase in response to immigration if immigrants and natives are not very substitutable within education-experience groups. These arguments highlight that the crucial parameter underlying the predicted total wage effects of immigration is the estimated elasticity of substitution between immigrants and natives within education-experience cells.

Both Ottaviano and Peri (2012) and Manacorda, Manning, and Wadsworth (2012) estimate the elasticity of substitution between immigrants and natives by relating the relative wage changes of immigrants and natives observed in a particular skill cell to the respective relative employment changes. The two studies report estimates of the elasticity of substitution of about 20 (from Ottaviano and Peri 2012) and 7 (from Manacorda, Manning, and Wadsworth 2012). But these estimates may be seriously impaired by the downgrading and thus misclassification of immigrants across skill cells, as Dustmann and Preston (2012) discuss in detail. This bias may increase further if wage changes of immigrants between two time periods not only reflect wage changes of existing immigrants in response to immigration, but also differences in wages between existing and entering immigrants within education and experience groups (Ruist 2013). If the estimates for the degree of substitutability between immigrants and natives are biased, then this will cause the estimates of the total and relative effects of immigration as predicted by the structure of the model to be biased—even if the model is correctly specified. In principle, the direction of the bias in the estimates for the elasticity of substitution between immigrant and natives is ambiguous. Based on the observed immigration shocks in the US context, downgrading is likely to lead to an overstatement of the negative (relative) wage responses of natives in the mixture and especially the skill-cell approach, but to an understatement of the (total) wage responses of natives in the structural approach.[6]

Discussion and Conclusions

In this paper, we revisit the question of why different studies on the effects of immigration on wages come to different conclusions, and why there is continued controversy in this debate. We classify the existing empirical studies that estimate wage effects of immigration in three types: studies that use variation in immigrant inflows across education-experience cells at the national level, as for example in Borjas (2003), studies that exploit variation in the total immigrant inflow across regions, as for example in Altonji and Card (1991), and studies that use variation in immigrant flows both across regions and across educations groups, as for example in Card (2001). We show that these three approaches identify different and not comparable parameters, which is one important reason for the continued controversy of the wage effects of immigration in the existing literature. While the national skill-cell approach identifies the effect of immigration on one experience group versus another within education groups, the mixture approach identifies the relative effect of immigration of one education group versus another. By contrast, the pure spatial approach recovers the total effect of immigration, which, unlike the first two approaches, takes into account complementarities across skill cells and across capital and labor.

We then relax the maintained assumption in much of the existing literature that native labor supply is either inelastic, or equally elastic across different skill groups. We show that in the presence of labor response heterogeneity, estimated relative wage effects of immigration from the national skill-cell approach yield misleading and hard-to-interpret estimates of the overall labor market impact of immigration. In contrast, estimates of total effects of immigration retain a clear interpretation, and remain meaningful and policy relevant. Employment and wage effects, however, need to be studied jointly to obtain an accurate picture of the overall labor market effect of immigration.

We finally discuss the possibility that immigrants "downgrade" and work in jobs below their observed education and experience level, and argue that downgrading will lead to biased estimates in the national skill-cell and mixture approaches, which both rely on variation of immigration inflows across skill cells.

[6] In the companion appendix to this paper, we provide, focusing on the high-skilled experienced group and observed immigration inflows in the United States, an example in which downgrading leads to an overestimate of the degree of substitutability between immigrants and natives–which will understate wage losses for the low-skilled inexperienced natives most exposed to immigration, overstate possible wage gains for the high-skilled experienced natives least exposed to immigration, and overstate the wage losses of previous immigrants.

Although the bias from downgrading generally cannot be signed, we illustrate that in the US context it may severely overstate the negative relative wage effect by experience in the national-cell approach. Downgrading is also likely to overstate the negative relative wage effect by education estimated by the mixture approach, but in the US context the bias is likely to be smaller than in the national skill-cell approach—which may be one reason why the mixture approach tends to produce less-negative wage effects than the national skill-cell approach. By contrast, the total effect of immigration identified by the pure spatial approach is robust to downgrading, as there is no need to assign immigrants to skill cells.

We further point out that downgrading poses a problem for structural approaches that allow immigrants and natives to be imperfect substitutes within education-experience groups, and we calculate relative and total effects of immigration based on estimated parameters and the structure of the model, as for example in Ottaviano and Perio (2012) and Manacorda, Manning, and Wadsworth (2012). Specifically, we show that in the presence of downgrading, immigrants and natives may appear to be imperfect substitutes within skill cells even though they are not. As such, downgrading will cause us to understate the wage losses of native workers, even if the model is correctly specified—which may help to explain why the structural approach typically produces positive (total) wage effects of immigration for natives.

In sum, we advocate that researchers exploit variation in the overall immigration shock for the identification of the total labor market effects of immigration. Not only does this approach identify a meaningful and policy relevant parameter, but it is also robust to heterogeneous labor supply elasticities across skill groups and the downgrading of immigrants.

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Journal of Economic Perspectives—Volume 30, Number 4—Fall 2016—Pages 57–82

Is the Mediterranean the New Rio Grande? US and EU Immigration Pressures in the Long Run

Gordon Hanson and Craig McIntosh

The tens of thousands of migrants streaming into Europe during late 2015 and early 2016 created an indelible image of how humanitarian crises—in this case associated with the Syrian civil war—propel international migration. Although political instability in the Levant may have kicked migration to Europe into a higher gear, immigration flows to the continent in the medium- and long-run are likely to be sustained by sharp differentials in labor-supply growth between regions to the north and to the south of the Mediterranean Sea. The present European migration scene is the latest act in a long-running global drama in which cross-country differences in population growth, abetted by disparities in aggregate labor productivity, create pressures for international migration. Periodically, economic or political crises unleash these pressures and generate sustained flows.

During the last quarter of the 20th century, the principal actors in this global drama were Mexico and the United States. The US baby boom came to an abrupt halt in the early 1960s, causing growth in native-born labor supply to slow sharply two decades hence, once the baby-boom generation had fully reached working age. In Mexico, birth rates declined much later. High fertility in the 1960s—when Mexico's fertility rate (the number of births per woman of childbearing age) averaged 6.8, versus 3.0 in the United States—meant that Mexico's labor force was expanding

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† For supplementary materials such as appendices, datasets, and author disclosure statements, see the article page at
http://dx.doi.org/10.1257/jep.30.4.57 doi=10.1257/jep.30.2.57

rapidly in the early 1980s, just as a severe financial crisis hit. This crisis, and the decade and a half of economic instability that ensued, unleashed a great wave of Mexican migration to the United States (Hanson and McIntosh 2010). Encouraging this flow was steady US economic growth during the "Great Moderation" period from the mid-1980s up through 2007 (Bernanke 2004). In a pattern common to migration events stretching back into human history, early migrants eased the transition for later arrivals by offering advice on how to find jobs and housing, opening familiar stores and restaurants, and creating enclaves in which Spanish was spoken alongside English (Massey, Alarcón, Durand, and Gonzalez 1987; Munshi 2003).

The Mexican migration wave to the United States has now crested. Fertility rates in Mexico, at 2.3 births per woman of childbearing age, are only modestly above those in the United States, at 1.9 (World Development Indicators, data for 2013). Labor-supply growth in the two countries is projected to be roughly the same in coming decades. Although living standards in Mexico remain well below US levels, Mexico has tamed the macroeconomic volatility it experienced during the 1980s and 1990s. Net US immigration from Mexico plunged after the onset of the Great Recession in 2007 and has been slightly negative every year since (Villarreal 2014; Gonzalez-Barrera 2015). Absent a significant new economic or political crisis in Mexico, or unexpectedly robust US economic growth, it is unlikely that Mexico-to-US migration rates will again reach the levels witnessed between the early 1980s and the mid-2000s.

The European immigration context today looks much like the United States did three decades ago. In Europe, which long ago made its demographic transition to low birth rates, declines in fertility in the 1970s and 1980s set the stage for a situation in which the number of working-age residents is in absolute decline (as discussed in this journal by Lee 2003). Countries in the North Africa and Middle East region, in contrast, have had continued high fertility, creating bulging populations of young people looking for gainful employment in labor markets plagued by low wages and the scarcity of steady work. Further to the south, population growth rates in sub-Saharan Africa, a region with still lower relative earnings, remain among the highest in the world.

Many countries in North Africa and the Middle East are in a period of profound political and economic upheaval. Migrants escaping military conflict in Afghanistan, Iraq, Libya, and Syria are crossing the Straits of Gibraltar, the land and sea borders that divide Turkey and Greece, and the narrow Mediterranean passage that separates northern Libya and southern Italy. Further to the south, conflicts in Chad, Eritrea, Mali, and Nigeria are also generating labor outflows. These new triggers are being tripped in a demographic environment that is ideal for perpetuating emigration well into the future. As further motivation, established populations of Algerians in France, Moroccans in Spain, the Turkish in Germany, and sub-Saharan Africans in Italy may offer support and solace to the new arrivals as they settle in.

In this paper, we assess the contribution of differentials in population growth to international migration in the long run. We look backward to the significant migration episodes of the last 30 years and forward to the pressures that will encourage flows in coming decades. Whereas in the 1970s, the world was neatly divided between a high-income and low-population-growth North and a low-income and high-population-growth South, by the 2040s the only high-population-growth countries likely to remain will be in sub-Saharan Africa and parts of the Middle East. We use past population growth to estimate a gravity model of bilateral migration and then apply the estimated coefficients to project future migration out to mid-century, as implied by population forecasts. This exercise projects the stock of first-generation immigrants to remain flat in the United States, as a consequence of the cessation of Mexico's emigration surge, and the stock of first-generation immigrants to nearly triple in the United Kingdom, Spain, and Italy.

Our exercise is not intended as a hard prediction of the future, but as a guide for how demographic trends will recalibrate pressures for international labor movements. If Europe tightens its borders significantly, the United States decides to relax entry restrictions, or the nations of East Asia change course to allow labor inflows at much higher levels than in the past, global migration may evolve in a very different manner from what our analysis suggests. Future migration will undoubtedly be shaped also by crises that we cannot foresee, much as the Arab Spring and the subsequent tumult around the Mediterranean caught the European Union by surprise, leaving it ill-equipped for mass arrivals of refugees on its shores. Yet there remains a certain destiny in global demography. Just as population growth in most of Latin America is cascading downward and looks set to drop below replacement levels within a couple of decades, it is proceeding apace in sub-Saharan Africa and much of North Africa and the Middle East. These patterns mean that the United States and Europe occupy neighborhoods whose future patterns of migration are likely to differ immensely from those of the past.

Global Migration Patterns

In 1970, there was little indication either in the United States or in Europe that immigration would become a major political issue by century's end. The share of the US population that was foreign-born in 1970 was at a 100-year low, at 4.7 percent. Concerns in western Europe centered not so much on excess entry as on restrictions that impeded those living behind the Iron Curtain from moving west (Joppke 1999). At the time, policymakers in Bonn, Paris, and London wanted, if anything, to facilitate immigration, not to block it. Today, of course, anxiety about the arrival of foreign workers is running high.

We begin our discussion by summarizing the present contours of immigration in the United States and other OECD nations. We focus on the OECD both because it is a grouping that includes all high-income destination economies, aside from the oil-rich states of the Persian Gulf, and because it provides immigration data by age cohorts that are comparable across countries. We then examine past and projected future population growth worldwide, paying particular attention to forecasted changes in growth rates in current migration hot spots.

Immigrant Presence in OECD Countries

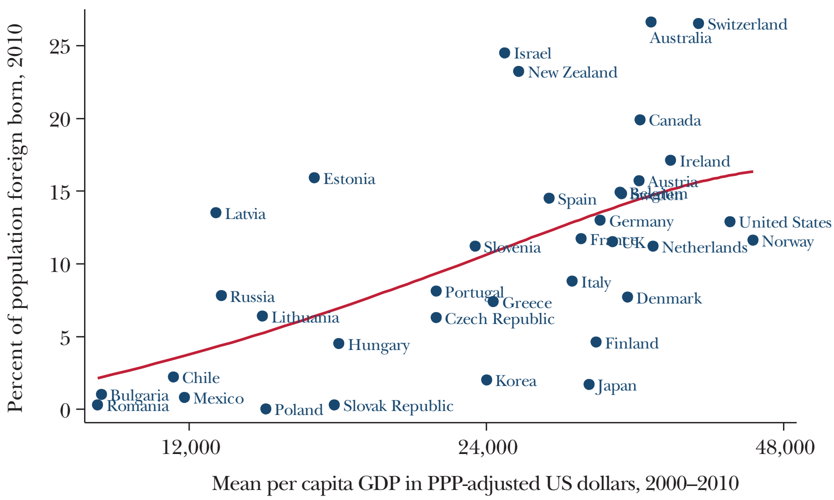
Perhaps the most fundamental concept in the economics of immigration is that international labor flows are driven by differences in income among countries. The seminal work of Sjaastad (1962) framed immigration as an investment decision, in which an individual considers incurring an up-front cost from migrating to another location—due to moving expenses, fees for obtaining a visa, time out of the labor market, and the psychic cost of leaving home—in return for a higher present discounted value of lifetime income. Although the migration decision in theory is based on comparing future income streams at home versus abroad, the vast majority of empirical work uses current income as a summary statistic for cross-country differences in labor-market conditions (for example, Clark, Hatton, and Williamson 2007; Mayda 2010). In our first foray into the data, we follow this convention. Later, we introduce differences in relative labor supply growth as an additional indicator of future income streams.

Figure 1 plots the share of the population that is foreign born in 2010 against mean purchasing-power-parity–adjusted per capita GDP averaged over 2000 to 2010 for OECD countries. Values of per capita GDP are from the Penn World Tables 8.0. The 2010 foreign-born population share summarizes immigrant inflows over proceeding decades, while mean income for the 2000s provides a metric of economic conditions in destination countries around the time during which the preponderance of migrants would have made their location choices.

Clearly, lower-income countries, such as Bulgaria, Chile, Mexico, and Romania, lure few immigrants, while higher-income economies are attractive destinations. The regression line is strongly positive and statistically significant at the 1 percent level. For every 10 percent increase in average income, the foreign-born population share rises by 0.4 percent. Yet even after controlling for income, there is also enormous heterogeneity in migrant inflows. While Australia and the Netherlands have near identical average per capita GDP, the former's foreign-born share (26.6 percent) is nearly two-and-a-half times that of the latter (11.1 percent). Also dramatic is the contrast between Germany and Japan, two countries that again have similar average living standards. Germany's foreign-born share at 13.0 percent is almost exactly on the regression line. At 1.7 percent, the share of immigrants in Japan's population is the lowest among the higher-income nations of the OECD. Other pairs with common average incomes but sharply differing foreign-born shares include Estonia (15.9 percent) and the Slovak Republic (0.3 percent); Slovenia (11.2 percent) and Korea (2.0 percent); and Belgium (14.9 percent) and Denmark (7.7 percent). International migration is apparently about more than current income differences between countries.

A vast literature examines the factors that shape bilateral migration flows. Similar to findings for the "gravity model" of trade (Head and Mayer 2014), migration is strongly decreasing in geographic distance between countries and significantly higher between country pairs that share a land border, a common language, and past colonial linkages (Mayda 2010). These additional factors explain in part why Anglophone countries are particularly popular destinations for international migrants. Four of the six highest foreign-born population shares are found

Figure 1
Income and Immigration in OECD Destination Countries



Source: Authors using GDP data from the Penn World Tables 8.0 and immigration data from the OECD.
Note: The figure plots the share of the population that is foreign born in 2010 against mean purchasing-power-parity–adjusted per capita GDP averaged over 2000 to 2010 for OECD countries. The fitted values use a cubic in per capita GDP. Turkey is missing from the figure due to the absence of OECD immigration data for the country.

in countries that are former British subjects: Australia, Canada, Ireland, and New Zealand. These nations have the appeal of speaking the language that the British Empire made the lingua franca of global commerce. Also, the era of empire helped establish migration networks—and later the creation of preferential immigration schemes such as those among British Commonwealth nations—that resulted in reduced costs for current labor flows between former colonies of the same hegemon and between a former colony and the hegemon itself.

The additional explanatory power of gravity variables would still not account for the idiosyncratic cases of very high or very low immigration, which are evident in Figure 1. High-inflow countries include Switzerland, whose long history of neutrality has made it the headquarters for international organizations that hire large numbers of foreign diplomats and other professionals, and Israel, whose national identity is predicated on encouraging immigration of those of Jewish descent (Friedberg 2001). Korea and Japan discourage immigration, ostensibly to maintain cultural homogeneity (Cornelius, Martin, and Hollifield 1994), resulting in low labor inflows. These historical features, which are manifest in policies that would be transparent to any person attempting to emigrate to these destinations, are difficult to measure systematically across countries and hence end up in the regression residual.

Another shortcoming of the gravity model, at least as conventionally applied, is a focus on current income as a predictor for bilateral migration. Because migration is a long-lived decision, individuals are likely to evaluate the extended prospects for their livelihoods in alternative destinations, as Sjaastad (1962) proposed. Obvious additional factors that affect future earnings include total factor productivity growth and capital accumulation, which are hard to forecast far into the future. Domestic labor-supply growth, on the other hand, is eminently forecastable. Current differences in birth rates between countries foretell how relative labor supplies—holding immigration constant—will change 15 to 20 years hence, when today's newborns enter the labor force. Because birth rates change much less abruptly than investment or innovation, demographers are able to forecast changes in birth rates two to three decades into the future with considerable accuracy (O'Neil, Scherbov, and Lutz 1999; Lutz, Sanderson, and Scherbov 2001). Thus, current population growth is informative about what domestic labor supplies would look like 40 to 50 years from now with no further flows of international migrants. In later sections, we use this insight to estimate an augmented gravity model of bilateral migration that accounts for both current relative incomes and expected future relative incomes as captured by anticipated changes in domestic labor supplies.

Figure 1 illustrates the potential pitfalls of using only current income alone as an indicator of coming migration. If one were to utilize nothing other than the residuals from the regression plot, it would appear that the United States is poised for relatively high immigration in the future. The foreign-born share of the US population at 12.9 percent is similar to that of the large countries of Europe: it is even with Germany, slightly above France, the Netherlands, and the United Kingdom, and slightly below Spain. Yet, US per capita GDP exceeds that of these other nations by substantial amounts. Moreover, the relatively high labor-market rewards to more-educated workers in the United States, in both pre-tax and post-tax terms, gives it a strong advantage in attracting more-skilled labor (Grogger and Hanson 2011). We will see next that a different picture of migration pressures emerges once we examine the composition of bilateral immigration stocks in major destination countries. These comparisons reveal that it is Europe, not the United States, in which the potential for substantial future inflows appears greatest.

Bilateral Migration Stocks in OECD Countries

To study bilateral migration, we use data on the numbers of the foreign born by country of birth from the Database on Immigrants in OECD Countries (DIOC).[1] Following categories used in the DIOC, we focus on individuals between ages 15 and 64. This range is more expansive than the definition of the working-age population that is conventional in US or European labor-market analysis. Whereas

[1] This OECD database is at http://www.oecd.org/els/mig/databaseonimmigrantsinoecdcountriesdioc.htm. For most countries, the source for the DIOC is a decennial census (OECD, 2008), whose large sample sizes permit the estimation of bilateral migrant stocks for the majority of sending countries. Measuring bilateral migration is problematic in Germany, which rarely conducts a census. The German data in the DIOC are based on labor force surveys, which suppress country of birth for immigrants from smaller origin nations. As a consequence, we lack data on bilateral stocks that account for two-fifths of German immigration.

many high-income nations require children to stay in school until age 18, in most lower-income countries mandatory schooling ends between grades six and nine. It is around age 15 that emigration rates in major sending countries pick up noticeably, as youths leave school and begin to seek work (McKenzie and Rapoport 2007).

Table 1 summarizes the number of immigrants living in the ten largest OECD migrant-receiving countries as of 2010, which is the most recent year for which the DIOC has comprehensive data on bilateral migration stocks. Considering absolute numbers, rather than the foreign-born population shares in Figure 1, the United States is by far and away the dominant destination country for international migrants. The 32.8 million working-age immigrants who resided in the United States in 2010 were 41.6 percent of all foreign-born individuals living in an OECD country. (For perspective, the United States accounted for one-quarter of the total OECD population in 2010.) Other destination countries are distant runners up. Next in line are Great Britain, with 7.9 percent of the working-age immigrants that reside in OECD countries; Spain, with 6.2 percent; and Canada, with 6.0 percent.

Equally impressive is that a single source country, Mexico, accounts for just under one-third of US working-age immigrants. The 10.2 million individuals born in Mexico and living in the United States accounted for fully 13.0 percent of all immigrants living in an OECD country in 2010. Remarkably for a country as large as Mexico, these immigrants were equal in number to 13.5 percent of Mexico's working-age population. Indeed, the Mexico-to-US migrant flow is one of the largest international migration episodes that the world has seen. Any substantial change in pressures for migration from Mexico to the United States could thus have a major impact on US immigrant presence. Ten of the 20 next-largest dyadic origin–destination groups in the OECD are also in the United States. They include migrants from high-population countries (China, India), low-income countries close to the United States (Cuba, the Dominican Republic, El Salvador, Guatemala), and countries in which US military presence has facilitated immigration (Germany, Korea, Philippines, Vietnam). Though China's and India's total volumes of migration to the United States are large, their emigration rates are low.

The United States is far from alone in having a few countries play a prominent role in its immigration picture. Poles, Indians, and Pakistanis together are 24.2 percent of UK immigrants; Romanians and Moroccans combine to represent 26.0 percent of immigrants in Spain; Algerians and Moroccans account for 28.0 percent of working-age immigrants in France; and individuals born in Turkey and Poland are 27.4 percent of German immigrants.[2] The Romanians living in Italy and Spain

[2] In Table 1, the foreign-born are 7.6 percent of Germany's working-age population, which seems low compared to 13.0 percent of Germany's total population as seen in Figure 1. This discrepancy reflects missing data on bilateral migration for Germany's smaller migrant-sending countries. To arrive at the estimate of the share of total German immigrants given in the text, we inflate the total number of German immigrants reported in panel A of Table 1 by an adjustment factor that accounts for "missing" bilateral migrants in the OECD data. This conversion factor is 13.0 (the percentage of the foreign-born in German's total population in Figure 1) divided by 7.6 (the percentage of the foreign-born in German's working-age population in Table 1).

Table 1
Counting First-Generation Migrants in 2010 (Those Born between 1946 and 1995)

A: Total Migrant Counts by Destination

Destination:	Total migrants, thousands:	% of Destination population	% of All migrants in data
USA	32,782	15.7%	41.6%
Great Britain	6,208	15.0%	7.9%
Spain	4,880	15.3%	6.2%
Canada	4,697	19.8%	6.0%
France	4,569	11.2%	5.8%
Italy	4,120	10.6%	5.2%
Germany	4,019	7.6%	5.1%
Australia	3,454	23.1%	4.4%
Japan	1,259	1.6%	1.6%
Netherlands	1,223	11.0%	1.6%

B: Total Migrant Counts by Origin

Origin:	Total migrants, thousands:	% of Origin population	% of All migrants in data
Mexico	10,406	13.7%	13.2%
China	3,036	0.3%	3.9%
India	2,957	0.4%	3.8%

C: Migrant Counts by Origin/Destination Dyad

Destination:	Origin:	Count, thousands:	% of Destination population	% of Origin population	% of All migrants in data
USA	Mexico	10,242	4.9%	13.5%	13.0%
	India	1,431	0.7%	0.2%	1.8%
	Philippines	1,296	0.6%	2.2%	1.6%
	China	1,089	0.5%	0.1%	1.4%
	El Salvador	1,022	0.5%	27.2%	1.3%
	Puerto Rico	993	0.5%	40.2%	1.3%
	Vietnam	914	0.4%	1.5%	1.2%
	South Korea	867	0.4%	2.4%	1.1%
	Germany	792	0.4%	1.5%	1.0%
	Guatemala	717	0.3%	8.6%	0.9%
	Dominican Republic	667	0.3%	10.8%	0.8%
	Cuba	603	0.3%	7.6%	0.8%
Germany	Turkey	1,021	1.9%	2.1%	1.3%
	Poland	870	1.6%	3.2%	1.1%
	Russia	780	1.5%	0.8%	1.0%
	Kazakhstan	611	1.2%	5.4%	0.8%
Italy	Romania	728	1.9%	5.3%	0.9%
	Albana	342	0.9%	17.5%	0.4%
	Morocco	315	0.8%	1.5%	0.4%
Mexico	USA	707	0.9%	0.3%	0.9%
	Guatemala	29	0.0%	0.3%	0.0%
	Colombia	12	0.0%	0.0%	0.0%
France	Algeria	699	1.7%	2.9%	0.9%
	Morocco	579	1.4%	2.7%	0.7%
	Portugal	379	0.9%	5.4%	0.5%
Spain	Romania	663	2.1%	4.8%	0.8%
	Morocco	636	2.0%	3.0%	0.8%
	Ecuador	392	1.2%	4.2%	0.5%
Great Britain	Poland	613	1.5%	2.2%	0.8%
	India	492	1.2%	0.1%	0.6%
	Pakistan	399	1.0%	0.4%	0.5%

Source: Authors' calculations from the Database on Immigrants in OECD Countries (DIOC).

are equivalent to 10.0 percent of the population of working age in Romania and Poles living in Germany and the United Kingdom equal to 5.7 percent of Poland's working-age residents. Flows of these magnitudes mean that labor-market shocks in these sending countries have potentially significant consequences for destination economies, and vice-versa.

Drivers of International Migration

Following the logic of the gravity model, it is no accident that many of the largest bilateral migration stocks involve nearby countries. There is both motive and opportunity for migration from Romania to Italy, Poland to Germany, and Morocco to Spain. The enlargement of the European Union in 2004 to countries across eastern Europe, which eliminated immigration restrictions on accession countries, further expanded opportunities for migration from eastern to western Europe (Elsner 2013). Also consistent with the gravity framework, colonial history has eased the movement of Algerians and Moroccans to France, Ecuadorans to Spain, and Indians and Pakistanis to the United Kingdom (Bertoli, Moraga, and Ortega 2011). Other flows, however, involve happenstance. The Turkish migration to Germany began in the 1960s, when West Germany sought foreign guest workers to fill low-wage positions during a period of soaring economic growth. This first generation of immigrants created family and kinship networks that facilitated immigration in later decades (Pischke and Velling 1997).

Motive and opportunity, however, are far from sufficient conditions for migration to occur. The United States and Mexico, which share a 2,000-mile land border, have long had widely divergent incomes. In 1960, per capita GDP (PPP adjusted) in the United States was triple that in Mexico, a ratio that remained essentially unchanged during the following two decades—yet there was only a modest migration response. As a share of Mexico's national population, the number of the Mexicans living in the United States stood at 1.5 percent in 1960 and 3.2 percent 20 years later. In 1980, immigrants from Mexico accounted for just 1.0 percent of the US population.

What sparked substantial labor flows from Mexico to the United States was the onset of the Mexican debt crisis of the 1980s and the "lost decade" of economic stagnation that followed (Hanson and Spilimbergo 1999). Between 1982 and 2000, the ratio of US-to-Mexico per capita GDP rose by over one-and-a-half times, from 2.3 to 3.8.[3] Financial crises are common triggers of migration episodes (Yang 2008; Bertoli, Moraga, and Ortega 2013), as are political upheaval and military conflict (Hanson and McIntosh 2012). However, temporary shocks need not induce permanent migration. During the Mexican Revolution (1911–1920), approximately

[3] If education, labor market experience, or other sources of human capital are higher in destination than in sending countries, bi-national differences in per capita GDP will overstate the gain in income that an international migrant can expect to obtain. Holding constant observable worker characteristics, Clemens, Montenegro, and Pritchett (2008) estimate that in 2000 a young Mexico-born male with mean years of schooling would see his earnings rise by 2.5 times (in purchasing power parity-adjusted terms by migrating to the United States (where the US/Mexico per GDP ratio for that year is 3.8).

700,000 Mexicans, or 5 percent of the population, fled to the United States. By the late 1920s, a large fraction had returned home (Cardoso 1980; Durand, Massey, and Charvet 2000).

To sustain international migration, it helps if individuals expect that economic conditions will diverge between origin and destination countries in coming years. In sending nations, increases in domestic labor supply, relative to abroad, are one impetus for such expectations. Between 1940 and 1960, the US baby boom matched rapid population growth in Mexico. In the ensuing two decades, birth cohorts in Mexico continued to grow in size, while the annual number of births in the United States fell in both relative and absolute terms. The consequence was that between 1960 and 1980 the relative size of US–Mexican cohorts born each year dropped precipitously from 4:1 to less than 2:1, a shift which meant that Mexico's relative labor supply was expanding at mach speed in the 1980s, just as its economy staggered.

The contribution of labor-supply growth to international migration is evident not just at the national level but also across regions within economies. Mexico's demographic transition occurred unevenly across space. First affected were richer Mexican states along the US border and around Mexico City; last affected were poorer states in central and southern Mexico. The Mexican migrants who moved north, while roughly similar in educational attainment to workers who stayed behind (Chiquiar and Hanson 2005; Kaestner and Malamud 2014), were not drawn randomly from across Mexico. They came disproportionately from states with pre-existing migration networks (Munshi 2003; McKenzie and Rapoport 2007) and with relatively high labor-force growth. Exploiting this regional variation, in Hanson and McIntosh (2010), we find that relative labor-supply growth can account for two-fifths of Mexican migration to the US between the 1970s and the 1990s.

The Hot Spots with Population Pressures for Migration

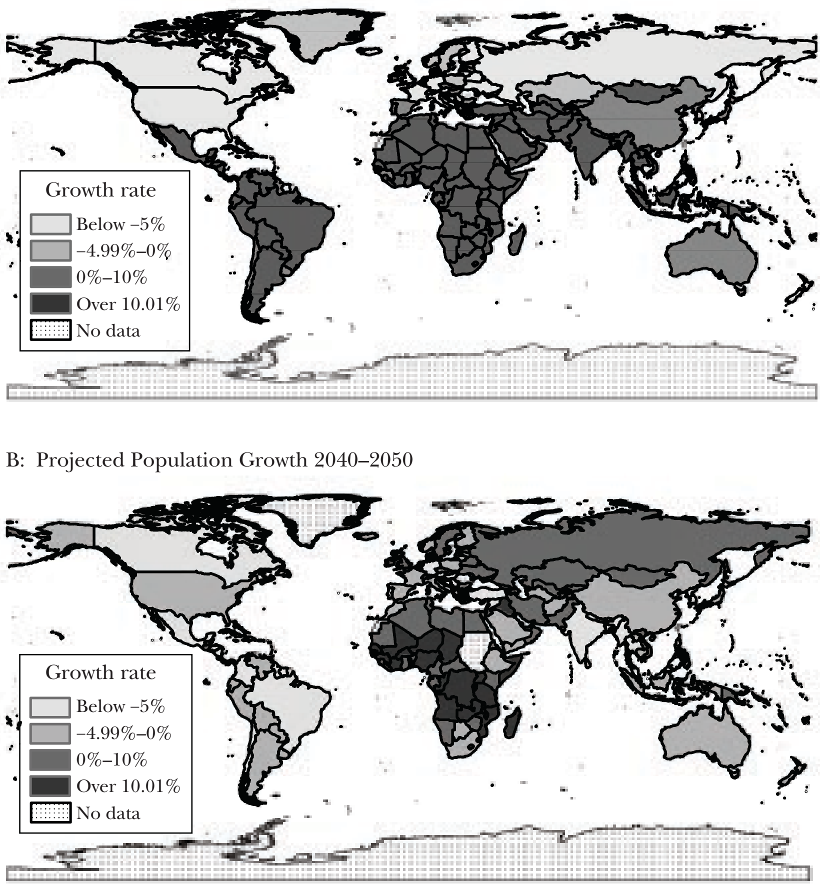
The argument here suggests that when international borders also draw a line between nations with significant differences in population growth, pressures for migration will result. To illustrate this theme more concretely, we calculated national growth rates between 1970 and 1980 for the population of native-born individuals 0 to 14 years old. Data are from the United Nations' World Population Prospects (at http://esa.un.org/unpd/wpp/Download/Standard/Population). These growth rates determine the number of the native-born who would be coming of working age about 15 years hence—in this example, between the years 1980 and 1995. We then did a similar calculation using population forecasts for the years from 2040–2050. The results suggest how the population pressures for migration will change over time.[4] Figure 2 maps the outcome of this exercise, where countries

[4] The UN Population projections by age and sex start in 2015 and are done using the open source CRAN R package bayesPop as documented in Raftery et al. (2012). We use the "Zero Migration" variants, which do not attempt to forecast future migration rates in projecting age cohort sizes.

Figure 2
Maps of Actual and Projected Population Growth
(percent change in population ages 1–14)

A: Population Growth 1970–1980

B: Projected Population Growth 2040–2050



Source: United Nations' World Population Prospects (http://esa.un.org/unpd/wpp/Download/Standard/Population).

with high population growth are shown in dark grey and countries with low population growth are shown in light grey.

In the 1970s, there was a stark North–South divide in the growth of the young population. Most richer countries including the United States, Canada, and most nations of western Europe show a decline in the relevant population from 1970 to 1980. Declines in these countries were the result of the end of the post–World War II baby boom and the lower birth rates that had taken hold by roughly 1960. Australia, Ireland, Japan, and Spain were the only higher-income countries with positive growth in the number of young people during the decade. In contrast, for most poorer countries, the growth rates in the 0–14 age group were positive from 1970 to 1980. The change in the youth population was positive to strongly positive in Latin America, Africa, the Middle East, and most of developing Asia. Growth in these regions was the result of continued high fertility combined with declines in infant mortality (Lee 2003). Among the countries in our data, only Cambodia, which suffered depopulation under the Khmer Rouge, Russia, which saw fertility plummet during the later years of the Soviet Union, and Suriname have negative growth in the number of 0 to 14 year-olds during the 1970s.

Bilateral migration flows will tend to be high between countries that are neighbors and that occupy different ends of this population growth continuum. Based on our analysis of the 1970s, the Mexico–US border shows up as one evident hot spot for migration. Other migration hot spots in this time period include Europe and North Africa and the Middle East. In particular, booming growth in the youth populations of Algeria, Libya, Morocco, and Turkey contrasted with sagging youth populations north of the Mediterranean, which helped fuel migration into Europe in the 1990s and 2000s. Other adjoining countries with both underlying age 0–14 population growth differentials in the 1970s and also meaningful differences in per capita income are Russia and most of the nations of Central Asia. In recent decades, there were substantial migration flows within each of these groups (Özden, Parsons, Schiff, and Walmsley, 2011).[5]

Looking forward, the geography of population growth will be very different than in the past, which also suggests that the population pressures for migration will shift. To construct the growth rate of the age 0–4 population between 2040 and 2050, we used projections from the United Nation's World Population Prospects. The UN Population Division constructs forecasts both including and excluding expected immigration in the future. Because our interest is ultimately in seeing how changes in the size of birth cohorts affects pressures for migration, we restrict our attention to UN forecasts that leave out projected future immigration.

The decade of the 2040s is far enough in the future for present trends of declining fertility in the Americas, Europe, and East Asia and of more stable fertility in Sub-Saharan Africa and parts of the Middle East to produce substantial differences in population growth between countries. By the 2040s, the North–South divide in population growth will be gone. Instead, the differences in population growth of the 0–14 age group will be primarily regional in nature. For example, essentially all countries of North and South America show declines in the age 0–14 population during the 2040s, with the exceptions of Guatemala and French Guiana,

[5] One anomaly is the Persian Gulf. Growth in the young population in the 1970s and 1980s was rapid in Saudi Arabia and the United Arab Emirates, yet these countries became importers of labor from South Asia, Egypt, and elsewhere in the Middle East in later decades (Jain and Oommen 2016). Low rates of labor-force participation among the native-born in Gulf states may account for the unusual combination of high growth in the native-born working-age population and high immigration.

Consequently, the US–Mexico border no longer appears as a hotspot for migration pressures in coming decades.

Most of Europe will have negative growth in the population of 0–14 year-olds in the 2040s, with the exceptions of Sweden and the United Kingdom, whose current high-fertility immigrant populations will keep future fertility from declining as rapidly as on the rest of the continent. Morocco, Turkey, and Saudi Arabia also have a projected decline in their age 0–14 native-born population during the 2040s, reflecting projected fertility declines in the more cosmopolitan countries of the Muslim world. However, nearby are the high-fertility countries of North Africa and sub-Saharan Africa. The Mediterranean thus appears likely to continue to be a hotspot for international migration out to mid-century. Further, new population-growth gradients seem ready to emerge within North Africa and the Middle East, contributing to pressures for intraregional migration. [6]

In this scenario, a question mark hangs over Asia. East, Southeast, and South Asia all show a decline in the age 0–14 population in the 2040s, with the exceptions of Vietnam and Papua New Guinea. The nations in this region have little history of large immigrant inflows. They are also far from high-population-growth areas in Africa. Both factors would suggest that migrant inflows in Asia may stay low in the future. Yet few nations in Asia have to this point experienced a demographic reality that entails persistent population decline. This coming drop may create pressures for immigration policies that are more open than in the past.

Population Pressures for Migration in the Past and Future

To formalize the connection between population pressures and migration, we estimate a simple gravity model of bilateral migration flows. We then use this model to project migration out to mid-century, based on forecasted growth of populations coming of working age.

A Gravity Model for Migration without the Legacy of Previous Migration

The standard framework for bilateral migration is the gravity equation, which posits that the movement of labor from one location to another is a function of relative earnings in the two locations, economic opportunities in alternative destinations, and bilateral migration costs (for example, Bertoli and Moraga 2013). Here, we describe one strategy for estimating a model of this kind and what it implies for how the population pressures for migration will evolve in the future. In an online

[6] Perhaps surprisingly, Russia shows up as a country with positive projected population growth. This reflects the tendency of projection models to impose some degree of regression to the mean; for example, China's actual male/female gender imbalance of 1.17 in 2015 is predicted to return linearly towards the global average over the coming decades. Following Russia's demographic collapse that began in the 1980s, forecasts push the country to have makeup population growth in the future.

Appendix available with this paper at http://e-jep.org, we discuss robustness and specification checks for this approach.

We look at the migration rate in a disaggregated way: specifically, the migration rate $y_{csd,t}$ is the percentage of age-gender group c from sending-country s that has migrated to destination-country d as of year t; for example, the share of 15 to 24 year-old men born in Mexico who are residing in the United States in 2000. The dependent variable is the change in the age-specific net emigration rate from a sending country to an OECD destination during the 2000s: for example, the percentage emigration rate to the United States for Mexico-born men who were 25 to 34 years old in 2010, $y_{csd,2010}$, minus that for those who were 15 to 24 years old in 2000, $y_{csd,2000}$. Using those who were 15–54 in 2000, we have four ten-year birth cohorts, two genders, and 3,457 sending-destination pairs covering 175 sending countries and 25 destinations. Missing data on GDP for early cohorts from some developing countries reduces the usable sample size from the potential 27,656 observations to the actual sample size of 18,297. By estimating the model in first-differences, we sweep out time-invariant migration barriers in a destination that are specific to a sending country (for example, visa policies that favor particular origin nations).

Our starting-point regression has nine explanatory variables, plus a constant term. The first is a demographic term based on differentials in the size of age-specific birth cohorts. The second is an incentive term based on income differentials between countries. The next four terms are commonly included in gravity models: they are (the log of) distance between countries where migration occurred, whether the two countries where migration occurred share a contiguous border, whether the two countries where migration occurred had a colonial relationship; and whether they share a common language. The final three terms are fixed effects for the age cohort, the sending country, and the destination country, which are intended to capture time trends in each of these dimensions. We will say a few words about each of these. But we will then find that it is important to include one more economic factor, made up of interaction terms that seeks to capture whether dyads of countries have been more or less closely linked by migration in the past, thus laying the groundwork for higher migration by the younger cohorts in the future.

The first regression term and the key explanatory variable for our analysis can be thought of as seeking to capture the relative abundance of labor in the sending and receiving economies. We calculate the relative size of an age-gender cohort in the sending and destination countries, $\frac{L_{cs,t}}{L_{cd,t}}$, and we look at how this changes over time. For example, we would look at the log Mexico/US birth cohort ratios for those aged 15 to 24 in 2000, minus the log birth cohort ratio for those aged 15 to 24 in 1990. In effect, this term measures the panel changes in labor supply over time for a given age cohort. The use of this variable is a way of exploiting the long panel on birth cohort sizes in a context where we have only a cross-section of migration flows (2000–2010). This variable captures one way in which labor-market conditions in the two locations differed at the time the cohort entered the labor market.

The second regression term looks at relative per capita GDP (PPP adjusted) in the sending and destination countries, $\frac{w_{cs,t}}{w_{cd,t}}$. Specifically, we include the log of the GDP ratios in the year that a cohort turned 15. This focus on initial conditions captures the logic in Borjas (2006), in which adjustment costs constrain migration, such that labor flows do not equilibrate wages across locations instantaneously.[7] Rather, labor moves from lower-wage to higher-wage locations over time in response to initial wage differentials.

The four standard gravity equation variables are the log geographic distance between the sending and destination countries, and dummies for whether the countries of a dyad share a land border, a common language, and past colonial linkages. These variables can be thought of as controls for bilateral migration costs.

By virtue of the first-difference specification, we can use fixed effects for age/gender cohort, sending-country, and destination-country, δ_c, δ_s, and δ_d to capture differential time trends along these dimensions, perhaps representing differential exposure to economic shocks, over the 2000 to 2010 period. More specifically, sending-country fixed effects help control for changes in the alternative labor-market opportunities of prospective migrants, while destination-country fixed effects absorb changes in immigration barriers in the destinations that are common across origins.[8]

The first column of Table 2 presents the results from this regression. The first column shows (contrary to our prior work in the Americas in Hanson and McIntosh 2012) that global migration is not effectively absorbing population in rapidly growing countries: the coefficient on labor supply growth is *negative* and significant at the 10 percent level. However, consistent with previous literature, the migration rate is higher for age groups confronting larger differences in per capita GDP in the destination versus the sending country. For birth cohorts ten years apart (that is, the same age group observed in successive decades), the one facing a 10 percent higher destination-sending country income ratio in the year of labor-market entry would have a 0.001 percentage-point lower bilateral migration rate (relative to a weighted sample mean flow migration rate of .02 percent between 2000 and 2010, with standard deviation of 0.23).

A Model Including Interactions with Earlier Migration

Bilateral migration is lumpy, as was apparent earlier in Table 1. Migrants from particular sending countries tend to cluster in particular destinations. Some of this lumpiness is due to gravity factors. Because Spain is the closest high-income country to Morocco, it is a favored destination for Moroccan emigrants. Clustering may

[7] To avoid reverse causality from migration to labor-market conditions, we measure relative labor supply for an age group in the birth year (or as close to the birth year as decennial censuses allow), and we measure relative per capita GDP around the year that an age group would have entered the labor force, which we take to be age 15.

[8] For those who would like to see their regressions written out in algebraic form, rather than the description in the text, it is: $y_{csd,t+1} - y_{csd,t} = \delta_c + \delta_s + \delta_d + \alpha\left[\ln\frac{L_{cs,t}}{L_{cd,t}} - \ln\frac{L_{cs,t-1}}{L_{cd,t-1}}\right] + \beta\left[\ln\frac{w_{cs,t}}{w_{cd,t}}\right] + \gamma\tau_{sd} + \rho\left(\left[\ln\frac{L_{cs,t}}{L_{cd,t}} - \ln\frac{L_{cs,t-1}}{L_{cd,t-1}}\right] * \tau_{sd}\right) + \varepsilon_{csd}$, where τ^i_{sd} is the value for gravity variable i (that is, distance, language, common border, or colonial linkages) corresponding to sending-country *s* and destination-country *d*.

Table 2

Interaction Effects of Birth Cohort Ratio Growth on Migration Flows

Dependent variable is change in % of cohort migrated within dyad, 2000–2010	No interactions: (1)	Columns show interaction between 1990–2000 change in log birth cohort ratios and the following covariate: Dummy variable indicating that 2000 dyad-specific migration rates among those over 50 are: in top 50% (2)	in top 20% (3)	in top 5% (4)	Log distance from origin to destination (5)	Origin and destination are continguous (6)	Colonial relationship (7)	Common language (8)
Interaction effect:		**0.0629*** (0.022)**	**0.186*** (0.052)**	**0.843*** (0.287)**	**−0.117*** (0.035)**	**1.139*** (0.429)**	**0.0764* (0.043)**	**0.142** (0.055)**
1990–2000 change in age-specific ln(origin/dest) birth cohort ratio	−0.0207* (0.011)	−0.0434*** (0.010)	−0.0424*** (0.009)	−0.0313*** (0.009)	1.016*** (0.307)	−0.0352*** (0.011)	−0.0226** (0.011)	−0.0373*** (0.011)
Interacted variable from column title:		−0.0184** (0.008)	−0.000599 (0.014)	0.155 (0.095)	−0.0186*** (0.007)	0.1 (0.084)	−0.0418** (0.017)	0.0528*** (0.008)
log distance	−0.0330*** (0.005)	−0.0350*** (0.005)	−0.0305*** (0.004)	−0.0270*** (0.005)		−0.0335*** (0.004)	−0.0326*** (0.005)	−0.0331*** (0.004)
Contiguous	0.108 (0.088)	0.111 (0.088)	0.114 (0.091)	0.0947 (0.078)	0.131 (0.094)		0.109 (0.088)	0.119 (0.091)
Colonial relationship	−0.0288** (0.014)	−0.0265* (0.014)	−0.0452*** (0.014)	−0.0543** (0.022)	−0.0343** (0.015)	−0.0380** (0.017)		−0.0335** (0.015)
Common language	0.0743*** (0.009)	0.0747*** (0.009)	0.0681*** (0.010)	0.0694*** (0.008)	0.0772*** (0.010)	0.0792*** (0.010)	0.0738*** (0.009)	
log (origin/dest) GDP ratio in year cohort turned 15	−0.00722 (0.007)	−0.00591 (0.007)	−0.00632 (0.007)	−0.00359 (0.006)	−0.00311 (0.006)	−0.000824 (0.007)	−0.00701 (0.007)	−0.00682 (0.007)
(log (origin/dest) GDP ratio in year cohort turned 15) squared	0.000553 (0.001)	0.000841 (0.001)	0.000659 (0.001)	0.00135** (0.001)	0.00116** (0.001)	0.00195*** (0.001)	0.000562 (0.001)	0.000686 (0.001)
Constant	0.721** (0.303)	0.768** (0.303)	0.714** (0.307)	0.663** (0.306)	0.593* (0.310)	0.721** (0.304)	0.718** (0.303)	0.751** (0.305)
Observations	18,297	18,297	18,297	18,297	18,297	18,297	18,297	18,297
R^2	0.081	0.082	0.085	0.101	0.084	0.096	0.081	0.082
F-test that (interaction+birth ratio) = 0		0.809	7.333	7.911	10.9	6.712	1.504	3.846
Prob > *F*		0.368	0.007	0.005	0.001	0.010	0.220	0.050

Source: Authors.

Note: Analysis includes fixed effects for 10-year birth cohorts, origin, destination, and gender. All regressions are weighted by birth cohort population size to make results representative for all individuals born in the origin countries. Standard errors are clustered at the dyad/gender/cohort level. ***p < 0.01, **p < 0.05, *p < 0.1.

also embody enclave effects, in which earlier generations of migrants ease assimilation for later generations, or built-in persistence created by migration policy, such as family-reunification provisions that give preferential access to visas to the kin of existing residents. The presence of migration networks means that initial labor-market conditions may affect bilateral migration. We wish to take these dyad-specific migration networks into account (Munshi 2003; McKenzie and Rapoport 2007; Beine, Docquier, and Özden 2011). Thus, we seek to interact initial labor-market conditions with the kernels around which networks may form.

In a first approach to capture this interaction, we calculate the stock of sending-country migrants over age 50 in the destination as of 2000. Since most international migration occurs when individuals are young, over-age-50 migrants in 2000 represent inflows that occurred in the 1960s, 1970s, and 1980s, when many networks were first being filled out. We use this measure because many dyads do not have available and age-specific bilateral migration data years before 2000, so we lack the ability to measure immigration networks comprehensively in earlier years. More specifically, we measure these migration networks using dummy variables that indicate whether the over-age-50 bilateral migration rate for a dyad was in the top 50 percent, top 20 percent, or top 5 percent across all dyads in 2000.

Our primary interest here is in the relationship between relative labor supply in the sending and destination country and bilateral migration. As noted earlier, the uninteracted effect of relative labor supply is negative, indicating that in countries without strong migrant networks, relative labor supply has little effect (indeed, a counterintuitively negative effect) on migration. However, the impact of relative labor supply on bilateral migration becomes strongly positive once interacted with indicators for migration networks. In columns 2, 3, and 4, we add the dummy variable for previous over-50 migration in dyad, as well as an interaction term between this and the change in the age-specific birth cohort ratio. For birth cohorts ten years apart, the one in which the sending-destination population ratio change was 10 percent larger would have a 0.006 percentage-point (column 2), a 0.02 percentage-point (column 3), or a 0.08 percentage-point (column 4) higher bilateral migration rate, depending on whether initial migration networks were above the median (over-age-50 bilateral migration rate in 2000 in the top 50 percent), strong (over-age-50 bilateral migration in the top 20 percent), or very strong (over-age-50 bilateral migration in the top 5 percent). All of these interactions are statistically significant at conventional levels.

When the existence of earlier migration networks between two countries is taken into account by using the size of the earlier migrant group, the relative supply of labor does have an effect on migration patterns. Another way to take the earlier migration networks into account is to use the interactions with each of the four gravity variables and the 1990–2000 age-specific birth cohort ratio. The relationship between bilateral migration and sending-destination country population ratios for an age group is stronger for dyads that are geographically more proximate (column 5), contiguous (column 6), or share a colonial language or common language (columns 7 and 8), where all of these interactions are precisely estimated. F-tests at the bottom of the table show that the effect of labor supply differentials are significantly positive within most of these well-networked dyad relationships.

Population Growth and Migration in the Future

Our next step is to utilize these results for understanding migration pressures in the future. We run a new regression (reported in the online Appendix) in which we add to the specification in column 1 all seven of the covariates used across columns 2 to 8 at the same time, as well as the interactions between these covariates and the relative labor supply effect.[9] This regression thus includes in a single specification all of the interactions that are shown individually in Table 2, and provides a way of predicting panel changes in bilateral migration over the coming decades.[10] We then combine our regression coefficient estimates with labor-supply projections derived from UN population counts and GDP per capita projections derived from IMF forecasts to predict the dyadic decadal migration flows that will occur for the four 10-year age cohorts from 2010–2020, 2020–2030, 2030–2040, and 2040–2050. We add these decadal inflows to any pre-existing migrant stocks to calculate future stocks of migrants from each origin in each destination in each decade. Where we observe stocks of migrants at the beginning of the period, we add the forecasted flows to these stocks. These predicted stocks can then be summed across gender, age, origin, or destination to calculate totals of foreign-born migrants aged 15–54 for each decade, as shown in Figure 3.

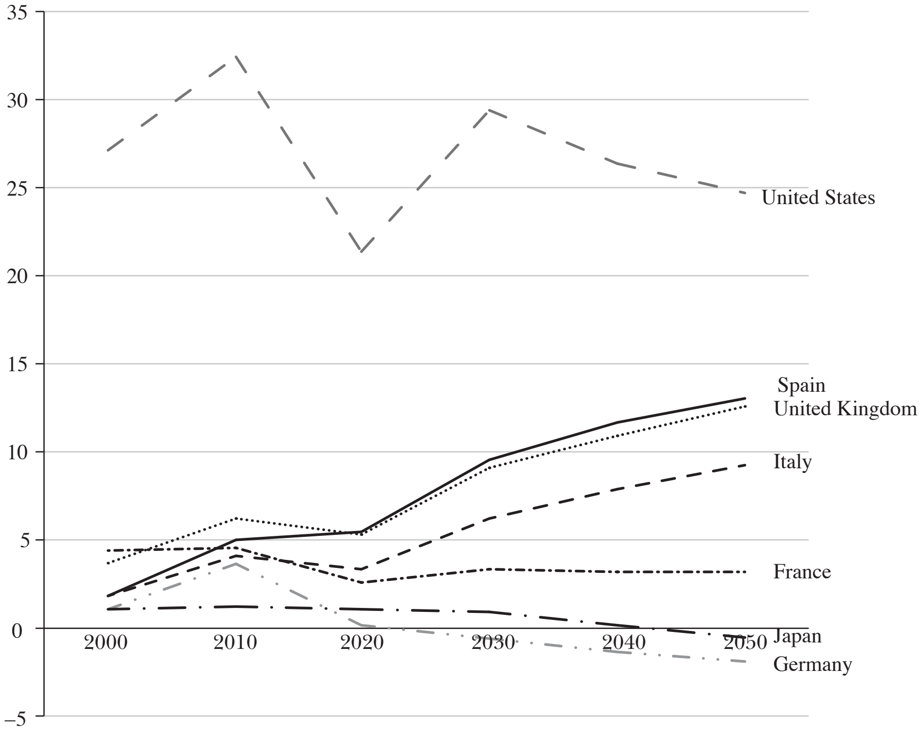
Several details of the forecasting exercise merit further discussion. By restricting the sample to individuals aged 15–54 in the initial year of a decade and dividing these individuals into 10-year age groups, we forecast a total of 16 decadal migration rates for each sending-destination dyad.[11] Because there is an assumed 15-year lag between when an individual is born and when that person enters the labor force, our projected changes in labor supply combine cohorts already born and cohorts yet to be born. This time lag also means that only two of the seven birth cohorts represented in the analysis were born after 2015. Thus, most of the changes in labor supply that we incorporate in the forecasts are based on population growth that has already occurred. We also allow initial relative per capita GDP to change over time

[9] We also add to the specification the square of relative GDP per capita at age 15, which helps account for nonlinearities in how income differentials affect migration. Whether or not we include this squared income term has little impact on the forecasts. An online Appendix provides further discussion.

[10] In an online Appendix, we discuss additional forecasts based on alternative assumptions regarding future GDP growth that we performed to check the robustness of our findings. These alternative forecasts yield predicted migration flows that are very highly correlated with those shown in Figures 3 and 4.

[11] The birth cohorts (and the number of times they are used in the analysis) are those born in 1965–1974 (which are used once over the 2010–2020 period), 1975–1984 (used twice over 2010–2030), 1985–1994 (used three times over 2010–2040), 1995–2004 (used four times over 2010–2050), 2005–2014 (used three times over 2020–2050), 2015–2024 (used twice over 2030–2050), and 2025–2034 (used once over 2040–2050).

Figure 3
Predicted Migration by Destination
(count of first generation immigrants age 15–64; millions)



Note: Because we use a linear model, in some dyads we predict negative migrant stocks (obviously not possible in reality). We retain these negative values in order to avoid biasing upward our totals when we sum predicted stocks across origins for a destination.

based on IMF forecasts of annual GDP growth for 2018–2020 (http://www.imf.org/external/datamapper/index.php), which we assume are sustained out to 2040.[12]

By holding all other regression variables constant in constructing migration forecasts, we are assuming that the impacts of distance, contiguity, common language, colonial linkages, and existing migration networks change at the same rate over future decades as they did between 2000 and 2010. These projections also incorporate our estimated age-and-gender group, sending-country, and destination-country fixed effects, which imposes the further assumption that time trends for migration

[12] In the online Appendix, we show that alternate GDP forecasts for low-income sending regions do not materially change our forecasts of future migration. Current IMF GDP growth projections do not extend beyond 2020. As growth rates for most countries are constant after 2018, we assume by this time they have achieved the expected long-run rate of growth.

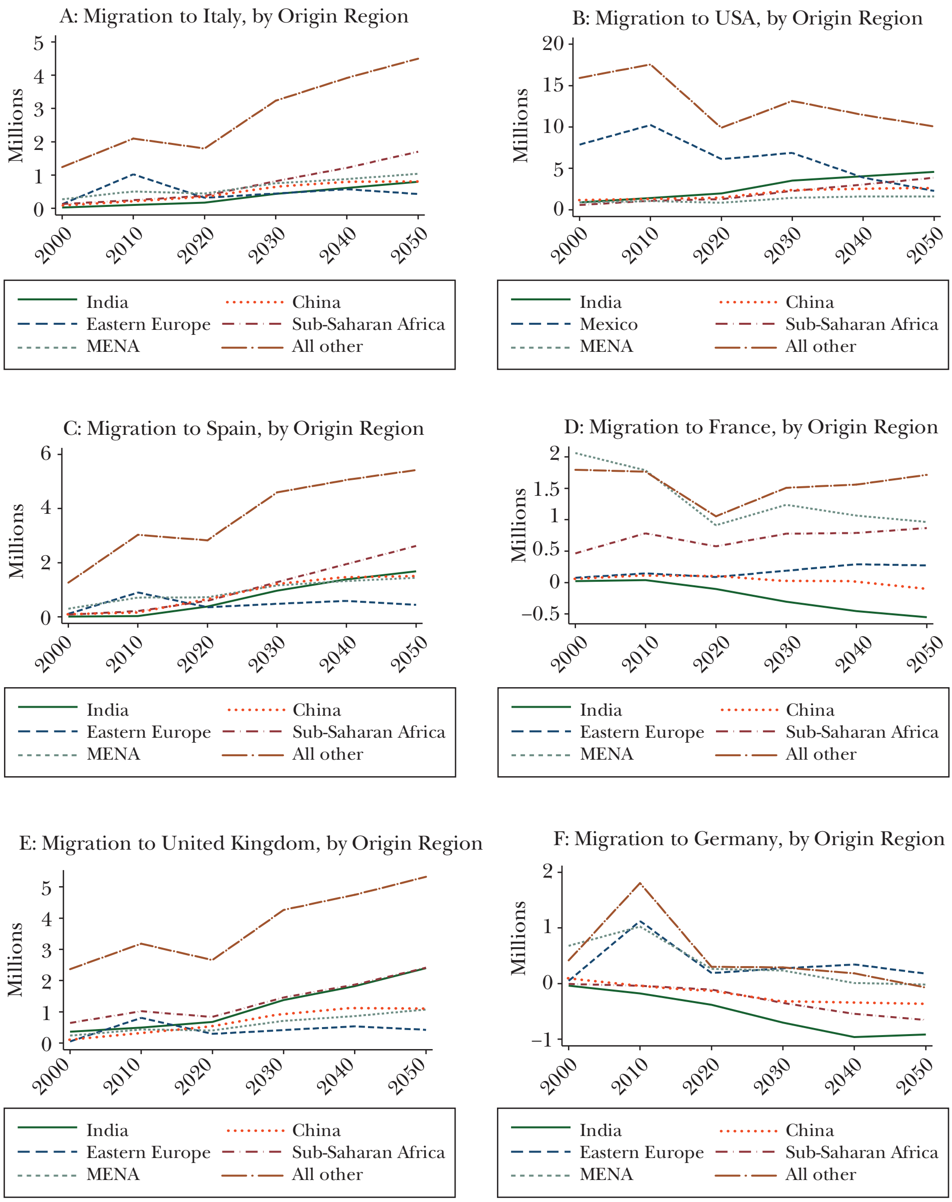
along these dimensions are the same in future decades as they were during the 2000s.[13] These are, of course, very strong assumptions. No decade is exactly like any other. Just as rapid productivity growth in developing countries could attenuate migration pressures, civil wars in sub-Saharan Africa, climate-change-induced coastal flooding in Southeast Asia, or a return to macroeconomic instability in Latin America could exacerbate them. Further, new countries outside of the OECD could emerge as major destinations for international migrants, possibly attenuating flows into current high-income nations. In holding sending-country fixed effects constant, we implicitly assume that destination options for these countries are unchanged as well. Thus, we emphasize that our intent is not to produce projections of future immigration levels around which policymakers should make decisions. Rather, we simply wish to see how the changing population-growth patterns over the next few decades will affect pressures for international migration.

Figure 3 shows the projected first-generation migrant totals (aged 15–64) for the major destinations through 2050. Destinations are heterogeneous in the population growth to which they are exposed through their current migrant stocks and the interaction between future changes in relative labor supply and the various migrant-network factors. The United States sees little net change in the number of immigrants between 2000 and 2050, meaning that arriving young immigrants replace those who age out of the working-age population with little net change in the total stock. Three European destinations are heavily exposed to rapidly growing sending countries and hence see tremendous future growth in immigration pressure: the United Kingdom, Spain, and Italy. Germany, exposed in the past primarily to relatively wealthy Turkey and Eastern Europe, sees a rapid decline in immigrant stocks over the coming 30 years in these calculations. However, it should be noted that our analysis precedes the recent burst of asylum-driven migration into Germany, which establishes a base of migrants that is likely to attract future migrants from those countries for years to come.

Figure 4 drills down into migration inflows for six key destination countries in more detail. Because of the interactive effect between relative labor supply and the gravity and migrant-network indicators, forecasted dyadic migrant inflows in major destination countries differ markedly across major sending regions. In the left-hand panels, we see the three rapidly growing destinations discussed above. The pattern in all three of these countries is relatively similar: future migration growth after 2020 coming mainly from sub-Saharan Africa and India, with a similar, slightly larger, amount coming from a diverse set of other countries. Spain and Italy, bordering the Mediterranean, are most exposed to migration from Africa. The United Kingdom, given its colonial linkages, is exposed to India and

[13] For cohorts that have a 2010 migrant count observed, we add the predicted flows on to the realized levels to simulate migrant stocks into the future. For younger cohorts in which 2010 stocks are not observed, we begin to cumulate the predicted changes from 0 and total the predicted flows across decades to arrive at a predicted stock of migration. Because we use a linear model, in some dyads we predict negative migrant stocks (obviously not possible in reality). We retain these negative values in order to avoid biasing upward our totals when we sum predicted stocks across origins for a destination.

Figure 4
Predicted Migration by Destination
(count of 1st generation immigrants age 15–64; millions)



Source: Authors' calculations based on data from the 2015 United Nations World Population Prospects and from the Database on Immigrants in OECD Countries.
Note: Because we use a linear model, in some dyads we predict negative migrant stocks (obviously not possible in reality). We retain these negative values in order to avoid biasing upward our totals when we sum predicted stocks across origins for a destination. MENA = Middle East and North Africa.

sub-Saharan Africa in equal measure. Origins that play a large role in these various destinations are: for Italy—Ethiopia, Philippines, and Nigeria; for Spain—Nigeria, Morocco, and Brazil; and for the United Kingdom—the Philippines, Kenya, and Pakistan.

In the right-hand panels, we see three destinations that are less exposed to these rapidly growing origins. The United States sees Mexican immigrant counts drop from over 10 million in 2010 to a little over 2 million in 2050, alongside substantial drops in migrants from all other destinations except India, China, and sub-Saharan Africa. France has relatively constant migrant stocks over time, resulting from a balance of declining migration from China and MENA and India and a small increase from sub-Saharan Africa. Germany displays the most pronounced decreases in future migration. This outcome arises from a combination of origins with rapidly falling fertility—Turkey, Eastern Europe—and the fact that Germany lacks the colonial and linguistic connections that are important in driving migration. Consequently, the top origins our model predicts for Germany in 2050 are very distinct from the other destinations: France, Romania, Morocco, Somalia, Iraq, Poland, and Russia. Japan is not shown separately in Figure 4, but given its tradition of demographic isolationism and its distance from population growth centers, it remains a low-migration destination. By 2050, only China is projected by our model to have more than a few hundred thousand migrants in Japan.

Discussion

Given the prominent role of economic shocks, political conflict, and natural disasters in driving international migration, predicting long-term migration flows is a hazardous proposition. The demographic component of migration can be useful in such an exercise, because medium-run changes in labor supply are determined by population growth that has already occurred, and longer-term differentials in population growth can be predicted with reasonably high accuracy. While changes in relative labor supply may not independently trigger large-scale migration, they set the stage for other types of shocks to set off the movement of large numbers of people across national borders.

This demographic way of thinking about immigration presents some stark implications. The era in which immigration levels are rising in a way that can feel out-of-control appears to be coming to an end in the United States, while it seems to be just beginning in the European Union, despite current political debates over immigration in the two domains that are quite similar. In the decades to come, America will find itself to be an island of slow population growth, insulated by the Atlantic Ocean from the motor of future population change in the Middle East and North Africa region and in sub-Saharan Africa. These weakening immigration pressures follow a decade-long buildup in US immigration enforcement, which has raised annual government spending by tens of billions of dollars (Roberts, Alden, and Whitley 2013). The completion of the demographic transition in most of the

Western Hemisphere leaves one to wonder whether the benefits of continued US enforcement spending will justify its costs.

Europe, by contrast, will be surrounded by an eastern region comprised of Belarus, Ukraine, Russia, and Central Asia that is showing faster population growth, and it is separated only by the Mediterranean from the still-growing countries of North Africa and the booming populations of sub-Saharan Africa. Thus, the conditions exist for western Europe to face strong population pressures for immigration for decades to come. Though the European Union allows the free movement of labor among member states, enforcement of immigration from outside the European Union largely falls to individual countries, creating a free-rider problem. Spending by Italy on patrolling its coast line, for instance, ultimately affects the number of immigrant arrivals in northern Europe (Labanca 2016). Given the potential for substantially greater immigration pressures in the future, one would expect that there would be positive gains to greater coordination of immigration policy within the European Union.

The sending countries will have an alternative perspective on demographically driven international migration. The possibility of emigration served as a safety valve for the burgeoning populations of southern Europe and Ireland as they went through their own demographic transformations in the late 19th and early 20th centuries (Hatton and Williamson 2005). Our previous work shows that emigration to the United States, Canada, the United Kingdom, and Spain was strongly driven by demographic growth in Latin America and the Caribbean during the latter half of the 20th century (Hanson and McIntosh 2012). Strikingly, this pattern does not hold at a global level. Countries with rapidly growing populations that lack the benefits of proximity or large established migrant populations already in OECD destinations see *lower* emigration rates than more slowly growing countries. This suggests that the migration safety valve may not operate for the next century's population growth in the way that it did in the past century. As an example, we predict the number of African-born first-generation migrants aged 15 to 64 outside of sub-Saharan Africa to grow from 4.6 million to 13.4 million between 2010 and 2050. During this same period, the number of working-age adults born in the region will expand from under half a billion to more than 1.3 billion, meaning that international migration would only absorb 1 percent of the overall population growth. Given an African continent expected to contain almost four billion people by 2100, the presence or absence of a migration safety valve would have profound implications. The coming half century will see absolute population growth in sub-Saharan Africa five times as large as Latin America's growth over the past half century. Even with our predictions for expanded population pressures to certain countries of Europe, which are likely to be perceived as very high levels of immigration by those countries, Europe would be absorbing only a small share of Africa's projected population increase.

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Journal of Economic Perspectives—Volume 30, Number 4—Fall 2016—Pages 83–106

Global Talent Flows

Sari Pekkala Kerr, William Kerr, Çağlar Özden, and Christopher Parsons

Highly skilled workers play a central and starring role in today's knowledge economy. Talented individuals make exceptional direct contributions—including breakthrough innovations and scientific discoveries—and coordinate and guide the actions of many others, propelling the knowledge frontier and spurring economic growth. In this process, the mobility of skilled workers becomes critical to enhancing productivity. Substantial attention has been paid to understanding the worldwide distribution of talent and how global migration flows further tilt the deck. Observed migration flows are the result of a complex tangle of multinational firms and other employers pursuing scarce talent; governments and other gatekeepers trying to manage these flows with policies; and individuals seeking their best options given the constraints imposed upon them.

We begin by sketching the landscape of global talent mobility. The number of migrants with a tertiary degree rose by nearly 130 percent from 1990 to 2010, while low-skilled (primary educated) migrants increased by only 40 percent during that

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† For supplementary materials such as appendices, datasets, and author disclosure statements, see the article page at
http://dx.doi.org/10.1257/jep.30.4.83 doi=10.1257/jep.30.4.83

time. A pattern is emerging in which these high-skilled migrants are departing from a broader range of countries and heading to a narrower range of countries—in particular, to the United States, the United Kingdom, Canada, and Australia. The globalization of economic ties is also leading to a rise in shorter-term and circular migration patterns for skilled labor; for example, global companies often insist that their rising executives live and work in other countries for a meaningful portion of their careers. We also give examples showing how global migration may be most pronounced for those at the very outer tail of the talent distribution and that high-skilled migration by females outnumbered males in 2010.

Next, we discuss the causes and consequences of high-skilled migration. We start with a basic model of the income incentives to migrate for different skill levels. We then expand the discussion to include important factors like advantages of agglomeration, productivity spillovers, intrafirm relocation of employees in multinationals, and how tertiary and graduate education abroad is linked to future job opportunities in other countries. These factors suggest why high-skilled immigration is often controversial. For recipient countries, high-skilled immigration is often linked to clusters of technology and knowledge production that are certainly important for local economies and are plausibly important at the national level. More than half of the high-skilled technology workers and entrepreneurs in Silicon Valley are foreign-born. For native workers, high-skilled immigration means both greater competition for certain jobs, but also a chance to benefit from the complementarities and agglomeration effects created by talent clusters. For sending countries, the loss of high-skilled workers raises concerns over "brain drain." On the positive side, high-skilled emigrants can create badly needed connections to global sources of knowledge, capital, and goods—and some will eventually return home with higher social and human capital levels.

With these controversies and tensions in mind, we then review the "gatekeepers" for global talent flows. At the government level, we compare the points-based skilled migration regimes as historically implemented by Canada and Australia with the employment-based policies used in the United States through mechanisms like the H-1B visa program. Because of the links of global migration flows to employment and higher education opportunities, firms and universities also act as important conduits, making employment and admission decisions that deeply affect the patterns of high-skilled mobility. There are ongoing efforts in many countries to tweak their immigration policies concerning high-skilled labor to tilt the social cost–benefit calculations in a more favorable direction. Looking forward, the capacity of people, employers, and governments to successfully navigate this tangled web of global talent markets will be critical for their success.

Trends in Global Talent Flows

Approximately 3 percent of the world's population lives in a country different from that of their birth, and despite the impression sometimes presented in the media, this share has been roughly constant since 1960 (Özden, Parsons, Schiff, and Walmsley 2011). Beneath this stable overall level, however, global migration patterns have become increasingly asymmetric and skewed along several dimensions, especially as skilled migration has become a greater force globally.

Most of the data concerning high-skilled migration that we discuss here are taken from a global bilateral migration database as described in Docquier, Lowell, and Marfouk (2009), in addition to the recently completed update of the Database on Immigrants in OECD Countries (DIOC) for 2010 (Arslan et al. 2014).[1] These databases report the stock of migrants by education level from each home country that have moved to each destination country. High-skilled workers, our main focus, are defined as those with at least one year of tertiary education. The data come from decennial national censuses conducted in 1990, 2000, and 2010 in the destination countries (where available) or from labor force surveys (when necessary). The data presented cover people of working age (25+) and are matched according to individual countries' definition of migration, which typically pertains to country of birth.[2]

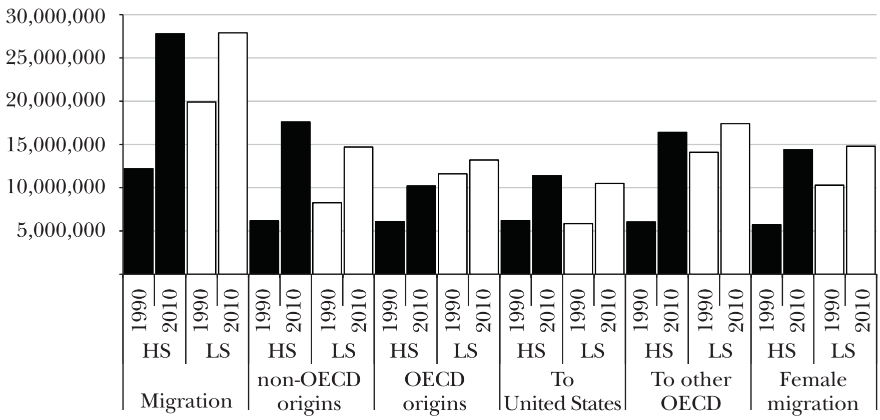
Figure 1 compares migration to OECD countries along multiple dimensions. There were about 28 million high-skilled migrants residing in OECD countries in 2010, an increase of over nearly 130 percent since 1990. By comparison, the growth rate for low-skilled migrants in the OECD countries from 1990 to 2010 was only 40 percent. (Throughout, we use the term "low skill" to designate migrants with only primary education and "other skill" to refer to those not classified as high-skilled.) While OECD countries constitute less than a fifth of the world's population, these countries host two-thirds of high-skilled migrants (*OECD Factbook 2013*; Artuç, Docquier, Özden, and Parsons 2015).

The exceptional rise in the number of high-skilled migrants to OECD countries is the result of several forces, including increased efforts to attract them by policymakers who recognize the central role of human capital in economic growth, positive spillovers generated by skill agglomeration, declines in transportation and communication costs, and rising pursuit of foreign education by young people. Among the resulting effects are the doubling of the share of the tertiary-educated in the labor force and fierce competition among countries hoping to attract talent (for example, Kapur and McHale 2005; National Academies of Sciences, Engineering, and Medicine 2016). While the migration of low-skilled workers mainly offsets the decline in low-skilled native workforces in advanced countries, high-skilled migration often complements the growth of skill levels for native workforces.

[1] The 2010 update was developed by the OECD, the World Bank, and the International Migration Institute at Oxford University. The details of the databases, their construction, methodology, and the main patterns are discussed in Arslan et al. (2014). There is a parallel DIOC-E database for non-OECD countries (http://www.oecd.org/els/mig/dioc.htm) described by Artuç, Docquier, Özden, and Parsons (2015).

[2] To achieve harmonized and comparable series over the 20-year period, we exclude Chile, Estonia, Israel, Slovenia, and South Korea from our analysis. Throughout this article, we use "OECD" to refer to the 29 remaining members, irrespective of their date of joining the OECD.

Figure 1
Migrant Stocks in OECD Countries in 1990 and 2010



Sources: Migration patterns taken from Database on Immigrants in OECD Countries and Docquier, Lowell, and Marfouk (2009).
Notes: High-skilled (HS) workers are defined as those with at least one year of tertiary education. Low-skilled (LS) workers are those with a primary education. The data presented cover people of working age (25+) and pertain to 29 OECD members with consistent data from 1990 and 2010.

Even among OECD destinations, the distribution of talent remains skewed. Four Anglo-Saxon countries—the United States, the United Kingdom, Canada, and Australia—constitute the destination for nearly 70 percent of high-skilled migrants to the OECD countries in 2010. The United States alone has historically hosted close to half of all high-skilled migrants to the OECD and one-third of high-skilled migrants worldwide. In 2010, the United States hosted 11.4 million skilled migrants, 41 percent of the OECD total. The attractiveness of English-speaking, high-income countries for high-skilled migrants has led other destination countries, such as France, Germany, and Spain, to increase their efforts to attract these workers. Nevertheless, the volume of skilled migration to the four Anglo-Saxon countries, coupled with the significant asymmetry in the concentration of leading universities, high-tech firms, and research centers, implies that the global competition for skills will continue to be fierce and will likely remain unequal.

Such stark inequalities in the concentrations of talent also exist across regions and cities within individual destination countries. In 2013, the southern California region, Silicon Valley, and New York City combined to host around one-eighth of total STEM employment (that is, jobs with a high component of science, technology, engineering, and mathematics) in the United States (Silicon Valley Leadership Group and Silicon Valley Community Foundation 2015). Moreover, 56 percent of STEM workers and 70 percent of software engineers in Silicon Valley in 2013 were foreign-born. Elsewhere, Western Australia has the highest percentage of foreign-born medical practitioners at around 60 percent in 2011. London, New York, Paris, and Milan continue to maintain their positions as the global capitals of finance and fashion.

Agglomeration can be even starker in the upper tail of the talent distribution (Stephan and Levin 2001; Wasmer et al. 2007; Stephan 2010; Weinberg 2011). Trends in the awarding of the Nobel prizes for Chemistry, Medicine, Economics, and Physics, where an institutional affiliation can be assigned with certainty, illustrate particular broad patterns. Since 1901, individuals affiliated with institutions in four countries—the United States (330 individuals), the United Kingdom (90), Germany (69), and France (33)—have been awarded over 80 percent of these Nobel prizes.[3] The US domination of these awards is fueled in large part by migration of prominent scientists. In the first third of the time period since 1901, 9 percent of these Nobel prize winners were born in the United States and 13 percent were affiliated with US institutions at the time of their winning. In the most recent third of the time period, however, academics associated with American institutions have won over 65 percent of these Nobel prizes, yet only 46 percent of this group was born in the United States. Of all Nobel prizes across the four subject areas, 31 percent (203 of 661) have been awarded to immigrants, of whom 53 percent (107 of 203) were affiliated with American institutions.[4] The asymmetry of the flows is remarkable. Only four Americans were affiliated with non-American institutions when they received the award, out of 230 total Nobel Prizes being awarded to Americans. Even among advanced economies, the most elite researchers are often clustered in very select locations.

Figure 1 shows that these observations are indicative of wider trends. OECD countries continue to attract larger numbers of high-skilled migrants, particularly from non-OECD countries. While high-skilled migration within OECD countries rose 68 percent to 10.2 million between 1990 and 2010, the total number of high-skilled migrants from non-OECD countries increased 185 percent, from 6.2 million to 17.6 million. This pattern is also evident in the extreme cases of sending countries. For the two decades prior to 2010, the United Kingdom was the largest origin country in terms of numbers of outbound skilled migrants. It was supplanted in 2010 by India (2.1 million) and the Philippines (1.5 million), while China (1.4 million) also had high absolute numbers of high-skilled emigrants. In terms of the greatest increases over time (and considering only those large countries that sent at least 25,000 highly skilled workers abroad), Algeria (a rise of 954 percent), Russia (910 percent), Bangladesh (459 percent), Romania (428 percent), Venezuela (423 percent), Ukraine (385 percent), Pakistan (380 percent), and India (370 percent) showed the greatest increases in high-skilled emigration between 1990 and 2010.

A remarkable and underappreciated component of this high-skilled migration surge is the role of females. Figure 1 shows that the stock of high-skilled female immigrants in OECD countries grew by 152 percent between 1990 and 2010, from 5.7 to 14.4 million. Indeed, in 2010, the stock of high-skilled female migrants surpassed

[3] Data for Nobel prizes is derived from AggData at https://www.aggdata.com/awards/nobel_prize_winners, supplemented with data from the Nobel Prize website for the years 2011–2015.

[4] Another recent example comes from the economics profession: The John Bates Clark Medal is awarded annually to a top American economist under the age of 40. Four of its nine winners since 2005 were born outside of the United States.

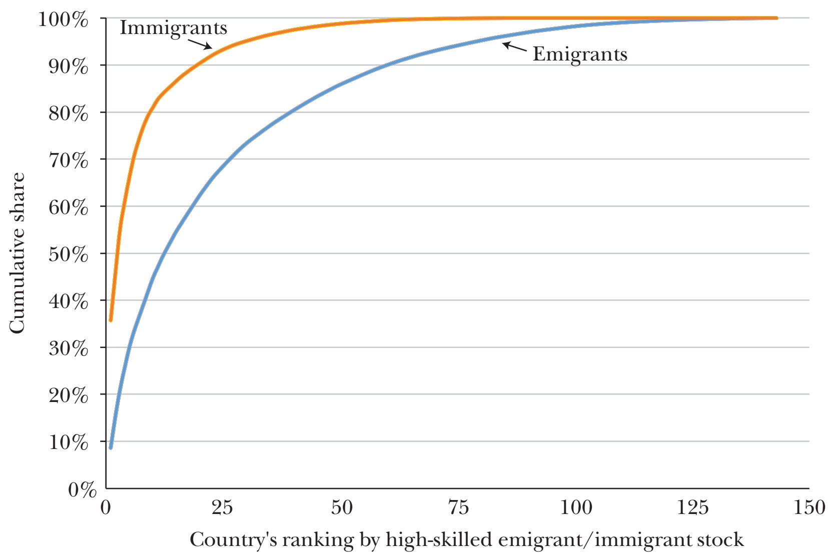
the stock of high-skilled male migrants. The root causes of this surge have yet to be traced out fully. Africa and Asia experienced the largest growth of high-skilled female emigration, indicating the potential role of gender inequalities and labor market challenges in origin countries as push factors. Evidence is accumulating that differences between origin and destination countries in women's rights underpin such flows (Nejad and Young 2014). The simple correlation between the growth in high-skilled female migration and the UNDP Gender Inequality Index is 0.43.

More broadly, research needs to trace out many features like the detailed occupational distribution of female immigrants. The available data highlight some interesting early patterns. In 2010, of the 4.2 million employed high-skilled female immigrants in the United States, 16 percent were employed as Healthcare Practitioners and Technical Occupations, 13 percent in Office and Administrative Support Occupations, and 12 percent in Education, Training, and Library Occupations. These constituted 66, 68, and 63 percent of the total high-skilled immigrants in these occupations, respectively. Notably, while only 3 percent of high-skilled female immigrants were employed in Healthcare Support Occupations, they represented no less than 80 percent of foreign-born workers in these jobs. Interestingly, the OECD reports that some 37 percent of high-skilled females in the United States were employed in occupations in 2010 that were not commensurate with their level of education.[5] Given the rising prominence of high-skilled females, this is an important avenue of future research. It will also be important to trace whether the extreme tail of the female talent distribution displays the same migration propensities as those documented for males.

Another important shift since 1990 is that OECD countries increasingly attract high-skilled migrants from a wider set of origin countries. Figure 2 summarizes this pattern by displaying cumulative distributions for high-skilled immigration and emigration stocks in 2010. The line at the top left of the graph shows the immigration distribution of high-skilled workers. We rank destination countries according to the stock of immigrants they attract, and we tabulate the cumulative share as we add more countries. This line starts at almost 40 percent, as the United States is the first-ranked country and accounts for the largest share of global immigration flows. As noted earlier, further adding the United Kingdom, Canada, and Australia pushes the cumulative share to almost 75 percent. The second line graphs the equivalent distribution for emigration of high-skilled workers, with countries now ranked by how many migrants they send abroad. The gap between the two lines clearly shows that skilled emigration originates from many countries, even if it flows to relatively

[5] Across Canada in the same year, observed patterns are comparable. In terms of occupations, 10 percent of high-skilled immigrant females worked as Teaching Professionals, 10 percent as Business and Administration Associate Professionals, 8 percent as Health Professionals, and 8 percent as Business and Administration Professionals. While only 4 and 7 percent of high-skilled immigrant females were employed as Health Associate Professionals and Personal Care Workers respectively, these represented 73 and 90 percent of the total foreign-born working in these occupations. In Canada, 38 percent of high-skilled immigrant females were employed in occupations in 2010 that were not commensurate with their level of education.

Figure 2
Cumulative Distribution of High-Skilled Immigrants and Emigrants, 2010



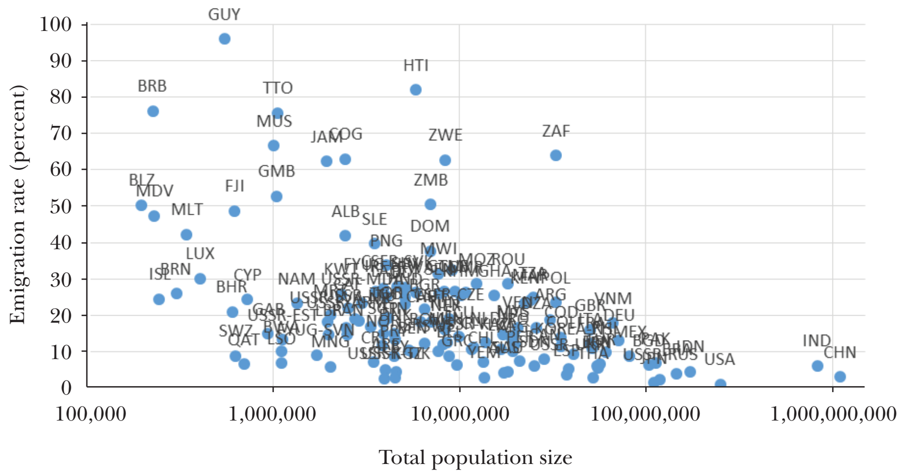
Sources: Data are from Database on Immigrants in OECD Countries (DIOC) and non-OECD Countries (DIOC-E).
Notes: High-skilled workers are defined as those with at least one year of tertiary education. The data presented cover people of working age (25+). Countries are ranked according to their share of total high-skilled immigrant inflows and outflows, respectively. These distributions demonstrate that emigration flows have a much wider base relative to the more-concentrated set of immigrant destinations.

few. By contrast, low-skilled immigrants in OECD countries are increasingly arriving from fewer origin countries.

Many poor and small countries have limited educational capacities and fiscal resources to train workers or to replace those that have emigrated. Countries experiencing particularly high emigration rates of high-skilled workers to OECD destinations in 2010 tend to be small countries and island states. As seen in Figure 3, the prominent examples of these are Guyana (96 percent), Haiti (82 percent), Barbados (76 percent), Trinidad and Tobago (75 percent), Mauritius (67 percent), and Jamaica (62 percent). In addition to these small island states at the very high end of the distribution, Figure 3 demonstrates the overall inverse relationship between country size and high-skilled emigration rates. Emigration rates are also decreasing in GDP per capita, and these patterns are much starker for high-skilled migration than for overall flows. These movements of high-skilled labor away from certain small and low-income countries have raised controversies about "brain drain"—a topic to which we will return when considering implications of these talent flows.

A natural consequence of these patterns is that host countries may end up with high concentrations of high-skilled immigrants in particular occupations. For example, immigrants account for some 57 percent of scientists residing in

Figure 3
Emigration Rates of High-Skilled Workers by Population, 2010

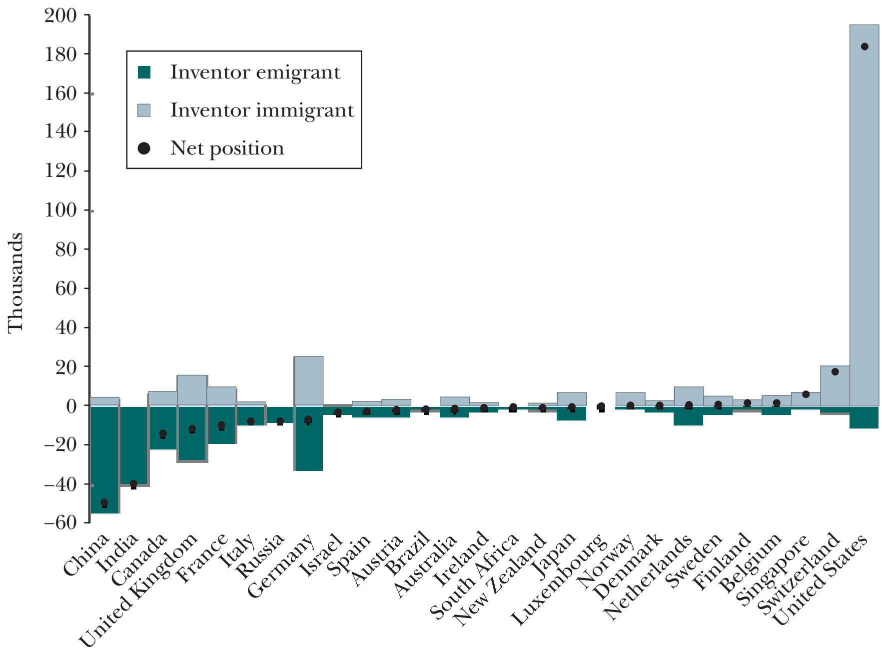


Sources: Emigration the data are from the Database on Immigrants in OECD Countries (DIOC) and non-OECD Countries (DIOC-E). Population data are taken from the World Development Indicators of the World Bank, accessible at databank.worldbank.org/wdi.
Notes: High-skilled workers are defined as those with at least one year of tertiary education. The emigration data cover people of working age (25+) and pertain to over 200 origin countries. The population data are also for people of working age (25+).

Switzerland, 45 percent in Australia, and 38 percent in the United States (Franzoni, Scellato, and Stephan 2012). In the United States, 27 percent of all physicians and surgeons and over 35 percent of current medical residents were foreign-born in 2010. Immigrants also accounted for over 35 percent of recent enrollments in STEM fields, with very high proportions in specific areas like electrical engineering (70 percent), computer science (63 percent), and economics (55 percent) (Anderson 2013). In the United Kingdom in 2014, the *Guardian* newspaper reported that the National Health Service (NHS), the world's fifth-largest employer, employed workers from some 200 countries worldwide and 26 percent of NHS doctors were not originally British citizens (as reported in Siddique 2014).

The global migration of inventors and the resulting concentration in a handful of countries have been well documented. Kerr (forthcoming) reviews the literature, and we focus here on patent records taken from the World Intellectual Property Organization (WIPO) database. Miguelez and Fink (2013) calculate that the global migration rate of inventors in 2000 stood at 8.6 percent, at least 50 percent greater in share terms than the average for high-skilled workers as a whole. Figure 4 shows migration patterns for inventors, building on WIPO global patent filings from 2001–2010. The United States has received an enormous net surplus of inventors from abroad, while China and India have been major source countries. Some countries like Canada and the United Kingdom are major destinations, but still

Figure 4
Migration of Inventors, 2000–2010



Source: Migration patterns for inventors taken from the World Intellectual Property Organization (WIPO) database and Miguelez and Fink (2013).

experience a negative net flow due to even larger emigration rates for inventors, usually to the United States.

Similarly striking levels of immigrant concentration are evident in sports, where global outliers in terms of talent and income are the norm. Spectators in the English Premier League, the most popular and profitable soccer league in the world, witnessed the fielding of players from 100 different nationalities during the 2013–14 season. As of 2015, the English Premier League featured more players of different nationalities than any other league in Europe, followed by Germany's Bundesliga (55 nationalities), Italy's Serie A (51), Spain's La Liga (50), and France's Ligue 1 (48). The highest-quality players in the world are typically concentrated in the top teams within the top flights, suggestive of increasing returns and productivity spillovers.[6] This pattern is similar to top academic departments where we

[6] Simply put, Neymar's productivity would probably be significantly lower without Messi or Suarez! One author of this piece confesses to not understanding one word of the football (soccer!) analogy. American readers may find it useful to consider the overwhelming concentration of basketball and hockey talent in US-centered leagues. In 2016, every team in the National Basketball Association had at least one player born outside of America. Since 1991, international players in the NBA have increased four-fold to over 100 and were drawn from 37 countries in the 2014–15 season.

observe above-average diversity of nationalities when compared to other employers. Furthermore, these patterns have long-term implications. Both soccer clubs and academic departments train the next generation of players/academics, leading to further agglomeration within the upper tail and reinforcing existing distributional patterns and inequalities. We turn next to the factors behind these migration flows.

Drivers and Consequences of Skilled Migration

The core theoretical framework for studying human capital flows dates back to at least John Hicks (1932), who noted that "differences in net economic advantages, chiefly *differences in wages*, are the main causes of migration." The standard textbook model (as in Borjas 1987, 2012) used to explain the self-selection of immigrants by skill level is typically built on the Roy (1951) model. One can explain certain aspects of current high-skilled migration patterns using this model. For example, the United States has a very wide earnings distribution and low tax levels and progressivity, especially compared to most source countries, including many high-income European countries. As a result, we can see why the United States would attract more high-skilled migrants relative to low-skilled migrants and relative to other high-income countries. It is also clear within this framework why demand for migration from developing economies is substantial, as their wage levels sit completely below those in advanced countries at all skill levels.

A more complete explanation of the causes and consequences of migration patterns of high-skilled labor requires adding multiple ingredients beyond the textbook model. Key factors include the importance of location, which in turn reflects institutional and educational differences across countries, productivity spillovers, agglomeration effects—and how both workers and employers interact with these differences.

Geographic locations provide different levels of access to financial and physical capital, technology, complementary institutions, and workers, which all impact the quality and productivity of the available jobs (Moretti 2012). Moreover, many high-skilled occupations show agglomeration effects, where an individual worker's productivity is enhanced by being near to or working with many other skilled workers in similar sectors or occupations. Indeed, in the presence of agglomeration effects, high-skilled migration need not diminish the returns to skills. In fact, due to agglomeration effects, a surge of high-skilled migration increases the incentive for other high-skilled workers to migrate to the same location. In simplest terms, the huge concentration of actors and actresses in Hollywood only heightens the migration of aspiring talent to it, especially for the very talented.

At the core of this clustering process is trade in products and services. Continuing with the last example, Hollywood studios compete with each other globally; their market is not limited to southern California. This is quite different than neighboring supermarkets, for example, which compete for the same local consumer base. Thus, there is no inherent limit as to how many studios can physically exist in

Hollywood. On the contrary, new migrants encourage the employment of others through establishing new studios or expanding existing production. Furthermore, thick local markets for skilled labor can allow specialization that helps Hollywood studios compete better globally. High-skilled immigrants like Christian Bale, Audrey Hepburn, or Natalie Portman allow native actresses and actors to specialize and become more productive, creating better products for worldwide consumption. Moreover, the agglomeration of activity in a specific location allows larger scale for complementary specialized inputs and providers such as legal counsels, voice trainers, and costume makers.

Another issue is that a substantial share of high-skilled migration is connected, at least initially, to differences in educational opportunities. Many "skilled immigrants" arrive with only raw talent and ambition, with the aim of improving their human capital level through formal schooling or by learning on the job. This is clearly a factor in the prominence of the four leading Anglo-Saxon countries as destinations. These four countries host 18 of the top 20 and 69 of the top 100 universities globally, as ranked by Academic Ranking of World Universities (the 2016 rankings are available at http://www.shanghairanking.com/ARWU2016.html).[7]

Moreover, schooling can provide an important entry point into desired labor markets for talented individuals (Rosenzweig 2006; Grogger and Hanson 2013). Kato and Sparber (2013) show how declines in the availability of high-skilled visas made American universities less attractive to foreign students, in terms of the number of foreign applicants and also the quality of those applicants as measured by SAT scores, compared to a handful of sending countries that were not impacted by the policy shift. Similarly, foreign students, mostly from East and South Asian countries, make up almost a quarter of the student population in Australian universities, and easier entry into the Australian labor market is often cited as one of the key factors in their location choices. At later points in the educational process, Bound, Demirci, Khanna, and Turner (2015) describe the use of graduate education in US universities to obtain access to the US labor market, and also the buffer that additional education can provide until a labor market match is realized.[8]

[7] Interestingly, different types of graduate education display varying geographic concentrations. A recent *Financial Times* ranking of business schools included institutions from nine countries among the top 30 schools, with only 14 of the top 30 programs in the United States. Even among the top 15 business schools, seven countries are represented (http://rankings.ft.com/businessschoolrankings/global-mba-ranking-2016). By contrast, the ranking of Amir and Knauff (2008) for economics PhD programs features only four countries, with the United States accounting for 24 of the top 30 departments and the United Kingdom accounting for an additional four programs. These rankings use different methodologies, so the comparisons are not precise, but the stark differences are worthy of further study.

[8] These channels are, of course, tightly connected and build upon each other. Exceptional students are attracted to the frontier of knowledge creation, where they can themselves contribute throughout their careers to further innovations within and outside of academia. Even if pursuing purely commercial activities, these migrants can continue to promote the system through tax revenues, creating robust labor markets for graduating students. If a location starts to lose its frontier advantages, however, it may then become less attractive to future generations, which in turn further distances it from other attractive choices.

Even when a labor market match occurs for skilled migrants, there is a substantial possibility of return migration—although the rate seems to vary across skill subgroups. The data on the subject remain limited, with OECD (2008) representing an extensive effort to compile the currently available information. This report shows that 20–50 percent of immigrants leave within five years of arriving, depending on the corridor and the time period. These levels are consistent with historical patterns; for example, Bandiera, Rasul, and Viarengo (2013) find that over half of the migrants who came to the United States during the age of mass migration in the late 19th century returned home. Another common yet overlooked pattern is transit migration where migrants move from one destination to another. For example, close to 15 percent of the high-skilled migrants in the United States actually arrived from a country different than their place of birth (Artuç and Özden forthcoming). Transit migration is especially common among migrants from developing countries who face high entry restrictions to the United States. In order to circumvent these policy barriers, they migrate to countries like the United Kingdom (for South Asian migrants) or Australia (for East Asians) and then move to the United States.

In some settings, high-skilled immigrants have been found to be more likely to return home than low-skilled migrants (Bijwaard and Wahba 2014).[9] Immigrants who decide to return to their home country tend to do so within a reasonably short time period (OECD 2008), and the likelihood to return has been connected to economic conditions (for example, Bijwaard, Schluter, and Wahba 2014), the difficulty of obtaining permanent residency or citizenship, and the ease of moving across national borders (Gundel and Peters 2008). Another pattern is that the relationship between return and skill levels is nonmonotonic. While high-skilled workers are more likely to re-migrate as a group, those at the very highest skill levels are often less likely to do so. For example, the OECD (2008) calculates that the United States retains about 65–70 percent of those who studied for a doctorate at the five-year mark after receipt of degree, higher than the share for university graduates as a whole. Several comparative studies show in diverse settings that those with a PhD or high productivity levels are less likely to return migrate than other skilled workers (Finn 2007; Gibson and McKenzie 2009; Harvey 2009; Gaulé 2014).

Yet another factor driving skilled labor migration is that many multinational companies require their executives to work in overseas positions as a prerequisite for senior leadership positions, in part because global opportunities are expected to account for the majority of such firms' long-term growth (Kerr, Kerr, and Lincoln

[9] Germany loses about 50 percent and Netherlands as many as 60 percent of foreign students coming to complete a degree within five years of graduation (Bijwaard 2010). Gundel and Peters (2008) find that high-skilled immigrants are more likely to re-emigrate from Germany. Pohl (2006) argues that a large share of high-skilled migrants exhibit short staying patterns, but once one controls for a number of other factors, the average high-skilled migrant is actually less likely to leave. Dustmann and Weiss (2007) use the British household panel and find that outmigration causes the remaining immigrant pool in the United Kingdom to become less skilled over time. In Canada, all immigrant groups display high re-emigration rates, but those arriving in the skilled class and business class were most likely to leave again (Aydemir and Robinson 2008). Dustmann, Bentolila, and Faini (1996) review policies related to return migration in Europe.

2015a). The scale and growth of workforces within multinational firms are often underappreciated in the migration literature. Global companies like IBM, General Electric, and Siemens, however, usually have at least half of their workforce employed outside of their headquarter country. Prominent firms with immigrant chief executive officers are not limited to high-tech (such as Google and Microsoft) but include many traditional firms such as Alcoa, Clorox, Coca-Cola, Dow Chemical, McDonalds, Pepsi, and Pfizer. While unskilled workers are often drawn from the local labor forces within the country of operation, high-skilled staff and especially senior managers are frequently transferred within the firm throughout their careers. In other cases, many large high-tech companies send recruiting teams to engineering schools in India and other developing countries. Given the large absolute numbers of students that are graduating abroad in countries like China and India (Freeman and Huang 2015), this traditional flow is quite likely to continue for some time.

One tangible outcome of this process is the rise of global collaborative teams for inventive work (Miguelez forthcoming; Kerr and Kerr forthcoming), which is well documented in patent filings and thus provides a source of data for studying certain effects of migration. For example, Branstetter, Li, and Veloso (2015) document that the majority of China's patents filed with the US Patent and Trademark Office come from multinational firms expanding into China and often taking US-based inventors along to facilitate the entry. Foley and Kerr (2013) more broadly show how the ethnic composition of US multinational firms can shape their foreign investment activity. This builds on earlier work concerning business networks and skilled migration (for example, Docquier and Lodigiani 2010; Kugler and Rapoport 2011), and Hovhannisyan and Keller (2015) relatedly connect high-frequency business travel to innovation outcomes.

Some Implications

Global integration is generating ever-greater returns for matching talent with the right job or opportunity. The implications of these global talent flows are profound, touching everything from business, to politics, to religion, culture, and entertainment. From this sea of potential topics, we briefly discuss a few insights with implications for understanding the role of immigration policy and the future patterns of high-skilled migration. Kerr (forthcoming) provides a longer review and more references for the issues highlighted below.

First, recent work confirms the importance of location for enhancing the productivity of skilled migrants (for example, Clemens 2013; Kahn and MacGarvie 2016), which is a critical first step towards connecting talent flows to higher worldwide productivities. Researchers are beginning to trace some of the details and nuances of how this occurs. With Fulbright scholars, for example, the productivity differences of individuals are mainly between advanced and developing economies, versus differences between the United States and other advanced economies. In other settings, the importance of location becomes more acute. More than half of the entrepreneurs in Silicon Valley are immigrants, and their productivity in global entrepreneurship depends upon the narrower geographic network to which they belong. The European Union offers a case study that should be a fruitful subject for research, given that it has removed restrictions on internal migrant flows imposed by individual countries. Of course, Brexit potentially offers a case study in the opposing direction.

Second, a substantial avenue of recent research has focused on the extent of the net innovation and productivity gains realized in receiving countries from the talent inflows, with the United States being the most studied case. This work is often framed in the themes of endogenous growth literature similar to Jones (1995). The empirical evidence remains debated. Studies exploiting long-horizon and spatial variation in high-skilled immigration often find results consistent with immigrants boosting innovation and productivity outcomes.[10] Conversely, other studies suggest immigrants mostly displace natives to yield a zero net benefit.[11] Outside of the United States, positive net impacts are observed in several European countries for national diversity on innovation.[12] Our perspective is that the weight of the evidence points to high-skilled immigrants boosting innovation and productivity—mainly through the increased quantity of skilled individuals pursuing innovative work—and we are sure this debate will persist for some time.

Researchers, following studies like Peri and Sparber (2011), are now developing a deeper understanding of the types of skills that port well across countries (such as STEM, computer programming, and academic research) and the underlying traits of these skills (such as weaker dependence on local culture and language, and limited returns to local experience). Developing this granularity has helped researchers better identify and interpret wage and employment implications of high-skill mobility on native workers. To illustrate, imagine a scenario in which high-skilled migration pushes American engineers to leave their occupations. Instead, those Americans move to marketing, where they receive a substantially higher wage and, more importantly, they work together with the migrant engineers. Does this scenario present the negative consequences of migration, with Americans crowded out of engineering jobs? Is it a story of a positive complementarity, in which migration allows immigrants and natives to specialize in occupations based on their comparative advantages and increase their joint productivity? Or perhaps without the presence of foreign engineers, the engineering work would have shifted abroad and Americans would have moved to marketing anyway, but perhaps would be less productive due to geographic distance from the engineering staff now abroad? These implications are not easy to assign and will be a focus of impactful research ahead.

[10] For example, see Hunt and Gauthier-Loiselle (2010); Kerr and Lincoln (2010); Stuen, Mobarak, and Maskus (2012); Moser, Voena, and Waldinger (2014); Kerr, Kerr, and Lincoln (2015b); Peri, Shih, and Sparber (2015); and Ghosh, Mayda, and Ortega (2014).
[11] For example, see Matloff (2003); Hira (2010); Borjas and Doran (2012); Doran, Gelber, and Isen (2014); and Bound, Braga, Golden, and Khanna (2015).
[12] For example, see Ozgen, Nijkamp, and Poot (2011); Parrotta, Pozzoli, and Pytlikova (2014); Bosetti, Cattaneo, and Verdolini (2015); Breschi, Lissoni, and Tarasconi (2014); Breschi, Lissoni, and Miguelez (2015); and Nathan (2015).

Finally, skilled migrants serve as effective conduits for many forms of multidirectional exchange in a networked world: trade, foreign direct investment, finance, knowledge, technology, cultural norms, and political views (for example, Parsons and Winters 2014; Saxenian 2002, 2006). Terms like "brain drain" and "brain gain" are now used to label settings where the gains to the sending country from migration fall short of, or exceed, the costs (for a review, see Docquier and Rapoport 2012). With respect to productivity development, analyses like Kerr (2008) and Agrawal, Kapur, McHale, and Oettl (2011) document that countries gain access to technical information from their overseas community, but there is substantial heterogeneity in the strength of these connections and the types of transfers facilitated. Thus, there is no one-size-fits-all answer here. Moreover, to develop informed cost–benefit analyses, we need much greater insights into where migrating individuals were trained, who funded the training, what other opportunities looked like (for example, Bhagwati 1976; Beine, Docquier, and Rapoport 2007; Özden and Phillips 2015), and the full range of multidimensional exchanges that are facilitated.

Policies and Gatekeepers

A wide array of factors leads countries to restrict migration, including political, cultural, and even philosophical motivations. One might question why high-skilled migration should ever be restricted, even if there are justifications for broader regulations of low-skilled flows (for example, Clemens 2011). The primary economic arguments in favor of restrictions on high-skilled migration center on possible adverse wage and employment effects on skilled native workers, as argued in Borjas and Doran (2012), Doran, Gelber, and Isen (2014), and Bound, Braga, Golden, and Khanna (2015). Another argument is that governments may want to limit the volatility of migration flows that might accompany and possibly amplify ups and downs of the cyclical labor markets characterized by technology booms and busts. Finally, national security concerns are proposed as reasons to restrict the employment of high-skilled immigrants in certain key industries or with certain sensitive technologies.

Advocates for flexible migration policies for high-skilled labor alternatively point to how skilled immigrants can benefit native workers through complementary skills, through the agglomeration effects generated by a dense cluster of skilled workers, or through the labor demand that results from immigrant entrepreneurship and innovation. These views are as passionately held as those who argue against immigration, and many advocates of greater skilled migration to the United States have adopted the phrase "national suicide" to characterize the current US restrictions on skilled inflows. More broadly, fostering and strengthening skilled immigration is often a prominent pillar in the economic development strategies of countries. In the 2013 *World Population Policies* report, 40 percent of countries reported policies to raise immigration of high-skilled workers, a large increase from 22 percent in 2005 (United Nations 2013).

There are two broad policy approaches used by countries to select high-skilled individuals, although as we discuss later, most countries display elements of both. The first approach is points or merit-based and is often referred to as a set of supply-side policies for migration, since it focuses on screening of individual applicants for admission. The second conceptual model is an employer-driven system. This is also described as a demand-side approach, because it places emphasis on firms selecting skilled workers to admit into the country.

Canada and Australia are prominent examples of countries that implement points-based systems for skilled migration. These programs select individuals based upon their observable education, language skills, work experience, and existing employment arrangements. Each factor is weighted by a formula, and online calculators often help migrants evaluate their characteristics for seeking a skilled work visa. In the Canadian example (as described at http://www.immigration.ca/index.php/en/who-qualifies-for-canadian-immigration-under-the-skilled-worker-program), migrants need to collect 67 points across six categories. In terms of education, for example, 15 points are awarded for a one-year postsecondary diploma, trade certificate, or apprenticeship, compared to 25 for a doctorate degree. With regards to work experience, six or more years of applicable experience receives 15 points, compared to 9 points for just one year of experience.

The points-based approach offers an explicit statement of migration priorities for public debate, thereby generally leading to stable immigration processes over time. Yet it also has certain disadvantages. Establishing and adjusting an optimal weighting scheme over time is hard and multiyear queues for applicants are possible. The screening process needs to catch migrants who are exaggerating or misrepresenting their qualifications, and there is some scope for adverse selection if those with few other migration options are otherwise attracted. Talented migrants may also find themselves underemployed after their arrival due to lack of demand for their skills, with the typical anecdote being a nuclear physicist who is driving a taxi due to lack of better opportunities. It could be argued that the underemployed migrant is still better off, as revealed by their continued stay in the host country; however, this underemployment often indicates the country did not realize the benefits of migration it sought. There may be public sector costs of the migration (for example, schooling of children) that are not covered by the tax receipts generated, and employers might have preferred someone further back in the queue.

The United States is the most cited example of a country that uses an employer-driven program for high-skilled immigration, with the H-1B and L1 visas as primary categories (Kerr, Kerr, and Lincoln 2015a). The H-1B visa allows US companies to temporarily employ skilled foreigners in "specialty occupations," defined to be those demanding application of specialized knowledge like engineering or accounting. The visas are popular in part due to their "dual intent" feature, which allows for the firm to also petition for permanent residency on behalf of the worker. Virtually all H-1B holders have a bachelor's degree or higher, and about 70 percent of the visas in recent years went to STEM-related occupations. India is by far the largest source country, accounting for about two-thirds of H-1B recipients in recent years. Visas are valid for three years and can be renewed once. Since 2004, the cap on new visa issuances has been 85,000, with 20,000 of these reserved specifically for advanced degree holders. Inclusive of renewals, 117,000 H-1B visas were issued in fiscal year 2015 on a "first come, first served" basis. To protect domestic workers, firms are required to pay the visa holder the higher of the prevailing wage in the firm for the position, or the prevailing wage for the occupation in the area of employment. The mean annual starting compensation for a new H-1B worker was $75,000 in 2014.

The L1 visa allows temporary migration of employees of an international company with offices in both the United States and abroad. The migrant must have worked for the company abroad for at least one of the previous three years before coming to the United States. The duration of these visas is set on a bilateral and reciprocal basis with foreign countries, with renewals and extensions allowing a maximum stay of seven years. The L1 visa also allows dual intent application for a green card. Inclusive of renewals, 75,000 L1 visas were issued in fiscal year 2015. As a third category, O1 visas for migrants with recognized extraordinary ability numbered about 9,000 for fiscal year 2015. There are no specific numerical limits for these categories.

Universities and colleges are the other important gatekeepers through their selection of individuals for the F1 (student) or J1 (exchange visitor) visas. Inclusive of renewals, 385,000 and 321,000 F1 and J1 visas were issued in fiscal year 2015, respectively. While these visas do not offer long-term employment, US firms often recruit graduates of US schools using visas like the H-1B. About 45 percent of new H-1B visas in fiscal year 2014 went to applicants already present in the United States, which includes school-to-work transitions.

In employment-based regimes, labor markets—via employers—play a more direct role in determining the level and composition of skilled migration flows. An advantage of this approach relative to the points-based approach is that employers choose whom they want and immigrants have a job upon arrival. This employer-employee match is guaranteed to connect the immigrant talent with a productive and commensurate job. Perhaps the largest liability of a quota-based program is its inherent potential to limit employers in the productive uses that they can make of talent workers. If the quota is set too low and agglomeration economies are strong, constrained employers will not be able to hire the foreign talent they desire and this will lower productivity growth and concomitant demand for native workers. In some years, including fiscal year 2016, applications for H-1B visas outstrip the available annual quota within a couple of days of the opening of the process.

More broadly, the centrality of employers in this approach can lead to certain disadvantages. First, firms may use the program for purposes that are not in line with the intentions of the government. For example, US policymakers intended the H-1B program to be used by companies to find workers for specific high-skilled jobs. Yet a large share of H-1B visas in the past decade have been granted to Indian outsourcing firms that have realized the program can be used to temporarily bring their workers from India to the United States. This was not the goal of the program! Independent of the impacts of outsourcing, this diversion makes it more likely the program will find itself constrained in accomplishing its original intent. Second, demand for visas under the employer-driven programs can show high volatility. For example, the share of H-1B visas going to computer-related occupations has fluctuated between 25 and 80 percent over the course of a few years during the last two decades. While this volatility signals the responsiveness of the program to underlying labor market conditions, one can also imagine negative consequences, such as taking the steam out of the job market for recent college graduates who have invested several years in a field of study that was hot earlier. Third, unlike points-based programs, the migrant in an employment-driven system is more tied to the sponsoring firm, at least for a period of time, and may be in a weak negotiating position, similar to a modern day "indentured servant."

Overall, the features of the two systems do not yield a clear absolute winner, and most real-world regimes combine different features of points-based and employment-driven systems. Superstar talent rarely competes for H-1B visas, for example, but instead gains direct access to the United States through O1 temporary visas for extraordinary ability and direct green card applications of the EB-1 level for those with even more exceptional talent. Both of these categories are always in surplus. In effect, the United States operates a points system for individuals with truly exceptional talents such as Nobel Prize winners, superstar athletes, and musicians (Rosen 1981). Coming from the other direction, countries with points-based approaches have added weights to whether the applicant has a verified job and developed two-step processes that include points-based screening followed by sponsorship roles. Broadly speaking, it appears the overall shift is towards demand-driven elements and away from pure points-based programs (National Academies 2016), thereby prioritizing migrants' employability over a more flexible notion of human capital. In a rare cross-country comparison, Czaika and Parsons (2015) find evidence in favor of the efficiency of supply-driven criteria, and future research should further quantify the impacts of these policy design choices.

Moreover, it's important to remember that while there are important de jure differences in policies regarding high-skilled immigration, de facto differences in implementation or outcome may be much smaller. Many talented and motivated individuals often find their way to the countries they want to move to, even if it means marrying an American (two authors of this paper possibly offering an example!). Immigration systems are quite complex, with rules on admissions for temporary migration, selections for permanent residency and ultimately citizenship pathways impacting skilled worker choices. The United States, for example, gives priority to family reunification rationales for obtaining permanent residency compared to employment-based objectives, making the United States' permanent residency policy tilted towards lower-skilled groups relative to those of other advanced countries. That said, temporary visas allow many skilled migrants into the United States for work, who then queue for permanent residency and are allowed to stay in the country until their case is finalized. Moreover, the United States derives advantages from the demand for high-skilled migration to the United States. Hunt (2011) compares different US entry routes and finds subsequent productivity and innovativeness to be highest for those entering directly for work or advanced schooling categories.

When it comes to talented foreigners, a number of countries not only remove restrictive visa regimes, but implement recruiting programs. Chile has received a lot of attention for its Start-up Chile program that pays foreign entrepreneurs to spend six months in the country as an effort to build global skill connections and a mini-Chilean "diaspora." Malaysia literally rolled out the red carpet at its airports in special lines as part of the Residence Pass Talent program (discussed in Del Carpio et al. 2015). Canada has been very active in targeting skilled migrants who are denied or frustrated by the H-1B visa system in the United States, even taking out ads on US billboards to attract such migrants. The impact of these recruiting programs depends upon perspective. Effective design can yield measureable growth from the perspective of an individual country, with Start-up Chile for example now supporting 200–250 new ventures per year and Chile having launched sister programs based upon the success. The other perspective, however, is that these localized wins tend to be a drop in the bucket compared to aggregate trends noted earlier like the steep concentration of high-skilled migration towards Anglo-Saxon countries.

Finally, countries also differ in the degree to which they can realistically reform their migration structures (Papademetriou and Sumption 2013; National Academies 2016). Some smaller and nimbler countries, like Singapore, can engage in "immigration engineering," in which policies are recalibrated frequently based upon market conditions and public preferences. The US political structure, by contrast, seems to allow a once-in-a-decade type of reform to skilled migration policies. For example, H-1B reforms are often discussed, and economists frequently propose many alternatives (like raising or lowering the cap or using a price or auction system to allocate the visas) to raise efficiency. Yet, the last major change was in the early 2000s, and the current annual visa caps were set in 2004. A number of political leaders have taken the stance that H-1B reforms can only be considered in the context of comprehensive immigration reform.

Conclusions

Looking forward, we believe skilled migration and the integration of global labor markets for high-skilled occupations will continue their march forward. There are natural limits to these forces, but escalating real estate prices and high-skilled wages in key clusters like London, New York, Hong Kong, and Silicon Valley indicate skilled migration won't be waning anytime soon. It is sometimes suggested that video conferencing, online labor markets, and other uses of communications technology can mitigate the need for talent flows and physical proximity. The evidence thus far is to the contrary, instead emphasizing how the new tools complement global movements instead of substituting for them.

While overall patterns will likely remain similar, different forms of high-skilled migration are likely to emerge and evolve. We expect that the skilled migration will increasingly involve shorter durations and circular paths, for example, as opposed to one-way and long-duration experiences, due to greater global integration, lower transportation costs, and rising standards of living outside of traditional advanced economies. The high-skilled members of the next generation appear to be less tied to any particular location or national identity, but instead have mentalities and connections that are much more global in nature than those of their predecessors. Moreover, the culture and outlook of companies and other employers, such as universities and football clubs, that employ global talent are also becoming more global as their workforce is drawn from different corners of the world.[13] Academics, business leaders, and policymakers have only just started to grapple with these implications. The most successful individuals, employers, and countries will be those that discern how to best navigate the current global labor markets and sidestep the government-imposed limitations on high-skilled immigration.

■ *We are grateful to the editors for detailed feedback and to Zovanga Kone for his assistance with the data work. Our research has been generously supported by the Alfred P. Sloan Foundation, the Kauffman Foundation, the National Science Foundation, the Smith Richardson Foundation, and Harvard Business School. Özden acknowledges financial support from the Knowledge for Change Program and the Multidonor Trust Fund for Trade and Development of the World Bank. The findings, conclusions, and views expressed in this paper are entirely those of the authors. They should not be attributed to World Bank, its executive directors, and the countries they represent.*

[13] Going back to the football example, Barcelona and Manchester United have 88 million and 77 million members, respectively, in their Facebook fan clubs, significantly greater than the populations of their home cities (or even countries!).

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Journal of Economic Perspectives—Volume 30, Number 4—Fall 2016—Pages 107–130

Game Theory in Economics and Beyond

Larry Samuelson

Within economics, game theory occupied a rather isolated niche in the 1960s and 1970s. It was pursued by people who were known specifically as game theorists and who did almost nothing but game theory, while other economists had little idea what game theory was. Game theory was taught only in occasional specialty courses. Nonetheless, game theory was surrounded by a buzz of anticipation and excitement, especially moving into the 1980s and early 1990s.

Game theory is now a standard tool in economics. Contributions to game theory are made by economists across the spectrum of fields and interests, and economists regularly combine work in game theory with work in other areas. Students learn the basic techniques of game theory in the first-year graduate theory core. Excitement over game theory in economics has given way to an easy familiarity.

This essay examines this transition, arguing that the initial excitement surrounding game theory has dissipated not because game theory has retreated from its initial bridgehead, but because it has extended its reach throughout economics. We begin with an overview of the development of game theory, with emphasis on its integration with economics. In the process, both the practice of economics and the nature of game theory have been transformed. We then turn to some key challenges for game theory, including the continuing problem of dealing with multiple equilibria, the need to make game theory useful in applications, and the need to better integrate noncooperative and cooperative game theory. The paper concludes with brief remarks about the current status and future prospects of game theory.

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† For supplementary materials such as appendices, datasets, and author disclosure statements, see the article page at
http://dx.doi.org/10.1257/jep.30.4.107 doi=10.1257/jep.30.4.107

Game Theory in Economics

Aggregating Individual Behavior

The social sciences are distinguished from one another not so much by what they study, but by how they study their subject. Economists stand out among the social sciences for their belief in *methodological individualism*—the tenet that explanations of social phenomena should be built up from the study of individual behavior—and the further belief that, within this paradigm, a common and parsimonious model can be consistently applied to examine whatever question arises. This model is built up from two principles. The first principle addresses individual behavior. The assumption here is that people have consistent and stable preferences, and that they choose the alternative from the set of feasible alternatives that is ranked highest under these preferences. The second principle addresses the aggregation of individual behavior to examine more complex phenomena. The standard organizing principle here was once the concept of a competitive market, with occurrences of market power viewed as exceptional cases. These twin principles were evident in the standard first-year graduate theory sequence, which consisted of a semester studying theories of optimization and its application to consumer and firm behavior, followed by a semester studying competitive equilibrium.

As the theory of competitive markets was reaching its culmination in Arrow and Debreu (1954), Debreu (1959), and McKenzie (1954) (see Düppe and Weintraub 2014 for a historical account), the foundations of game theory were also being laid (von Neumann and Morgenstern 1944; Nash 1950a, b, 1951, 1953). Game theory retains the familiar model of individual behavior, but offers an alternative and more general view—containing competitive markets as a limiting case—of how models of individual behavior are aggregated to examine more complex phenomena. Game theory has subsequently become the standard organizing principle for examining interactions between people, and has become established as the second pillar of methodological individualism. One again sees this evolution in the typical first-year graduate theory sequence, where general equilibrium theory has been nearly swept off stage in order to make room for game theory.

It will help to maintain a running example. We begin with the simplest model of a Cournot (1838) duopoly. Firms 1 and 2 simultaneously choose quantities of a homogenous good that they costlessly produce and sell. They sell their outputs at a common price, determined by a linear market demand function that gives the price as a function of the total quantity produced by the two firms. Figure 1 illustrates the Nash equilibrium[1] of this Cournot duopoly game. The point of departure is a market demand function, presumably derived from utility-maximization models describing the price-taking consumers in the market. A model based on competition would similarly derive a supply curve from profit maximizing models of price-taking firms. The Cournot model instead assumes there is a small number of firms (for

[1] A Nash equilibrium is a profile of strategies, one for each player, with the property that each player's strategy maximizes that player's payoff, conditional on the strategies of the other players.

simplicity of illustration, two), each cognizant of its effect on price, and seeks quantities satisfying the equilibrium condition that each firm maximizes profits given the residual demand function induced by the other firm's quantity. One can view a competitive market as the limiting case of this model as the number of firms grows arbitrarily large.

Classical Game Theory

Game theory has been transformed as it has percolated into economics. Game theory was initially dominated by a classical view, whose key component was that the game should be viewed as a literal description of the situation of interest, rather than just an approximation. Perhaps the clearest statement of this classical view appears in Kohlberg and Mertens (1986, p. 1005), who state:

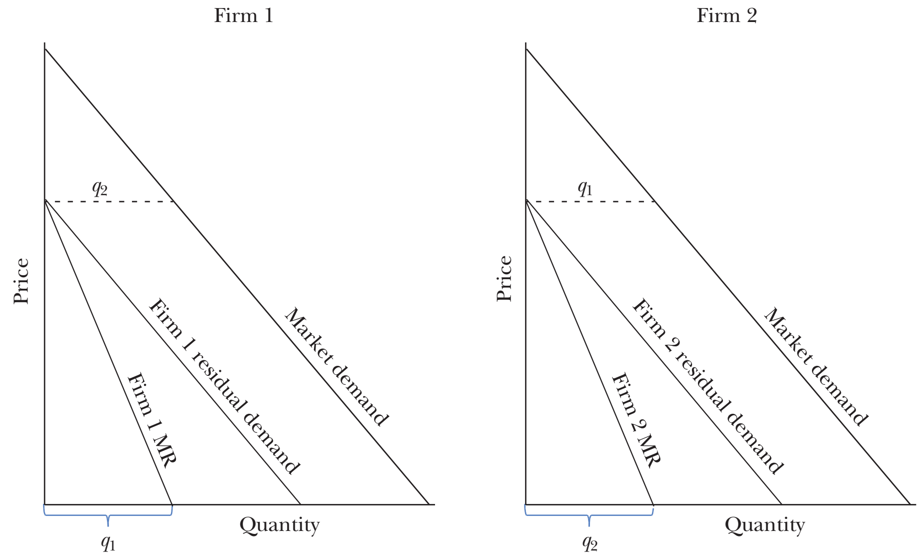
> We adhere to the classical point of view that the game under consideration fully describes the real situation—that any (pre)commitment possibilities, any repetitive aspect, any probabilities of error, or any possibility of jointly observing some random event, have already been modelled in the game tree. … In principle, in situations where those restrictions are not met, the game tree is just used as a shorthand notation for the rules of a much bigger 'extended game' … , and it is the stability of the equilibria of the extended game that has to be analyzed.

The classical view makes game theory neatly self-contained. There is no need to worry about whether the players in the game can communicate, or make agreements, or collude, or send signals to one another, or make commitments, and so on. If any of these were possible, they would be already included as moves in the game.

For example, Cournot's (1838) model of imperfect competition viewed firms as choosing their quantities of output, and then selling these outputs at a common market price determined by the total quantity produced in the market, as in Figure 1. In 1883, with the dates perhaps reflecting a slower pace of academic life, Bertrand wrote a review of Cournot's work (from 1838), arguing that firms should be modeled as choosing prices rather than quantities of output.[2] When the firms set different prices, all consumers buy from the lower-priced firm. The differing implications are dramatic. In the market portrayed in Figure 1, Cournot's firms choose quantities that lead to a market price higher than marginal cost and to positive profits, while ruthless price-cutting forces Bertrand's firms to set prices equal to marginal cost and to earn zero profits. How do we choose between the two models? Under the classical view, the answer is conceptually straightforward—we should check what firms actually do. If they choose quantities, we should use the Cournot model. If they set prices, we should use the Bertrand model. If they do

[2] For translations of Bertrand (1883) and the relevant chapter of Cournot (1838), see Daugherty (1988).

Figure 1
Illustration of Nash Equilibrium of Cournot Duopoly



Note: Firm 1 faces a residual demand function, given by the market demand function shifted to the left by the quantity q_2 of Firm 2's output, and maximizes profits by choosing that value q_1 that sets the resulting marginal revenue equal to the marginal cost, zero in this case because production is assumed to be costless. Firm 2 does likewise. Each firms' equilibrium quantity of output is a best response (that is, it maximizes profits) given the quantity produced by the other firm (that is, given the residual demand function induced by the other firm's quantity).

some combination of the two, or do something else, then we need a different model (for example, Kreps and Scheinkman 1983).

Once one has selected the appropriate game, attention typically turns to equilibrium behavior. Under the classical view of game theory, one should be able to deduce the equilibrium play from the specification of the game and the hypothesis that it is commonly known that the players are rational. An analyst observing the game should be able to make such a deduction, as should the players in the game. This immediately answers an obvious question: Why are we interested in the equilibrium of a game? In the classical view, the equilibrium implication of a game will be obvious to rational players, and will just as obviously be reflected in their behavior.

In the Cournot duopoly of Figure 1, it is straightforward to identify Nash equilibrium behavior, and to ascertain that there is only one such equilibrium. In general, however, games have many equilibria. Suppose, for example, that our two firms from Figure 1 interact not just once, but repeatedly. It is an equilibrium for the firms to act in each period just as they do in the equilibrium of the one-shot game. However, following the lead of Friedman (1971), if the firms are sufficiently patient, it is also an equilibrium for them to set the monopoly price and share the monopoly profits in each period, with any cheating on such collusion prompting a switch to the behavior described in the preceding sentence. Indeed, the folk theorem (Fudenberg and Maskin 1986) tells us that with sufficiently patient players, virtually anything is an equilibrium outcome.

Multiplicity of equilibria is not limited to repeated games. If the firms in Figure 1 faced nonlinear demand functions or nontrivial cost functions, there could well be multiple equilibria. Settings characterized by uncertainty, such as signaling models, are well-known breeding sites for multiple equilibria. More generally, multiple equilibria arise in many settings for many reasons. How are we to identify the equilibrium implication of the game in the presence of multiple equilibria?

Equilibrium Refinements

The response to this question was the equilibrium refinements literature (van Damme 1991, 1992), which sought "refinement" criteria for limiting attention to a subset of the set of Nash equilibria. For example, one might restrict attention to Nash equilibria that do not play weakly dominated strategies.[3] For much of the 1980s, work on refinements lay at the center of game theory and economic theory more generally. The holy grail of this quest was an equilibrium notion that economists and game theorists could embrace as *the* equilibrium notion, giving rise to a unique specification of play in any game to which it might be applied. Perhaps the culmination of the refinements program was Harsanyi and Selten's (1988) theory of equilibrium selection, which indeed delivered unique outcomes, but is now most often cited for having introduced the distinction between risk dominance and payoff dominance.[4]

The equilibrium refinements literature was not a complete success. Instead of producing an equilibrium refinement that could command consensus, the literature gave rise to an ever-growing menagerie of refinements. New refinements tended to give rise to examples highlighting their weaknesses, followed by successor refinements destined to serve as the raw material for the next round. This seemingly endless cycle prompted Binmore (1992, p. 1) to liken the refinements quest

[3] A strategy for a player is weakly dominated if there exists an alternative strategy that ensures the player a payoff that is always (that is, for any opponents' strategy) at least as high as that of the dominated strategy, and that is sometimes (that is, for some opponents' strategy) strictly higher.

[4] In two-by-two symmetric games with two symmetric pure equilibria, one of the equilibria payoffs dominates the other if the former gives both players higher payoffs. One equilibrium risk dominates the other if the former involves strategies that are strict best responses to equal mixtures on the part of opponents, allowing an interpretation of being less subject to the risk that the opponent may not play her equilibrium strategy. Harsanyi and Selten (1988) has become a contender for being the most frequently misquoted work in game theory. It is common to find assertions that Harsanyi and Selten's theory of equilibrium selection selects the risk-dominant equilibrium in two-by-two coordination games. Contrast this with their statements: "The solution function … for the application of our general concept to this class [2x2 games with two strict Nash equilibria] gives absolute priority to payoff dominance" (p. 90) and "Risk dominance and payoff are combined to form a *dominance relationship* that gives precedence to payoff dominance" (p. 196).

to Hercules' quest to kill the Hydra, with two new heads appearing in the place of each predecessor.

At the same time that many game theorists were busy inventing and reinventing refinements of Nash equilibrium, difficulties appeared in the attempt to show that at least Nash equilibrium, much less refinements of Nash equilibrium, could be deduced from the specification of the game and the hypotheses that the players are commonly known to be rational. The opening salvos in this investigation, by Bernheim (1984) and Pearce (1984), concluded that the common knowledge of rationality allowed one to infer only that players will restrict attention to rationalizable strategies. In some games, this is enough. To identify rationalizable strategies in the Cournot duopoly game of Figure 1, for example, one first observes that no firm would ever find it optimal to produce more than the monopoly quantity, no matter what it thinks the other firm will do. One can then eliminate any quantity larger than the monopoly quantity as not being rationalizable, putting an upper bound on the set of rationalizable strategies. Next, if a firm is confident its opponent will not produce more than the monopoly quantity, then the firm will never want to produce less than the optimal output corresponding to the residual demand function created by the opponent's production of the monopoly quantity. We can thus eliminate lower quantities, putting a lower bound on the set of rationalizable strategies. But now, knowing that no firm would produce less than this lower bound, we can deduce that no firm would find it optimal to produce the entire monopoly output. This tightens the upper bound on the set of rationalizable strategies. It is not immediately obvious, but it is straightforward to show that in the case of the Cournot duopoly shown in Figure 1, this process continues until there is only one rationalizable strategy left standing, which is the Nash equilibrium output. Here, the common knowledge of rationality very neatly gives rise to Nash equilibrium.

Unfortunately, many other cases do not work nearly as well. Consider the matching pennies game. In one version of this strategic problem, Sherlock Holmes and James Moriarty (in a scene from Sir Arthur Conan Doyle's "The Final Problem") are aboard separate east-bound trains from London, each with the option of alighting at either Canterbury or Dover. Moriarty wins (and Holmes loses, with payoffs 1 for Moriarty and -1 for Holmes) if they choose the same stop, whichever it is, and Holmes wins (and Moriarty loses) if they choose different stops. This game has a unique Nash equilibrium, in which each player chooses each strategy with probability one-half, perhaps achieved by tossing a coin and choosing Canterbury if heads, Dover if tails. In contrast to this unique Nash equilibrium, every strategy is rationalizable. In particular, every option available to Homes, including alighting at Canterbury, alighting at Dover, and any random choice between the two, is a best response to something Moriarty might do (and vice versa for Moriarty). In this setting, the rationalizability calculation thus never eliminates any strategies. This example is not an isolated one—rationalizability often has little bite.

The refinements literature has faced challenges on two fronts. Arguments based on a formal examination of the common knowledge of rationality prompted people to argue that sometimes even the Nash equilibrium notion was too restrictive, while those in pursuit of refinements argued that sometimes the Nash equilibrium notion was too permissive.

An Instrumental View of Game Theory

In response, the classical view of game theory gave way to an instrumental view. In this view, the game is not a literal description of an interaction, but is a model that one hopes is useful in studying that interaction. In the words of Aumann (2000, p. 38; originally 1985), "Game-theoretic solution concepts should be understood in terms of their applications, and should be judged by the quantity and quality of their applications." The game is thus a deliberate approximation, designed to include important aspects of the interaction and exclude unimportant ones. Under this view, for example, the choice between the Cournot and Bertrand models hinges not on what one thinks firms actually do (though talking to people who run firms might be a good source of intuition and inspiration), but on which model gives the most useful insights. Are we working in a setting in which competition between even two firms is enough to drive prices to marginal cost? If so, the Bertrand model may be appropriate. Do we think that the entry of a new firm into the market is likely to decrease the profits of existing firms? If so, the Cournot model is likely to be appropriate.

An implication of the instrumental view is that making a model more realistic does not necessarily make it a better model. It is obvious that making a model more *complicated* does not necessarily make it a better model. After all, as Lewis Carroll (1893, p. 169) wonderfully illustrated with the vision of a map on the scale of one-to-one, a model as complicated as its intended application is also typically useless. The more important point is that, even without extra complication, more realism need not be a step forward for a model. For example, models of infinitely repeated games are often criticized because "nobody lives forever." A more realistic model would incorporate a finite horizon.[5] However, the relevant considerations when assessing the time horizon revolve around human behavior rather than human mortality tables (for a discussion, see Osborne and Rubinstein 1994, p. 135). Do people allow end-game considerations to affect their behavior in the early periods of a repeated interaction? For example, suppose an antitrust case hinged upon the accusation that two firms in a repeated version of the market captured in Figure 1 were colluding by continually jointly producing the monopoly output, sustaining this behavior by the realization that any deviation would prompt a switch to the perpetual play of the less-lucrative Nash equilibrium of the one-shot game. This behavior is an equilibrium in an infinitely-repeated interaction between the two firms (given sufficient patience), but not in a finitely-repeated interaction with a fixed end period. In the latter case, the candidate monopoly equilibrium unravels

[5] Arguments that we can think of the repeated game as a game whose length is finite but uncertain do not address this concern, since they give analogous results only if the continuation probability is bounded sufficiently far away from zero, which is no more realistic than an infinite lifetime. See Mailath and Samuelson (2006, chap. 4) for a discussion.

on the strength of a backward-induction argument. In particular, producing the joint monopoly output is not an equilibrium in the final period, where the only equilibrium behavior is given by the Nash equilibrium described in Figure 1. But once we have locked down behavior in the final period, the Nash equilibrium described in Figure 1 is the only equilibrium behavior in the penultimate period (since no variations in continuation play are available to induce players to take any other action), and similarly in all previous periods. However, suppose that the defense team in the antitrust case argued that the life of our planet is surely finite (since the sun will expire in a few billion years), making this a finitely repeated game and hence ensuring that collusive behavior could not possibly be part of an equilibrium. Would anyone be convinced by such an argument? Would we be convinced by a similar argument that fiat money is worthless, and hence refuse to accept it? If so, then games with infinite horizons are out of place. If not, then such models are appropriate. The relevant criterion is not the realism of the model, but its ability to provide insights into the behavior of interest.

The instrumental view complicates game theory. A world of literal descriptions and perfectly rational players is typically more orderly than are approximations of a complicated world filled with people. Consider a version of the prisoners' dilemma, the most studied single game in game theory, formulated as the "push–pull" game by Andreoni and Varian (1999). Alice has an apple, worth 1 to her and worth 3 to Bob. Bob has a banana, worth 1 to him and worth 3 to Alice. Alice and Bob simultaneously decide whether to keep their good (pull, or defect) or give it to the other person (push, or cooperate). It is a strictly dominant strategy for Alice to keep her apple—she is better off doing so no matter what Bob does. The same is true of Bob, of course, and mutual defection is the unique (Nash and indeed strictly dominant strategy) equilibrium in the prisoners' dilemma.

Will people defect in the prisoners' dilemma? In the classical view, yes; this is not only obvious but is a tautology (as Binmore 1994, chap. 3 explains). Under this interpretation, the numbers that appear in the payoff matrix are utilities, derived from a revealed preference analysis of behavior. The fact that larger numbers are attached to defecting than to cooperating indicates the agent in question "derives higher utility from defecting," which under the revealed preference interpretation is synonymous to saying that the agent defects. Asking whether the agent might cooperate is equivalent to asking whether we have gotten the game wrong. If the game is correct, there can be no outcome other than defection.

Things are more complicated under an instrumental view. First, the actions "cooperate" and "defect" are approximations of alternatives that may be much more complex. Cooperation may involve colluding in an oligopoly market or signing a nuclear arms agreement, while defection may involve flooding the market with increased output or installing an antiballistic missile shield. In addition, we typically cannot hope to measure utilities, and the numbers in the cells are instead measures of profits or some other more-readily-measured quantity. Will the players defect? Equivalently, have we chosen well in approximating the interaction as a prisoners' dilemma? This can be a difficult question.

Evolutionary Game Theory

How do we think about equilibrium under the instrumental view? Here, we bring game theory back to long-standing traditions in economic theory. Economic models of individual behavior (the first of the two pillars of methodological individualism) are built around maximization. When presenting the idea of utility maximization or profit maximization in introductory economics classes, one invariably encounters questions as to whether people or firms really maximize, often accompanied by examples of experience with satisficing behavior, cost-plus pricing, or some other behavior that appears to bear no relationship to maximization. A standard response (for example, see Alchian 1950) is that people or firms probably do not literally maximize, but rather they make choices and adjust these choices in light of their experience, sometimes experimenting and sometimes making mistakes, while continually noting which alternatives appear to lead to better outcomes than which others. This gives rise to an adaptive process leading them (at least approximately) to the alternatives that solve their maximization problem. The original economic models of the second pillar, competitive markets, similarly made an appeal to a (sometime implicit) market adjustment process. Walras (1874) not only introduced the notion of competitive equilibrium, but also the *tâtonnement* process that he envisioned leading to such an equilibrium.

Evolutionary game theory applies analogous reasoning to games (for book-length treatments, see Fudenberg and Levine 1998; Samuelson 1997; Sandholm 2010; Vega-Redondo 1996; Weibull 1995; Young 1998). The idea is not that players deduce the equilibrium actions from the structure of the game, or that the equilibrium springs into life upon the appearance of the game. Instead, we think of people as accumulating experience with the game. They choose alternatives, check how well these alternatives work, perhaps experiment with other alternatives, and sometimes make mistakes, all giving rise to a trial-and-error process that (one hopes) tends to push them toward equilibrium. Using phrases reminiscent of other areas in economics, the rational calculations of the classical approach are replaced by the limiting outcomes of an adaptive process. This view brings the methods used in game theory not only closer to that of traditional economics, but also closer to that of the physical sciences. In the latter, it is common that one first specifies a dynamic process, and then views equilibria as the rest points of this dynamic process. Classical game theory is noteworthy in that equilibria come into being divorced from a dynamic process. Evolutionary game theory puts the dynamic process back into the picture. Interestingly, Cournot (1838) motivated his equilibrium for the duopoly illustrated in Figure 1 as the limiting outcome of a best-response-based adjustment process.

Evolutionary game theory was initially surrounded by a great deal of excitement, and like equilibrium refinements, for a while (approximately the 1990s) lay at the center of game theory as well as perhaps economic theory more generally.[6]

[6]For an overview, see the Spring 2002 *Journal of Economic Perspectives* "Symposium on Evolutionary Economics," including Bergstrom (2002), Nelson and Winter (2002), Robson (2002), and Samuelson (2002).

More recently, it has receded into the background. To a large extent, this reflects the success of evolutionary game theory. Evolutionary game theory addressed two basic questions. Can we expect the dynamic processes shaping behavior in games to lead to Nash equilibria? Can we expect them to lead to refinements of Nash equilibrium? We now have a good understanding of these questions.

Broadly speaking, the answer to the first is a statement of the form that "stable outcomes of evolutionary models are Nash equilibria." More detail would be required to make this summary statement precise, and there are a variety of settings in which it does not hold (see Hofbauer and Sandholm 2011 for a particularly strong example and Vega-Redondo 1996 for an example pertaining to the duopolists of Figure 1). However, precise versions of this result have appeared in a wide variety of models and settings (Samuelson 2002). Consequently, the consensus is that economists working with game theoretic models can devote attention to Nash equilibria confident that, in the appropriate circumstances, there are foundations for this convention.

The answer to the second question is negative—evolutionary models do not consistently lead to any of the standard refinements of Nash equilibrium, much less produce a consensus on what a useful refinement might be. The point of departure for equilibrium refinements is the presumption that players in a game will not select weakly dominated strategies.[7] For example, in two-player games, refining the Nash equilibrium concept by stipulating that players avoid weakly dominated strategies leads to the concept of a perfect equilibrium, one of the first and most important equilibrium refinements. Elsewhere the relationship between weak dominance and equilibrium refinements is more subtle, but the spirit of weak dominance still permeates the refinements literature. However, evolutionary dynamics do not routinely eliminate weakly dominated strategies (for example, Samuelson 1993).

On the strength of these insights, evolutionary game theory has moved off center stage, while game theory itself remains inextricably woven throughout economics.

Challenges for Game Theory

We discuss here three central challenges facing game theory.

Equilibrium Selection

Games often have multiple equilibria. This can be true of the simplest games, with only two players and only two actions per player. For example, people drive on the right side of the road in some countries and drive on the left in others. The obvious way to model this behavior is as a coordination game. It is natural to think of payoffs that make it a best response for any given player to drive on the

[7] See footnote 3 for a definition of weak dominance.

right as long as others do so, and similarly to drive on the left as long as others do, giving two equilibria (plus a mixed equilibrium in which each driver chooses to drive on the left with probability one-half and to drive on the right with probability one-half, though this mixed equilibrium is presumably not helpful in describing driving behavior).

There is nothing exceptional about this case—many games give rise to multiple equilibria. McLennan (2005) shows that standard normal-form games can have enormous numbers of equilibria, while Ledyard (1986) shows that any undominated behavior can be rationalized as the equilibrium of a coordination game. One need not generalize the Cournot duopoly very far beyond the linear demand and cost functions of Figure 1 to obtain multiple equilibria. Multiple equilibria even more obviously arise in repeated games, such as a repeated version of the Cournot duopoly, where, as noted earlier, a collection of "folk theorems" tell us that if the players in such a game are sufficiently patient, then almost any outcome can be an equilibrium (Fudenberg and Maskin 1986; Mailath and Samuelson 2006).[8] A common lament is that a theory that predicts anything can happen has no predictive power at all. Continuing in this vein, concern is sometimes expressed that the multiplicity of equilibria renders repeated games useless, if not game theory itself.

Game theory is not alone in giving rise to multiple equilibria. Many other economic models have multiple equilibria, reflected in such notions as liquidity traps or poverty traps, as well as in explanations for the Great Depression as an unfortunate equilibrium in a game with multiple equilibria (Cooper and John 1988). More strikingly, the Debreu–Mantel–Sonnenschein theorem gives us a result analogous to the folk theorem of repeated games: *any* continuous function satisfying linear homogeneity, Walras' law, and a "boundary condition" (that the quantity demanded of a good explodes as its price goes to zero) is an excess demand function of some economy (Debreu 1974; Mantel 1974; Sonnenschein 1973). Nonetheless, the response has not been a call to abandon the theory of competitive equilibrium, partly because one can find empirical content in general equilibrium models (for example, Brown and Kübler 2008; Brown and Matzkin 1996; Chiappori, Ekeland, Kübler, and Polemarchakis 2004), and partly because the welfare theorems provide useful insights despite the prospect of multiple equilibria.

One possible reaction is that the multiplicity of equilibria is more troubling in the case of game theory, or at least repeated games, than with competitive equilibrium. One often generates multiple outcomes in general equilibrium partly by varying the technology or preferences in the model. A repeated game more readily gives multiple equilibria despite holding the technology and preferences fixed. But this comparison masks other, countervailing differences. Competitive equilibrium models assume that agents perceive themselves to be negligible in the market.

[8] Slightly more precisely, for any payoff profile that is feasible in the stage game and that is individually rational, in the sense that there is no way for either player to guarantee that they receive a higher payoff, if the players are sufficiently patient, then there is an equilibrium of the repeated game giving that payoff.

Repeated games have no counterpart of this convention, and it is no surprise that one can construct more equilibria when given more degrees of freedom.

Multiple equilibria is not the only respect in which game theory has been troubled by an abundance of riches. Game theory seeped slowly into economics after its origins in the work of von Neumann and Morgenstern (1944) and Nash (1950a, b, 1951, 1953), but then the use of game theory in economics exploded in the 1980s. This burst of work began with articles, such as Rubinstein (1982), Kreps and Wilson (1982a, b), and Milgrom and Roberts (1982a, b), that demonstrated the power of (primarily noncooperative) game theory and served as the catalyst for an outpouring of work.

Industrial organization was a natural area of application for this work, and the result was a strategic revolution in industrial organization. A field that had been heavily empirical, seeking relationships between empirical measures of concentration and other structural features of an industry on the one hand and profits or other performance measures on the other, became enthusiastically theoretical. To see this change, one need only compare the Econometric Society World Congress lectures on industrial organization given by Weiss in 1969 (Weiss 1971), Schmalensee in 1980 (Schmalensee 1982), and Roberts in 1985 (Roberts 1987). Strategic models came to be used to explain price discrimination, advertising, entry deterrence, limit pricing, and a host of other phenomena. The difficulty was that an impression soon formed that a sufficiently determined modeler could construct a model explaining any behavior, no matter how counterintuitive. Here was another version of a folk theorem, pertaining not to a specific model such as a repeated game, but to a modeling approach. A common view is that a successful tool must exclude as well as include certain behaviors, and as a result the strategic revolution in industrial organization did not maintain its momentum.

How will we make progress on equilibrium selection in games? One response is to focus on results that depend only on the presumption that *some* equilibrium is chosen, without being specific as to which equilibrium. For example, one reason economists are comfortable with multiple equilibria in a competitive economy is that the first welfare theorem applies to all equilibria. This allows basic results in welfare analysis to be established that do not depend on which of possibly many competitive equilibria might be relevant. At this point, however, game theory has not produced functional equivalents of the welfare theorems.

A second possibility is to let empirical methods point the way to an equilibrium. The emphasis on strategic models in industrial organization has given way to a current emphasis on structural empirical models, as seen in the 2010 Econometric Society World Congress lectures on industrial organization given by Bajari, Hong, and Nekipelov (2013) and Aguirregabiria and Nevo (2013). Papers in this area often consider models that admit multiple equilibria and respond by assuming that the observed behavior reflects *some* equilibrium, and that this same equilibrium is reflected consistently throughout the data. This is typically enough to proceed, with the results providing clues not only about the structure of the game but also about the resulting behavior.

Yet another possibility is to note that in some cases, models with multiple equilibria may provide the best match for the interaction being studied, and we should embrace the multiplicity rather than endeavor to abolish it from our models. In the bank run scene from the 1946 film *It's a Wonderful Life*, George Bailey (played by James Stewart) gives an impassioned speech that a game theorist might reasonably paraphrase as, "There are two equilibria to this game, one in which the bank fails and one in which it survives, and we should endeavor to have the latter." Diamond and Dybvig (1983) capture this intuition in a model that relies crucially on the presence of multiple equilibria. A large subsequent literature has developed this idea.

In many other applications of game theory, however, results hinge on selecting a particular equilibrium for study. Progress in dealing with multiple equilibria will then require taking the instrumental rather than classical view of game theory quite seriously. In the instrumental view, the choice of equilibrium concept, and indeed the choice between multiple equilibria satisfying that concept, is part of the construction of the model, and should be informed by the details of the application one has in mind. If one is modeling an encounter between two agents that have limited experience and knowledge of one another, such as the president of the United States and a Middle Eastern dictator suspected of harboring weapons of mass destruction, a restriction to rationalizable strategies may be too demanding. Instead, one might reasonably question whether the participants are rational, much less whether it is common knowledge that they are rational. On the other hand, we have no difficulty applying Nash equilibrium, and even applying a particular Nash equilibrium, in settings where the participants have enough historical or cultural experience with the game. We take it for granted that people will drive on the left in the United Kingdom and on the right in the United States.[9] Backward induction is a reasonably reliable expectation when games are played by chess grandmasters, but less so when played by ordinary undergraduates (Palacios-Huerta and Volij 2009).

Suppose the two duopolists of Figure 1 are considering entering a market in which production is costly. Staying out of the market gives either firm a payoff normalized to be zero. The market demand function is such that a firm who is the sole entrant—no matter which one—earns a monopoly profit of one. However if both firms enter, they each lose one. This "entry game" has three Nash equilibria. Two of them are asymmetric but pure equilibria, in which one firm enters and the other firm does not. The third is a symmetric, mixed equilibrium in which each firm enters with probability half. If played by unacquainted strangers with no contextual clues and no asymmetries in the environment or the presentation of the game, perhaps in a laboratory, we would have no reason to expect one of the pure equilibria to appear. If play is to resemble an equilibrium, it will have to be the mixed equilibrium. However, when studying entry decisions on the part of two

[9] This observation may seem trivial, but it does not arise out of Harsanyi and Selten's (1988) analysis of equilibrium selection under the classical view of game theory, which denies itself any help that might come from the context in which the game is played.

firms, we might much more reasonably expect a pure equilibrium. In the latter case, the actual entry process is complicated and dynamic, and some institutional details—one firm got there first, or has cost synergies arising out of a better developed distribution network, or something else—will allow the firms to coordinate on what looks like a pure equilibrium in the static model. Which pure equilibrium? Like the distinction between the mixed and pure equilibria, this depends on details that have been left out of the game, but that should be incorporated in the model by choosing an equilibrium in light of the modeler's study of the institutional details.

These institutional details will typically involve elements of history that have been omitted from the description of the game. The model of the game makes no mention of whether the players are encountering the game for the first time, or have a personal or cultural history with the game. The strategies in the mathematical representation of the game are typically given neutral labels. In practice these strategies correspond to actions that are interpreted in light of the personal and cultural context of the game. As Schelling (1960) vividly illustrates, this context can have an almost magical effect in distinguishing between the various equilibria of the game.[10] Classical game theory views the specification of the model as straightforward, and focuses on what to do once one has the model. Under instrumental game theory, the specification of the model takes center stage. This specification requires an understanding of the application, setting, and history of the game, all of which should inform the specification not only of the game but also of the choice of equilibrium concept and equilibrium.

Considerable work remains to be done on identifying both which equilibrium concept we should be using and which of the potentially many equilibria consistent with that concept should command our attention. John Maynard Keynes remarked (in a letter to Roy Harrod written in 1938, reproduced as letter 787 in Besomi 2003) that, "Economics is the science of thinking in terms of models joined to the art of choosing models which are relevant to the contemporary world." Graduate courses in economics tend to focus on the science of working with models. Progress on equilibrium selection will come from careful work on the art of choosing models. This is a joint choice involving both the game and the relevant equilibrium, and will typically depend on the setting to which the analysis is to be applied.

[10] Schelling (1960) introduces the concept of a focal point, to capture the idea that the context in which a game is played often affects expectations and behavior in the game. For example, Schelling considers the case of two people who have fixed a day to meet in New York City, but have said nothing about either the time or location. The abstract representation of the game provides no way to distinguish different times and locations, and hence no hope that the two will actually meet. Schelling reports that in informal surveys, nearly every respondent indicated that they would attempt to meet at noon, and a majority chose Grand Central Station (perhaps reflecting the time in which the book was written) as a location. A large literature has subsequently grown around the idea of focal points (for example, Binmore and Samuelson 2006), but there is still much work to be done, as is reflected in Schelling's remark (at the Arne Ryde Conference held in his honor in Lund, Sweden on August 23, 1997) that the theory of focal points has done more for game theory than game theory has done for the theory of focal points.

Applications

Game theory is much more successful in some applications than others. Two of the obvious successes of game theory are auctions (for example, Klemperer 2004; Krishna 2002; Milgrom 2004) and matching (for example, Roth 2008a, b, 2015). Research in these areas has produced not only a rich body of new theoretical results, but has also transformed the way that resources are allocated in a wide variety of markets. Resources that governments used to give away are now routinely auctioned, with significant implications for government revenue and, perhaps more importantly, for the efficient allocation of resources. Auctions have become a common mechanism for firms to price their products, including relatively new products such as online advertising opportunities, but also quite familiar products such as electricity. New entrants in a variety of professional fields are now allocated to employers via matching algorithms, as are students allocated to schools. As applied to the "market" for matching suitable kidney donors to recipients, one could argue that matching theory has saved thousands of lives.

The result has been a flourishing new field of market design, which might be described as the application of game theoretic models, insights, and intuition to the solution of practical resource allocation problems. Economists are fond of market tests, and in the form of market design, game theory has clearly passed a market test of its usefulness. Designing markets and advising the participants in these markets now presents brisk employment opportunities for game theorists.

Other applications of game theory have been less successful in such market tests, with perhaps the leading example being the theory of bargaining. Edgeworth (1881, pp. 20–30) identified the bargaining problem as the basic point of departure for studying economics. Nonetheless, for decades afterwards, it was common to say that we might expect bargaining outcomes to be efficient, but that economic reasoning was not helpful in identifying which of the typically many efficient outcomes might appear. Game theory staked its claim to bargaining early. Two of Nash's quartet of early papers (Nash 1950b, 1953) addressed the bargaining problem. Rubinstein's (1982) analysis of bargaining played a role in spurring the use of game theory in economics. A new literature on bargaining followed (for a summary, see Muthoo 1999). However, game theory has not had the same success in bargaining that it has had with auctions or matching. One cannot easily point to examples where bargaining methods have been overhauled in response to game theoretic insights. Game theorists routinely bring game theoretic models to bear when called upon for advice concerning auctions and matching processes, but are less likely to appeal to game theoretic models when consulted on bargaining problems.

A common concern about game-theoretic models of bargaining is that the outcomes are too sensitive to fine details of the model. The timing of offers and counteroffers, the specification of the information structure, the length of the horizon, the length of a time period, and other details can all have an important effect on the outcome. For a striking example, Shaked (1994) shows that it can make an important difference whether one party to the bargaining process can quit the game *before* or *after* hearing a counteroffer from the other side. It is seldom clear when examining an interaction between a union and a firm or between political groups in the Middle East whether we should model this as a discrete or continuous time game, a rigidly alternating offers game or a game in which either side can make an offer at any time, and so on. Given a choice from a collection of models that give sharply different results, with little guidance as to which is appropriate, it is not surprising that one might avoid using such models.

This explanation for the limited role of game theoretic analysis in bargaining does not tell the whole story. Modeling an auction also gives rise to a seemingly endless series of choices—are values common or idiosyncratic, are the bidders risk neutral or risk averse, is there a resale market, will the bidders collude, are the bidders symmetric, and so on—again without definitive indications as to which is the obvious modeling choice. The difference appears to be a belief that auction models have come sufficiently close to isolating the essential features of an auction, and auction theorists have sufficiently honed their intuition in the course of working with such models, that the models are useful tools in designing, running, and participating in auctions. It is less clear that bargaining models have isolated the essential features and allowed us to sufficiently hone our intuition. The basic tradeoff in a model of a first-price auction is clear—shading one's bid below one's valuation makes the outcome more lucrative if one wins, but makes one less likely to win. This appears to be a first-order effect in many auctions. The basic feature highlighted in most bargaining models is patience, with less-patient people being in a weaker bargaining position. It is less obvious that patience is typically a first-order effect in bargaining,

As is the case with economic theory, much of the progress in game theory comes not from the science of applying models, but from the art of formulating them. Game theory has hit upon extraordinarily useful models in some areas, but has been less successful in others. One hopes this means that there are still important discoveries ahead for game theory.

Cooperative Game Theory

Noncooperative game theory assumes that players act independently, with the central question being whether a player can gain from a unilateral deviation. Cooperative game theory assumes that players can form coalitions, with the central question being whether a collection of players can find a (binding) allocation of the payoffs available to the coalition that would allow them all to gain from forming the coalition. Figure 1 is an example of the noncooperative approach to a Cournot duopoly, which assumes the two firms choose their outputs simultaneously and independently. A cooperative approach would recognize that both firms could do better by forming a coalition and splitting the resulting monopoly profits.

The early work in game theory was dominated by cooperative game theory: for example, von Neumann and Morgenstern's (1944) *Theory of Games and Economic Behavior* devoted much of its attention to cooperative games. One of the fundamental results in general equilibrium theory, the Debreu–Scarf theorem (Debreu and Scarf 1963), offering a precise version of the intuition that a large economy should be essentially a price-taking economy, is based on the (cooperative) notion of the core.[11] The Shapley value (Shapley 1953) has proven to be useful in studying the power of political coalitions (as in Winter 2002) and more practically in solving cost-allocation problems (Young 1994).[12] The "nucleolus" (Schmeidler 1969) has attracted attention for (among other things) unexpectedly turning out to explain a bankruptcy prescription from the Talmud (Aumann and Maschler 1985), solving a problem that had remained the subject of discussion and contention for millennia.[13] There are many other examples.

More recently, cooperative game theory appears to have disappeared from economics. First-year graduate theory courses routinely cover the basics of noncooperative game theory, but may not even mention the core. The classic texts that shepherded game theory into widespread use in economics, Fudenberg and Tirole (1991) and Myerson (1991), are weighted toward the discussion of noncooperative game theory. How can game theory avoid losing the tools and insights of cooperative games?

We can go back to the beginnings for the answer. Nash (1953) introduced what has since come to be called the "Nash program." In this paper, Nash presented a noncooperative bargaining game whose outcomes coincided with the Nash bargaining solution (an axiomatically motivated rule for sharing a surplus) that he had introduced earlier (Nash 1950b). Work in a similar vein has subsequently provided noncooperative foundations for the core (Perry and Reny 1994), the Shapley value (Gul 1989), and the nucleolus (Shubik and Young 1978). The idea of the Nash program is that one should combine the cooperative and noncooperative approaches. Our understanding of a cooperative solution concept is bolstered by examining the noncooperative games that lead to such a concept. Our understanding of noncooperative games is bolstered by a cooperative characterization of their outcomes. Both directions are important. We understand best and can most usefully apply concepts that can be given both cooperative and noncooperative foundations.

Recent work in matching has brought the Nash program back into the mainstream (for an introduction, see Roth and Sotomayor 1990). The basic equilibrium concept in this literature is that of a stable match. When matching students to schools, for example, stability requires that there should be no student and school who are currently unmatched and who have the property that the student prefers the school to her current match and the school would rather have the student than one of their existing students (or an empty seat). This is a cooperative equilibrium concept, closely related to the idea of the core, as it revolves around the requirement that there be no two-person blocking coalitions (with larger coalitions coming into play in more complicated matching environments). However, the standard

[11] A specification of payoffs for the players in a game is in the core of that game if there is no "blocking" coalition that can form and distribute its payoffs in such a way as to make all of its members better off.

[12] Intuitively, the Shapley value is a specification of payoffs that allocates to each player in a game the average of the marginal contributions that the player makes to the various coalitions that might form.

[13] Intuitively, the nucleolus is the allocation in which the coalition that is least happy about its share of surplus is at least as happy as possible.

route to proving the existence of a stable allocation is to construct a noncooperative process, such as the deferred acceptance algorithm, that leads to stable allocations (Gale and Shapley 1962).[14] Indeed, the deferred acceptance algorithm lies at the heart of the processes used to implement outcomes in the many matching markets that have recently been transformed by applications of game theory. We are left doubly confident of the procedure, with the cooperative lens confirming that it leads to outcomes with attractive properties and the noncooperative lens ensuring that one gets there via an intuitive procedure.

The Nash program thus holds out the promise of combining the best of cooperative and noncooperative game theory. However, considerable work remains if we are to realize the potential of this approach. In some cases, it will require new work in cooperative game theory. Noncooperative game theory has been especially fruitful in examining problems of incomplete information, an area in which cooperative game theory has not been particularly active (for a recent step in this direction, see Liu, Mailath, Postlewaite, and Samuelson 2014). In other cases, as Binmore, Rubinstein, and Wolinsky (1986) point out, implementing the noncooperative component of the Nash program requires considerable care. In yet other cases, the approach has not produced immediate gains. For example, one can view the research on "renegotiation proofness" as an attempt to use cooperative ideas, namely that players should not be content with a continuation equilibrium whose payoffs are Pareto dominated by an alternative continuation equilibrium (and hence is blocked by a coalition of the whole), to select equilibria in a repeated game. Applications of renegotiation proofness have been hindered by the specter of multiple notions of renegotiation proofness. For an introduction to this issue, see Mailath and Samuelson (2006, Chapter 4.6); for a recent alternative perspective, see Miller and Watson (2013).

Prospects and Directions

Game Theory beyond Economics

We live in what might be called the imperial age of game theory, in which game theory has become influential in an ever-growing variety of other disciplines. Game theory is now a standard tool in political science. For example, McCarty and Meirowitz (2007) provide a book-length overview of how game theory can be used to examine the relations between countries, the behavior of political parties, electoral behavior, the workings of legislatures, lobbying, and so on. For an earlier

[14] For example, consider a male–female marriage market and the "men-proposing" version of the deferred acceptance algorithm. Each unmarried man proposes to the woman who is his first choice. Each woman who receives at least one proposal holds her most-preferred proposal and rejects the rest. In the next round, each man who has been rejected then proposes to his top preference among the women to whom he has not yet proposed. A woman who receives proposals in this round holds her most-preferred proposal, whether it is a new one or one held from the previous round, and rejects the rest. Successive rounds follow. In a finite number of rounds, this process reaches a stable allocation, at which point no more offers are made, and the current portfolio of held proposals is accepted.

application of game theory insights to political economy issues, economists will of course think of the work of Elinor Ostrom (for example, 1990) on governing a commons. Ostrom's graduate training was in political science, although she shared the Nobel Prize in economics in 2009. Game theoretic analysis is now common in law: for book-length overviews, see Baird, Gertner, and Picker (1994) and Zaluski (2015). Game theory appears in the study of philosophy, especially ethics, with Binmore (1994, 1998) on *Game Theory and the Social Contract*, Gauthier (1986) on the foundation of moral norms, and Skyrms (2004) on the evolution of social structure offering good examples. Psychologists, especially experimental psychologists, have turned to game theory, with Colman (1999) presenting an overview of *Game Theory and Its Applications in the Social and Biological Sciences*, as have neuroscientists (for example, Glimcher, Camerer, Fehr, and Poldrack 2009). Perhaps the greatest empirical success of game theory is in biology, with Maynard Smith and Price (1973) and Maynard Smith (1982) being the obvious point of departure, while Broom and Rychtář (2013) provide a more recent book-length overview of *Game-Theoretical Models in Biology*. Hammerstein and Riechert (1988) is a particularly striking application of a game-theoretic analysis of two populations of desert spider. Under the guise of algorithmic game theory, game theory has spread throughout computer science (for example, Nisan, Roughgarden, Tardos, and Vazirani 2007). Game theory has become a standard tool in electrical engineering, as seen in Lasaulce and Tembine's (2011) *Game Theory and Learning for Wireless Networks*. Game theory has been influential in operations research, as seen in the prevalence of game theory papers in *Operations Research* and *Mathematics of Operations Research*, and has moved into other areas of business schools, such as accounting and marketing.

As remarkable as the breadth of the disciplines that have felt the reach of game theory is the breadth of agents who have appeared in game theoretic models. Behind the rather bland moniker of "players" one can obviously find people, but can also find firms, unions, political parties, and countries. One can find parts of people, in the form of cells and neurons. One can find plants and animals stretching from the most intelligent to the lowliest of microorganisms. One can find mechanical devices, such as switches and routers in distributed information-processing systems. Notice that many of these interpretations of a player are clearly incompatible with a classical conception of a player as a rational actor, or with the view of a player being able to deduce the equilibrium implications of a game. As game theory has spread beyond economics, it has necessarily moved every more firmly into the instrumental camp. Game theory appears to be on its way to becoming not just the language of economics, but the language of the social sciences, and perhaps beyond.

A New Home for Game Theory?

The first hints of game theory appeared in mathematics, including Cournot's (1938) analysis of duopoly, Zermelo's (1913) examination of finite games of perfect information, and Borel's formulation of the notion of a strategy and of zero sum games (Dimand and Dimand 1992, pp. 18–23).[15] When game theory was established as a field of study in the 1940s and early 1950s, it was pursued primarily within mathematics (for an accessible history of game theory, see Leonard 2010).

The situation is now reversed. It is a rare department of mathematics that offers a course in game theory. In contrast, every first-year graduate sequence in economic theory includes a substantial amount of game theory, and undergraduate and graduate game theory courses are common in economics departments. This shift from associating game theory with mathematics to economics is reflected in the journals. Following the appearance of the *International Journal of Game Theory* in 1971, the next journal devoted to game theory was *Games and Economic Behavior*, first appearing in 1989 and building the link to economics into its title.

Should game theory be housed in economics? The answer is not obvious. On the one hand, the interaction between economic applications and basic results in game theory has been particularly fruitful. Many of the advances in game theory have been motivated by particular economic applications. The study of duopoly in Cournot (1838) gave rise to a precursor of the idea of Nash equilibrium. Later, von Stackelberg's (1934) examination of duopoly gave rise to a precursor of backward induction. Friedman's (1971) study of collusion gave rise to a precursor of the folk theorem. Edgeworth's (1881, pp. 34–56) consideration of competitive markets gave rise to an early counterpart of the core. Such interactions may be sufficiently fruitful that game theory is most efficiently studied within economics.

On the other hand, as we have noted, game theory is becoming increasingly influential in a variety of disciplines beyond economics. It is presumably inefficient to have a community of people within each discipline working independently on related problems in game theoretic techniques. There may be economies of scale to be gained from establishing departments of game theory. If one is convinced of the virtues of interdisciplinary work and inclined to create new academic structures to foster such work, then game theory may be a prime target.

The Future

What does the future hold for game theory in economics? It seems a safe bet that game theory will continue to be the language of economics. It appears to be an equally safe bet that new areas of inquiry in economics will both make use of game theory and leave their mark on game theory. For example, one of the most striking recent developments in economics has been the advent of behavioral economics (for example, Cartwright 2014). From its beginnings, behavioral economics has provided new ground for the application of game theory. Strotz (1955–56) noted that dynamic utility maximization problems could give rise to inconsistencies, with a single person at different times effectively being different selves with diverging interests. Game theory provides the tools to examine the interaction between these

[15] Borel wrote a series of papers on game theory between 1921 and 1927. The most accessible point of entry for these papers is *Econometrica's* publication of three of them, translated by Leonard Savage and with a commentary by John Von Neumann (Borel 1953a, b, c).

multiple selves. However, behavioral economics has much more to offer beyond multiple selves, and the new behavioral insights are finding their way into "behavioral" game theory (Camerer, Loewenstein, and Rabin 2004; Camerer 2003). Once again, we see a fruitful interaction between economics and game theory, with each leaving its mark on the other.

■ *I thank Ken Binmore, Scott Kominers, and the editors of the* Journal of Economic Perspectives *for helpful comments and discussions. The views expressed in this essay have been shaped by years of work with many extraordinary coauthors, to whom I am immensely grateful. I thank the National Science Foundation (SES-1459158) for financial support.*

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Journal of Economic Perspectives—Volume 30, Number 4—Fall 2016—Pages 131–150

New Directions for Modelling Strategic Behavior: Game-Theoretic Models of Communication, Coordination, and Cooperation in Economic Relationships

Vincent P. Crawford

Half a century ago, before the game-theoretic revolution that began in the 1960s and 1970s, economics largely lacked the tools to analyze strategic interactions. There was clearly a perceived need for such tools, and considerable excitement had greeted the publication of von Neumann and Morgenstern's *Theory of Games and Economic Behavior* (1944, 1947, 1953). But despite the initial excitement, for several decades game theory remained mostly a branch of mathematics, whose economic applications were the work of a few pioneers, such as Nash (1950, 1953), Schelling (1960), Shapley and Shubik (1954, 1971), and Shubik (1959). Some economists, making a virtue of presumed necessity, claimed that questions involving strategy or information were unimportant. A memorable example is Rothschild's (1973, p. 1283) quoting of a "prominent" colleague: "The friction caused by disequilibrium and lack of information accounts for variations in the numbers we observe at the fifth or sixth decimal place. Your stories are interesting but have no conceivable bearing on any question of practical economic interest."

Finally, in the 1960s, 1970s, and 1980s, game theory began to change the landscape of economics. If economists from that time could examine a modern graduate microeconomics text (such as Mas-Colell, Whinston, and Green 1995—still thoroughly "modern"), they would find their theories of market competition transformed beyond recognition, with rich, explicit game-theoretic analyses of preemption and

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† For supplementary materials such as appendices, datasets, and author disclosure statements, see the article page at
http://dx.doi.org/10.1257/jep.30.4.131 doi=10.1257/jep.30.4.131

entry deterrence; signalling and screening with asymmetric information; competition via explicit and/or implicit contracts; and platform and network competition. They would also find unfamiliar but flourishing subdisciplines on game-theoretic topics such as auctions; bargaining and coordination; agency and contract theory; strategic communication; social choice; public goods; cooperation in long-term relationships; and design of markets and other institutions. Such analyses, whose strategic aspects had made them seem intractable, now make up most of the microeconomics core in leading graduate programs. In the 21st century, game theory has fulfilled a large part of its promise, giving systematic, illuminating analyses of many central questions. Indeed, game theory has also begun to unify the rest of the social sciences, transforming parts of political science, computer science, and evolutionary biology—though not yet having as much effect on anthropology, sociology, or psychology.

Although most of the research that revolutionized game theory was done by economists, the revolution was not primarily a question of economics coming to game theory. Rather, game theory and economics coevolved, with game theory supplying a precise and detailed language for describing strategic interactions and a set of assumptions for predicting strategic behavior, while economics contributed questions and intuitions about behavior against which game theory's predictions could be tested and improved. In the process, the research frontier shifted from the earlier stages of figuring out how to model economic interactions as games and getting the logic of rational strategic behavior right to a later emphasis on relaxing unnecessary restrictions and refining behavioral assumptions. As game theory enriched economics, economics drove adaptations of game theory's assumptions and methods, transforming it from a branch of mathematics with a primarily normative focus into a powerful tool for positive economic analysis with a mainly descriptive or predictive focus.

In this paper, I discuss the state of progress in applications of game theory in economics and try to identify possible future developments that are likely to yield further progress. To keep the topic manageable, I focus on a canonical economic problem that is inherently game-theoretic, that of fostering efficient coordination and cooperation in relationships, with particular attention to the role of communication. I thus favor microeconomics, omitting important macroeconomic applications of game theory such as Summers (2000), Garcia-Schmidt and Woodford (2014), and Evans and McGough (2015), whose discussions of financial crises and expectations formation nonetheless touch on some of the game-theoretic issues discussed here. I also favor noncooperative game theory, omitting notable successes of cooperative game theory.[1] I further narrow the focus to problems specific to game theory

[1] The established terms "noncooperative" and "cooperative" game theory are misnomers, in that, paradoxically, noncooperative game theory is better suited to explaining (as opposed to assuming) cooperation than cooperative game theory. Noncooperative game theory starts with a detailed model of the structure of a game and makes specific assumptions about how rational players will respond to it. Cooperative game theory starts instead with a general description of the structure, sidestepping most details, and makes general assumptions intended to characterize the possible outcomes of frictionless bargaining among rational players. A notable economic application of cooperative game theory is the

by assuming that individuals are rational in the decision-theoretic sense of choosing strategies that are best responses to consistent beliefs.

I begin with an overview of noncooperative game theory's principal model of behavior, *Nash equilibrium*, henceforth shortened to *equilibrium*. I next discuss the alternative "thinking" and "learning" rationales for how real-world actors might reach equilibrium decisions. I then review how equilibrium has been used to model coordination, communication, and cooperation in relationships, and discuss possible developments. Throughout the paper, I make no attempt at comprehensive coverage or referencing, with apologies to those whose work is slighted.

The Notion of Equilibrium in Noncooperative Game Theory

Equilibrium is defined as a combination of decision rules or *strategies*, one for each decision maker or *player*, in which each player's strategy maximizes her/his personal expected utility or *payoff* given the strategies of others who are deciding in the same way. The generality, tractability, and precision of equilibrium analysis have made it the method of choice in most economic applications of game theory (Myerson 1999). However, equilibrium goes well beyond the notion of rationality of individual decisions in that it requires a particular relationship among players' strategies. How players' strategies might come to be in equilibrium is a difficult question, which is still on the research frontier and which is intimately related to the question of how players can foster coordination and cooperation in relationships, as explained below.

Consider the game in Figure 1, in which the players choose their moves simultaneously and it is assumed that the game's structure is known to the players as *common knowledge*, in the sense that each player knows the structure, including what the other knows; knows that the other knows the structure; and so on.

This game has a unique equilibrium, in which the Row player (whose payoffs are in the lower-left corners of the cells of the matrix) chooses the strategy Middle and the Column player (whose payoffs are in the upper-right corners) chooses Center. To see this, note that if Row chooses Middle, Column will look across the choices of Left, Center, or Right, and see that Center then has the highest payoff (its two is better than the zeros for Left or Right). Further, if Column chooses Center, Row will look across the choices of Top, Middle, or Bottom, and see that Middle then has the highest payoff (its two is better than the zeros for Top or Bottom). The outcome of {Middle, Center} is therefore an equilibrium. The reader can confirm that, starting

theory of matching markets, which uses game-theoretic notions like the core to model the outcomes of competition, with or without prices, among heterogeneous traders. For more on matching theory and applications, in the context of the Nobel Memorial Prize in Economic Sciences awarded to Lloyd Shapley and Alvin Roth in 2012, see Economic Sciences Prize Committee of the Royal Swedish Academy of Sciences (2012).

Figure 1
Equilibrium and Rationalizability: A Dominance-Solvable Game

Column player

Row player

	Left	*Center*	*Right*
Top	0 7	5 0	3 0
Middle	0 5	2 2	0 5
Bottom	7 0	5 0	3 7

Note: This game has a unique equilibrium, in which the Row player (whose payoffs are in the lower-left corners of the cells of the matrix) chooses the strategy Middle and the Column player (whose payoffs are in the upper-right corners) chooses Center. A strategy choice is *strictly dominated* by another if it yields a strictly lower payoff regardless of what choice another may make. The game in Figure 1 is *dominance-solvable:* Row knows that Column is rational, and thus knows that Column will not play Right, which is strictly dominated by Center. In turn, Column knows that of the remaining choices, Row will not play Bottom, which is strictly dominated by Middle once Column's strategy Right is eliminated. Next, Row knows that of the remaining choices, Column will not play Left, which is strictly dominated by Center once Row's strategy Bottom is eliminated. The fourth step then leads precisely to the {Middle, Center} equilibrium.

from any other cell, holding one player's choice constant, the other would prefer to switch to a different choice, so {Middle, Center} is the only equilibrium.[2]

However, just knowing that {Middle, Center} is the unique equilibrium is not enough to ensure that rational players will make those choices. Suppose players have possibly probabilistic beliefs about each other's strategy choices. Then in the game in the first panel, a rational Row will play Middle only if Row's beliefs assign high enough probability to Column playing Center. Conversely, if Row's beliefs assign high probability to Column's choosing Left or Right, then Row will be tempted to play Top or Bottom. By contrast, a rational Column will never play Right, because for Column that choice is *strictly dominated,* meaning that for Column, Right yields a strictly lower payoff than Center, without regard to Row's strategy choice. But a rational Column might play Left, if Column's beliefs assign high probability to Row's choosing Bottom.

How can this ambiguity of rationality-based predictions be resolved?[3] One common approach is to strengthen the rationality assumption by making players' rationality (in addition to the structure of the game) *common knowledge,* in the sense that all players are rational, all know that all are rational, and so on ad infinitum.

[2] I ignore randomized, or *mixed,* strategies throughout the paper, and they are irrelevant to the points I make here.
[3] Manski (2003) has argued that economists should be tolerant of ambiguous predictions or as he calls them, *incomplete models.* However, his main focus is on modelling individual decisions. In games, ambiguous predictions of individual decisions frequently "multiply up" to create severe ambiguity of predicted game outcomes (Aradillas-Lopez and Tamer 2008).

Figure 2
Equilibrium and Rationalizability: A Unique Equilibrium without Dominance

Column player

Row player	*Left*	*Center*	*Right*
Top	0 7	5 0	7 0
Middle	0 5	2 2	0 5
Bottom	7 0	5 0	0 7

Note: Like the game of Figure 1, this game also has the unique equilibrium of {Middle, Center} (Row player choses Middle and Column player chooses Center). However, this problem cannot be solved by iterated strict dominance.

Common knowledge of rationality does in fact yield a unique prediction in the game in Figure 1, which is *dominance-solvable*—meaning if players eliminate their strictly dominated strategies, and after that, their strategies that become strictly dominated once others are eliminated, and so on, the game gradually reduces to one in which only the unique equilibrium choices remain. The logic of the argument works like this: Row knows that Column is rational, and thus knows that Column will not play Right, which is strictly dominated by Center. In turn, Column knows that of the remaining choices, Row will not play Bottom, which is strictly dominated by Middle once Column's strategy Right is eliminated. Next, Row knows that of the remaining choices, Column will not play Left, which is strictly dominated by Center once Row's strategy Bottom is eliminated. The fourth step then leads precisely to the {Middle, Center} equilibrium. In dominance-solvable games whose players have more strategies, such epistemic reasoning may go on even longer before reaching equilibrium.

Now consider the game in Figure 2. It also has a unique equilibrium: If Row plays Middle, then the best choice for Column is Center; and if Column plays Center, the best choice for Row is Middle. But in that game, no choice is strictly dominated for either player, and so, even with common knowledge of rationality, epistemic logic alone does not narrow the possibilities down to a single outcome. In fact, for any strategy combination in this game, one can construct a "tower" of beliefs to show that it is consistent with common knowledge of rationality. A rational Row, for instance, might play Top because of a belief that Column will play Left (hoping for the high payoff of 7), while a rational Column might play Left because of a belief that a rational Row will play Bottom (hoping for the high payoff of 7). Some beliefs that are consistent with common knowledge of rationality lead to the equilibrium, but most do not.

More generally, Bernheim (1984) and Pearce (1984) showed that common knowledge of rationality, with no further restrictions on beliefs, implies only that each player's strategy is *rationalizable*, which can be iteratively defined as follows. A *1-rationalizable* strategy is one for which there is some profile of others' strategies that makes it a best response; a *2-rationalizable* strategy is one for which there is a profile of others' 1-rationalizable strategies that makes it a best response; and so on. A rationalizable strategy is then one that is *k*-rationalizable for all *k*. In the game in Figure 1, the choices of Middle for Row and Center for Column are both 4-rationalizable, referring to the four steps in which the players eliminate various choices via *iterated strict dominance*; and four rounds of iterated strict dominance identify the unique equilibrium. In the second game (Figure 2), all of each player's strategies are *k*-rationalizable for all *k*, and the equilibrium cannot be identified by iterated strict dominance, even though it is also unique.

The dominance-solvability of Figure 1's game is atypical in applications, as indeed is the uniqueness of the equilibrium in the games of Figure 1 and 2. As the examples suggest, equilibrium is a much stronger behavioral assumption than the rationalizability that follows from common knowledge of players' rationality. It also requires that players' beliefs be coordinated.

Equilibrium via Thinking or Learning

If epistemic arguments based on common knowledge of rationality do not justify the coordination of players' beliefs or strategies required for equilibrium, how might it be justified? Assuming for simplicity that the structure of the game is common knowledge and that the players know that each other is rational, it is useful to sort applications into two groups according to the most plausible rationale for equilibrium: "thinking" applications, in which players can plausibly reason their way to an equilibrium; and "learning" applications, in which it is plausible that players who adjust their strategies adaptively will converge over time to some equilibrium. The rationale for assuming equilibrium affects the credibility of assuming equilibrium in applications, so I now discuss each approach.

Thinking Applications

In thinking (as opposed to learning) applications, players play a game with no prior experience with analogous games. If assuming equilibrium is justified, it must then be because players can reason their way to equilibrium beliefs and strategy choices. In theory, this is possible if there is a commonly known principle that focuses players' beliefs on a unique prediction, because in the standard framework such common knowledge implies that their beliefs must be the same, and therefore, given rationality, in equilibrium. (For a good introduction to epistemic game theory in this journal, see Brandenberger 1992.) In this view, equilibrium becomes an *equilibrium in beliefs*, in which rational players' beliefs are statistically correct, given the best responses they imply.

Applications for which the thinking justification for equilibrium is behaviorally plausible are limited because in all but the simplest games the reasoning it requires is dauntingly complex. In Figure 1's dominance-solvable game, such reasoning requires four iterative rounds; and in the second, Figure 2, game, finding the equilibrium requires what is called "fixed-point reasoning," whereby players' strategy choices are justified as best responses to others' choices in a *two-way* recursion. (That is, one player's choice is a best response to the other's, and vice versa; dominance reasoning is also recursive, but only one-way.) In experiments that elicit subjects' initial responses to games, and that separate fixed-point and other kinds of strategic reasoning, subjects rarely follow fixed-point reasoning or indefinitely iterated dominance (Crawford, Costa-Gomes, and Iriberri 2013, Section 3). It is sometimes suggested that experienced decision makers will nonetheless use fixed-point reasoning when the stakes are high, but I have yet to find even anecdotal evidence that quants or artificial intelligence analysts of poker use reasoning that subtle.

Equilibrium reasoning becomes still more complex when the game has multiple equilibria. The logic of epistemic equilibrium-in-beliefs requires a selection among equilibria because a player who is unsure which equilibrium others have in mind will not generally find it rational to play her or his part of any particular equilibrium. Further, many important applications have multiple *strict* equilibria, in which each player has a strict preference for a strategy given others' strategies; in which case, unique equilibrium selection requires common knowledge of a complex *coordination refinement,* designed (unlike most equilibrium refinements) to discriminate among such strict equilibria. The leading examples of such refinements are from Harsanyi and Selten's (1988) classic work *A General Theory of Equilibrium Selection in Games*, which is part of the work for which they shared the 1994 Nobel prize in economics with John Nash. Their notion of *payoff-dominance* favors equilibria whose payoffs are not Pareto-inferior to those of other equilibria. Their alternative notion of *risk-dominance* favors equilibria with (roughly) larger "basins of attraction," that is, larger sets of beliefs that make their strategies best responses. Harsanyi and Selten showed that a logically consistent theory could be built on those foundations, with added tie-breaking devices, to select a unique equilibrium in any (finite matrix) game. It was a major achievement to show that such a theory could be constructed; but it rests on some unavoidably arbitrary choices and is complex enough to render it far from compelling, behaviorally (for discussion, see Aumann's "Foreword" to Harsanyi and Selten's 1988 book). But compellingness is essential in applications that involve thinking about multiple equilibria.[4]

How do people choose their strategies in thinking applications if fixed-point or indefinitely iterated dominance reasoning or equilibrium selection principles are too complex to focus their beliefs on an equilibrium? It may seem unlikely that any

[4] Some theorists believe the problem of equilibrium selection via thinking in games with multiple strict equilibria is settled by "global games" analyses (Carlsson and van Damme 1993). Such analyses add privately observed payoff perturbations to the original game in a way that makes the game dominance-solvable, and in simple coordination games makes the risk-dominant equilibrium in the unperturbed game the unique equilibrium. Although such analyses provide a systematic way to analyze how the information structure influences equilibrium selection, I believe they do not provide a conclusive argument for selecting the risk-dominant equilibrium, because the payoff perturbations are artificially introduced, and a behaviorally implausibly high number of rounds of iterated dominance are often needed to reach equilibrium in the perturbed game.

alternative model can predict observed behavior systematically better than a rational expectations notion such as equilibrium, or that such a model could be identified from among the enormous number of possible models. However, a growing body of experimental work surveyed in Crawford, Costa-Gomes, and Iriberri (2013, section 3) shows that subjects' initial responses to games often follow simple *level*-k (Costa-Gomes, Crawford, and Broseta 2001; Costa-Gomes and Crawford 2006) or *cognitive hierarchy* (Camerer, Ho, and Chong 2004) rules, in which players anchor their beliefs in a naive model of others' responses to the game and then adjust their beliefs by thinking through a small number of iterated best responses, a number which varies across players but with a stable population distribution. Such rules are decision-theoretically rational, and in sufficiently simple games they mimic equilibrium strategies. In more complex games, such rules may lead to outcomes that deviate systematically from equilibrium. Importantly, level-*k* or cognitive hierarchy models predict not only that deviations from equilibrium will sometimes occur, but also which settings are likely to evoke them, the forms they are likely to take, and their relative frequencies. When applied to games with multiple equilibria, with estimated population frequencies of rules, they predict selection among equilibria (or not), while avoiding the complexity of coordination refinements.

The literature on strategic thinking in initial responses to games is evolving rapidly, and level-*k* and cognitive hierarchy models are mentioned here not as the last word, but to illustrate that structural nonequilibrium models of strategic thinking are possible, and can be helpful.

Learning Applications

In learning applications, players have ample prior experience with closely analogous games. The learning process is modelled as repeated play of a given game, with the game that is repeated called the *stage game* and each stage game normally with a different partner.[5] Players' choices are modelled as *adaptive learning*, in which they adjust their stage-game strategies over time in ways that increase their own stage-game payoffs on the (usually false) assumption that others' stage-game strategies will continue as before. In adaptive learning models, players have a strong tendency to converge to some equilibrium in the stage game. There are few general theoretical results, but there is strong experimental support for such convergence.

Even if learning assures convergence to some equilibrium, nonequilibrium strategic thinking often remains relevant. Suppose that only long-run outcomes matter, but the stage game in the applications has multiple equilibria, as in many important applications. Then all we need from game theory is a reliable prediction of the prior probability distribution of the possible equilibrium outcomes. But with

[5] Unless players' partners vary across the stage games, repeated-game strategies are relevant, and it is implausible that players focus on their choices of stage-game strategies, stage by stage, as opposed to thinking about the effectiveness of their alternative repeated-game strategies. I ignore the literature on *rational learning* models, in which players are assumed to play an equilibrium in the repeated game that describes the entire learning process, because this approach seems less useful than adaptive learning models in applications (for example, Crawford 2001, Section 6.4.4).

multiple equilibria, learning dynamics are normally history-dependent, so people's initial responses influence limiting outcomes, as do the structures of their learning rules (Van Huyck, Cook, and Battalio 1997; Crawford 1995, 2001; Camerer and Ho 1998, 1999).[6] Moreover, even if the stage game has a unique equilibrium, analogies across games are rarely as close in applications as adaptive learning models assume, and analysis of the thinking needed to learn from imperfect analogies has just begun (Rankin, Van Huyck, and Battalio 2000; Van Huyck and Battalio 2002; Cooper and Kagel 2003; Samuelson 2001).

Communication, Coordination, and Cooperation in Economic Relationships

To perform well, an economic relationship must solve one or more strategic problems. For example, players may face *incentive problems* that encourage them not to cooperate, even though cooperating would be in both of their interests, as in the well-known Prisoner's Dilemma game discussed further below. Players may face *assurance problems* that make it seem too risky to play the strategies that would lead to efficient equilibria, as in the Stag Hunt game discussed below. Players may also face *bargaining/coordination problems* that make it difficult to coordinate on one of multiple efficient equilibria.[7] To be useful in applications, game theory must offer theoretically coherent and behaviorally credible analyses of these kinds of problems.

In the standard approach to these problems, in one-shot interactions all three problems are solved (or not) within an equilibrium, sometimes augmented by principles that govern selection among multiple equilibria. In the standard approach to repeated interactions, all three problems are again solved (or not) within an equilibrium, now with refinements like *subgame-perfect equilibrium* applied to the game that describes the entire relationship.[8] Solving strategic problems may look quite different in situations of static play or repeated play—although if a game is repeated with fixed rather than varying partners, it becomes a game that is effectively static,

[6] Some theorists consider the problem of equilibrium selection via learning to be settled by analyses of "long-run equilibria" (Kandori, Mailath, and Rob 1993; Young 1993). But those analyses achieve equilibrium selection by modelling the dynamics of learning as ergodic and passing to the limit as randomness in the dynamics becomes negligible. Neither feature seems realistic, nor do the results seem to correspond closely to equilibrium selection in the lab or the field (Crawford 2001).

[7] Here I follow Schelling (1960) and Roth (1987; see also Crawford 1997, Section 5.3) in suggesting that most real bargaining is best modelled as unstructured and is then primarily a coordination problem, not a problem that is resolved via delay costs in the subgame-perfect equilibrium of a game with artificially imposed timing of offers and counteroffers (Rubinstein 1982).

[8] A *subgame* is any part of a game that remains after part of it has been played. A *subgame-perfect equilibrium* is an equilibrium strategy profile that induces an equilibrium in every subgame. In effect, subgame-perfect equilibrium adds a time-consistency requirement to the notion of equilibrium. This notion can be generalized to games with asymmetric information, via notions called "sequential equilibrium" or "perfect Bayesian equilibrium" (Mas-Colell, Whinston, and Green 1995, chapters 8–9).

Figure 3
Prisoner's Dilemma

	Cooperate	*Defect*
Cooperate	3, 3	0, 5
Defect	5, 0	1, 1

with players making a one-time choice among strategies that describe how they will act as the game unfolds.

If players can communicate during their interactions, that is usually modelled via "cheap talk" messages, which involve no direct payoff consequences and have no power to commit players to actions (Crawford and Sobel 1982; or in this journal, Farrell and Rabin 1996).

In this section, I begin to explore new directions for modelling communication, coordination, and cooperation in relationships. I first explain the standard approaches, and then suggest alternative directions that seem likely to be feasible and potentially useful.

Coordination and Cooperation in Long-Term Relationships

Most existing work in repeated games seeks to identify ways to support cooperation in a subgame-perfect equilibrium of the infinitely repeated Prisoner's Dilemma or some other well-behaved repeated game (Fudenberg and Maskin 1986). Consider, for instance, the version of the Prisoner's Dilemma in Figure 3. The best symmetric outcome arises if both players choose Cooperate. However, Defect is a dominant strategy for each player in that Defect yields each player a strictly higher payoff than Cooperate whether or not the other player chooses Cooperate. Is there a way to support cooperation in equilibrium in relationships based on the Prisoner's Dilemma?

First suppose that the Prisoner's Dilemma in Figure 3 is played repeatedly for a potentially infinite number of times by the same two players; and after any given number of plays the conditional probability of continuing remains bounded above zero, so it never becomes common knowledge that any particular period will be the last one in the relationship. Assume that players will choose a strategy to maximize their payoffs added across plays of the game, but downweight future payoffs with a discount factor (because otherwise undiscounted payoffs over an infinite horizon are not well-defined). A relatively low discount factor means that the players do not place much weight on future payoffs. In that case, only repeated choices of {Defect, Defect} are consistent with equilibrium. By contrast, a high discount factor means that the players place high weight on future payoffs; and that is enough to make {Cooperate, Cooperate} consistent with subgame-perfect equilibrium. For example, both players could follow the "grim trigger" strategy "Cooperate until the other player Defects, then Defect forever," which happens to be a subgame-perfect equilibrium and yields the outcome {Cooperate, Cooperate} in every period.

Why is it important that the game be played a potentially infinite number of times? Suppose instead that the Prisoner's Dilemma in Figure 3 is played repeatedly for a commonly known, finite number of times by the same two players. Assume again that players' preferences are defined by the addition of players' payoffs across plays of the game, with or without discounting. The unique equilibrium then entails both players choosing Defect in every period. During the last period of the game—which is known in advance—Defect is a dominant strategy for both players. Knowing that, in the second-to-last period, the players recognize that they cannot avoid Defect-Defect in the last period, and Defect is therefore a conditionally dominant strategy for both. Working backward, both players will see that Defect is a dominant strategy in every period.

Most existing work in repeated games assumes that players' beliefs will focus, with certainty, on a particular subgame-perfect equilibrium as common knowledge, and seeks to characterize the "Folk Theorem" set of outcomes, those which are consistent with some such subgame-perfect equilibrium (for more on the Folk Theorem, see the Wikipedia entry: https://en.wikipedia.org/wiki/Folk_theorem_(game_theory)). However, with a potentially infinite horizon, the set of equilibria is usually enormous. In the Prisoner's Dilemma in Figure 3, consider the strategy combination: "Row initially Cooperates and then alternates between Defect and Cooperate, and Column always Cooperates—in each case until either player deviates (that is, Row Defecting when not supposed to, or Column Defecting at all), in which case both players Defect from now on." In this asymmetric strategy combination, Row does better and Column worse than in the symmetric equilibrium described above (where both use the grim-trigger strategy), but if the discount factor is high enough, then the punishments for deviations are costly enough to make it a subgame-perfect equilibrium as well. And there are many others.

This multiplicity of equilibria is an important difficulty because, in applications, uncertainty about one's partner's strategic thinking is of the essence. The complexity of repeated-game equilibria and the general difficulty of equilibrium selection make the thinking justification especially implausible here. And in real long-term relationships, players' opportunities for learning about the effectiveness of alternative repeated-game strategies are limited (but see Dal Bó and Fréchette 2011 for some intriguing experimental evidence on learning repeated-game strategies).

Applications of such repeated-games analyses must confront a number of issues, of which I mention four. First, Folk Theorem equilibria are normally supported by extreme punishments even for tiny deviations. (The punishments are often taken to be more extreme than necessary to support cooperation because that gives a cleaner characterization of the Folk Theorem set.) Imagine a relationship slightly more complicated than a repeated Prisoners' Dilemma, whose players start out with different beliefs about their repeated-game strategies: For example, one player might believe they are playing "Cooperate until a player defects, then defect forever," while the other believes they are playing the asymmetric strategy combination described in the previous paragraph. In this case, they will deviate while intending to cooperate, and the trigger strategies meant to support their cooperation will end cooperation. This brittleness suggests that in applications, people will favor strategies that are more robust to deviations. There are few such analyses, but see Porter (1983), van Damme (1989), and Friedman and Samuelson (1994).

A second issue involves the ambiguity of predictions associated with the extreme multiplicity of equilibria in repeated games analyses. This ambiguity has been a serious impediment to empirical applications, and I believe that it has slowed the co-evolution of theory, experiment, and empirics that has been such a powerful engine of progress in other parts of game theory. Perhaps surprisingly, there seems reason to hope that closer attention in theoretical analyses to the need for strategies to be robust will, as a side benefit, help reduce ambiguity of predictions of players' behavior. Recent experimental work by Blonski, Ockenfels, and Spagnolo (2011), Breitmoser (2015), and others suggests the possibility of better and more precise theory.

A third issue is that long-term relationships enable *strategic teaching*, in which a player whose future cooperation with current partners is worth preserving may try to benefit by deviating from a short-run payoff-maximizing strategy in a way that could influence others' future beliefs and choices (Camerer, Ho, and Chong 2002). For instance, in the repeated Prisoner's Dilemma game of Figure 3, Row would benefit if it were possible to teach Column to play the asymmetric equilibrium described above (Row initially Cooperates and then alternates between Defect and Cooperate, and Column always Cooperates—in each case until either player deviates) rather than the symmetric equilibrium in which both players follow the "grim trigger" strategy, which shares the surplus equally. Row could try to teach Column by deviating from the latter equilibrium, risky as that is. Such considerations highlight the importance of robustness, but are assumed away in a standard equilibrium analysis.

Van Huyck, Battalio, and Beil's (1990) experiments with two-person minimum-effort coordination games, like the Stag Hunt game presented below but with seven symmetric Pareto-ranked equilibria, provide an intriguing example of strategic teaching. When their subjects played the games in fixed pairs, but with only one repetition per play, many of them adjusted their current decisions to try to teach their partners to coordinate more efficiently, and 12 of the 14 subject pairs converged via various routes to the most efficient equilibrium. (By contrast, subjects in the analogous treatment with random re-pairing of partners did not try to teach their partners, and had significantly worse outcomes.) The puzzle is how did they learn enough about the effectiveness of their alternative repeated game strategies to play the efficient stage-game equilibrium? In Crawford (2002), I suggested that Van Huyck et al.'s results might be explained by a strategic teaching model like that of Camerer, Ho, and Chong (2002), in which some players are adaptive learners while others are forward-looking and *sophisticated* in the sense of best responding to the correct mixture of adaptive and sophisticated subjects.

The fourth and last issue I will mention here is that in most standard repeated-game models, players who are well-informed about the structure of the game have nothing to communicate in equilibrium, so such models imply no substantive role

Figure 4
Stag Hunt

	Stag	*Rabbit*
Stag	9, 9	1, 8
Rabbit	8, 1	7, 7

for communication (for a recent exception, see Awaya and Krishna 2016). Yet communication appears to interact in important ways with the phenomena just discussed, and to play an essential role in real relationships.

Using Communication to Foster Coordination and Cooperation

Humans appear to be uniquely capable of using language to build, communicate, and counterfactually manipulate mental models of the world and of other people. This capability has a powerful influence on how people structure and maintain their relationships, and on what they can accomplish in them. Yet existing models of collusion and cooperation assign a limited role to communication. For example, most repeated-games analyses imply that firms can accomplish as much via tacit collusion as with communication. Why, then, does American antitrust law bother to prohibit firms from communicating about pricing and output decisions (Genesove and Mullin 2001; Andersson and Wengström 2007)? Presumably, when an agreement has gone awry, communication is an important aid to understanding what went wrong and restoring the relationship. Better models of how communication helps are needed.

To begin to explore these issues, consider the well-known Stag Hunt game, which traces back to a scenario laid out by Rousseau (1754 [1973]), who wrote:

> If a deer was to be taken, everyone saw that, in order to succeed, he must abide faithfully by his post: but if a hare happened to come within the reach of any one of them, it is not to be doubted that he pursued it without scruple, and, having seized his prey, cared very little, if by so doing he caused his companions to miss theirs.

A two-player Stag Hunt game with a set of payoffs is shown in Figure 4. The game has two pure-strategy equilibria, "all-Stag" and "all-Rabbit." All-Stag is better for both players than all-Rabbit, and is therefore "payoff-dominant" and a preferable equilibrium using one of the Harsanyi and Selten (1987) criteria. But as Rousseau's scenario suggests, how can the two players build trust that they will stay at their posts so that each can get a stag, rather having one of them deviate and try to bag a Rabbit? Rabbit also has a fairly large payoff, and there are far larger sets of players' beliefs that make Rabbit a best response. For the payoffs given in Figure 4, a player finds it optimal to play Rabbit if the belief is that the player's partner will play Rabbit with probability at least 1/7, while it is optimal to play Stag only under the belief that partner will play Stag with probability at least 6/7. Thus, using another of the Harsanyi and Selton criteria for choosing between equilibria, the all-Rabbit equibrium is "risk-dominant."

Experiments suggest that if people play Stag Hunt with no opportunity to communicate, a large majority of them will play Rabbit, as in other settings with a strongly risk-dominant equilibrium (Straub 1995). But now imagine, following Aumann (1990; see also Farrell 1988), that Stag Hunt is to be played only once, but that before play, one player, the *sender*, must send a clear message about the sender's intended strategy, Stag or Rabbit. As already noted, in game theory such communication is usually modelled via cheap talk messages, which are nonbinding and have no direct payoff consequences. Even so, such a message might benefit the sender by influencing the *receiver*'s choice (Crawford and Sobel 1982; Farrell and Rabin 1996).

Aumann (1990) notes that whether or not the sender plans to play Stag, the sender prefers that the receiver play Stag ($9 > 1$ and $8 > 7$). He argues that for this reason, the receiver will infer that the sender's message is self-interested and the message can convey no information to the receiver, so that the outcome will be the same as without communication. Aumann's argument is related to Farrell and Rabin's (1996) distinction between messages that are "self-committing" in that if the message convinces the receiver, it's a best response for the sender to do as he said; and those that are "self-signaling" in that they are sent when and only when the sender intends to do as he said. In this case, a message of intention to play Stag is self-committing, but not self-signaling. Aumann's argument is correct as a matter of logic, yet many of us would expect most senders to send *and* play Stag, and most receivers to play Stag as well. This conclusion is confirmed in most experiments (Cooper, DeJong, Forsythe, and Ross 1992; Charness 2000; Ellingsen, Östling, and Wengström 2013; but see Clark, Kay, and Sefton 2001).

One reason for the discrepancy has to do with Aumann's (1990) exclusive reliance on the logic of equilibrium, even though the multiplicity of equilibria, with one payoff-dominant and another risk-dominant, seriously undermines the thinking justification for equilibrium. When uncertainty about others' thinking is of the essence, it is unlikely that intelligent people will interpret a sender's message as if there were no chance whatsoever that it would influence equilibrium selection or whether players' choices are even in equilibrium. Rabin (1994; see also Farrell 1987, 1988) relaxes the assumption that players' beliefs are perfectly coordinated on some equilibrium, using a combination of rationalizability and behaviorally plausible assumptions about how players use language to analyze the process of negotiating how to play one of a class of finite matrix games. He shows that if players can communicate as long as desired, they will use their messages to agree on an equilibrium that is no worse for either player than the worst Pareto-efficient equilibrium for that player—thus, for example, yielding all-Stag in Stag Hunt.

Ellingsen and Östling (2010) take a different nonequilibrium approach, adapting the level-*k* model of Crawford (2003) to resolve some puzzles regarding the comparative effectiveness of one- or two-sided communication in coordination and other games.[9] They show, among other things, that even one-sided communication may allow players to coordinate on a Pareto-dominant equilibrium in a wide class of games including Stag Hunt, again resolving the puzzle. Notable recent experimental work includes Andersson and Wengström (2012) and Cooper and Kühn (2014), who study communication and renegotiation in two-stage games.

A more subtle reason for the discrepancy between Aumann's (1990) prediction and prevailing intuitions and experimental evidence on the effectiveness of communication in Stag Hunt may be his assumption that players are limited to a fixed list of messages, as in most theoretical work on communication: in his case, strategy labels whose meanings are assumed to be understood. Yet Stag Hunt is one of many situations in which people, even if well-informed about the structure, might benefit from a discussion more nuanced than stating an intention before deciding how to play. A sender who could send an unrestricted natural-language message would probably try to convey not only an intention but also a broader understanding of strategic issues. A fuller message might say, trying to give the assurance needed to support All-Stag: "I can see, as I am sure you can, that the best outcome in this game would be for both of us to play Stag. But I realize that Stag is risky for you, as it is for me. Despite the risk, I have concluded that Stag is a better bet for us. I plan to play Stag, and I hope you will too." In experiments such natural-language messages can be very effective (Charness and Dufwenberg 2006, 2010).

How could game theory incorporate such richer communication? Relaxing the standard assumption that people are limited to a fixed list of messages about intentions or private information to allow "metatheoretical" messages like my quotation is a theoretical challenge, and it seems difficult even to formalize an epistemic thinking justification for equilibrium when there is uncertainty about the principles of equilibrium selection, or even whether such principles ensure that players play some equilibrium. Even so, the gains from understanding natural-language communication, and how it interacts with people's other decisions, seem likely to be very large. McGinn, Thompson, and Bazerman (2003) report experimental evidence on how subjects use natural-language messages, which may help in devising better theories (on this point, see also Valley, Thompson, Gibbons, and Bazerman 2002; Weber and Camerer 2003; Charness and Dufwenberg 2006; Houser and Xiao 2011; Burchardi and Penczynski 2014).

Better theories of communication will certainly include some elements of players' rationality and their knowledge of the rationality of others, but they cannot be entirely epistemic. Rather, such theories are likely to combine rationality-based

[9] In Crawford (2003), I studied deceptive preplay communication of intentions before a zero-sum two-person game, which can happen in a plausible level-*k* model, but not in equilibrium. This level-*k* model has a more plausible thinking justification than equilibrium and also has some experimental support (Wang, Spezio, and Camerer 2010).

reasoning about the meaning of messages with empirically-based restrictions, such as those used by Farrell (1987) and Rabin (1994) and, or perhaps like those embodied in level-*k* rules like those studied by Ellingsen and Östling (2010).

Conclusion

Some economists seem less excited about game theory than during the period in the 1960s, 1970s, and 1980s when the ability to analyze strategic interactions was altering the landscape of many subfields of economics. But if the excitement over game theory has in fact diminished, I do not believe it is because game theory has ceased to be a major driving force in economics—quite the contrary!—it is mainly because its centrality makes economists less aware of its presence. Modern economists' relationship to game theory may resemble fully adapted aquatic creatures' relationship to water: they are less aware of water than their amphibian ancestors, for whom swimming was always a choice, but also more agile in their new medium.

That said, if game theory is to continue as a major force for progress in economics, it must continue to co-evolve with economic applications and incorporate the empirical knowledge they provide, rather than pursuing an inwardly focused agenda. In this paper, I have tried to give some concrete illustrations of what that might mean, critiquing existing game-theoretic approaches to the canonical problem of using communication to foster coordination and cooperation in relationships and suggesting some directions in which further progress might be made.

■ *I thank Colin Camerer, Gary Charness, Miguel Costa-Gomes, Martin Dufwenberg, Nagore Iriberri, Robert Östling, H. Peyton Young, the editors, and especially Joel Sobel and Tore Ellingsen for their helpful discussions and comments. My research received primary funding from the European Research Council under the European Union's Seventh Framework Programme (FP7/2007-2013) / ERC grant agreement no. 339179. The contents reflect only my views and not the views of the ERC or the European Commission, and the European Union is not liable for any use that may be made of the information contained therein. I also thank All Souls College, Oxford, and the University of California, San Diego, for research support.*

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Journal of Economic Perspectives—Volume 30, Number 4—Fall 2016—Pages 151–170

Whither Game Theory? Towards a Theory of Learning in Games

Drew Fudenberg and David K. Levine

When we were graduate students at MIT (1977–81), the only game theory mentioned in the first-year core was static Cournot (1838) oligopoly, although Eric Maskin taught an advanced elective on game theory and mechanism design. Just ten years later, game theory had invaded mainstream economic research and graduate education, and instructors had a choice of three graduate texts: Fudenberg and Tirole (1991), Osborne and Rubinstein (1994), and Myerson (1997).

Game theory has been successful in economics because it works empirically in many important circumstances. Many of the theoretical applications in the 1980s involved issues in industrial organization, like commitment and timing in patent races and preemptive investment. For example, Kreps and Wilson (1982) developed sequential equilibrium to analyze dynamic competition more effectively, Milgrom and Roberts (1982) showed how to apply game theory to limit pricing, and most of Tirole (1988)'s influential industrial organization textbook is applied game theory of one form or another. An array of other applications has followed, including problems ranging from auctions to market organization, and to monetary, fiscal, and international agreements involving trade and environmental issues. Many of these

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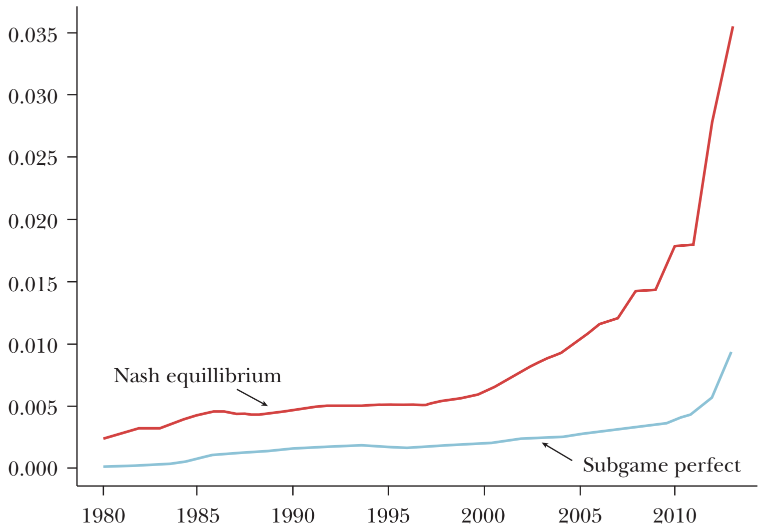
† For supplementary materials such as appendices, datasets, and author disclosure statements, see the article page at
http://dx.doi.org/10.1257/jep.30.4.151 doi=10.1257/jep.30.4.151

Figure 1
Google Scholar Results for "Nash equilibrium" and "subgame perfect" Relative to Results for "economics" for 1980 to the Present



Source: Authors using Google Scholar.

theoretical applications have had successful empirical application: for example, a substantial fraction of the roughly 4,000 papers that cite the Berry, Levinsohn, and Pakes (1995) game-theoretic empirical study of oligopoly in automobile markets are themselves empirical game-theoretic studies. Moreover, feedback from theory to the laboratory and back has become an important way to refine and improve game theoretic predictions, as in the literatures on ultimatum-game experiments following Güth, Schmittberger, and Schwarze (1982), on inequity-averse preferences following Fehr and Schmidt (1999), and on the winner's curse following Kagel and Levin (1986).

Now that the basic tools of Nash equilibrium analysis are well understood and have been widely applied, work by abstract game theorists is no longer as tightly focused and has diffused into a number of themes. This hardly means that interest in or use of game theory has declined, as illustrated by Figure 1, which compares Google Scholar hits for "Nash equilibrium" and "subgame perfect" to those for "economics" from 1980 to the present. The role of game theory in economics does not seem to be in much doubt. Moreover, game theory continues to draw top young scholars into the field, as indicated by the recent award in 2016 of the John Bates Clark medal to Yuliy Sannikov, a game theorist.

There continue to be important theoretical developments in game theory: for example, over the last decade we have made tremendous progress in understanding the role of information in dynamic games. As theoretical understanding improves, it is important also to improve our understanding of a wider range of field and lab settings. Theoretical research has helped explain the circumstances in which game theory does a good job empirically. It has also helped explain the circumstances in which game theory does a poor job empirically: for example, when equilibria are not robust, the environment is complex, or when circumstances are unfamiliar, standard game theory is less likely to perform well in the sense of making too wide a range of predictions (for example, Levine and Zheng 2015). Moreover, we know from laboratory studies—for example, those involving "beauty contest" games in which the players must estimate what everyone else is going to choose—that equilibrium theory does a poor job when people have inadequate time to learn about the game and the behavior of their opponents. As we have argued in the past, learning theory offers a way to improve and widen game theory's predictive power by shedding light on what sorts of equilibria to expect in various contexts (Fudenberg and Levine 1998; Fudenberg and Levine 2009). However, not enough is known about the speed of learning, an issue that we feel deserves much more attention.

Game Theory and Learning

Nash equilibrium has proven itself to be a remarkably powerful tool for understanding human interactions. As one commonplace example, the rush-hour traffic game is played on weekday mornings in major cities in the world. It lasts several hours. The millions of players are the commuters traveling by car from home to school or work. The actions are the many different routes that they can take: main highway, side streets, a North or a South route, and so forth. Commuters may also have some leeway over their departure times. To the first approximation, their preferences are to reach their destination as quickly as possible (although an expanded game could include additional preferences about outcomes like time of arrival and safety during the trip). Nash equilibrium holds when no commuter can save any time by taking a different route. For this equilibrium to be approximately true, for example, it must be true that if you get off the congested main highway and dodge through side streets you find that just enough other people are doing the same thing that you derive no advantage from doing so. One of us has considerable experience with a particular version of the rush-hour traffic game and, after extensive experimentation, has concluded that Nash equilibrium fits well. Less anecdotally, traffic engineers usually assume that traffic flow is well described by Nash equilibrium, although they call it "user equilibrium" (for example, Florian 1976).

If we believe that Nash equilibrium is applicable in many practical situations, as the large body of empirical work using it suggests, then it is natural to inquire as to why this should be so. For several reasons, most economists have come to think of Nash equilibrium and its variations as arising not from introspection and calculation, but rather from some nonequilibrium adaptive process of learning, imitation, or evolution. First, as the rush-hour traffic game makes clear, in many practical instances, it seems infeasible to find Nash equilibrium by rationality alone: after all, commuters do not and could not choose routes by contemplating the rational play of all other commuters and working out how they should best respond. Instead, commuters approximate an optimal choice through by trial and error learning. Second, initial choices in laboratory games do not usually resemble Nash equilibrium (except in some special cases); instead, there is abundant experimental evidence that play in many games moves toward equilibrium as subjects play the game repeatedly and receive feedback (some classic citations include Smith 1962; Selten and Stoecker 1986; Van Huyck, Battallio, and Beil 1990, pp. 240–41). Finally, in many coordination problems with multiple equilibria, it is difficult to believe that reasoning from first principles could lead to Nash equilibrium. For example, the rush-hour traffic game can work equally well if the players all drive on the right or all on the left. But that coordination problem is not likely to be solved by introspection alone.

There are several reasons for our interest in the process by which Nash equilibrium is reached. First, "how we get there" may provide clues as to which of multiple equilibria are likely to be chosen. Second, as we shall discuss, there are cases where convergence to equilibrium does not occur quickly enough to be empirically observed. Third, even when a Nash equilibrium is reached and persists for a long time, regime changes may still occur. For example, in Sweden, the coordination equilibrium changed from driving on the left to driving on the right in 1967. We next offer two examples of significant regime change, one that took decades and one that took minutes.

Learning about Monetary Policy

Views about the tradeoff between inflation and unemployment have changed over time. The view of the Federal Reserve in the 1960s was summarized in this way by Ben Bernanke several decades later (as quoted in Domitrovic 2012): "[E]conomic theory and practice in the '50s and early '60s suggested that there was a permanent tradeoff between inflation and employment, the notion being that if we could just keep inflation a little bit above normal that we could get permanent increases in employment, permanent reductions in unemployment." This view is now widely regarded as wrong. It took the Fed four decades to figure this out, which we would describe as "slow" learning (for example, see Sargent 1999).

To help explain how it is possible to become stuck with a wrong theory, we use a simplified version of an idea from Sargent, Williams, and Zha (2006) that we described in Fudenberg and Levine (2009), which we will refer to as the Phillips curve game. There are two players: the Fed and a representative consumer. The Fed chooses a monetary policy, which we take to be either high or low inflation; the consumer observes the chosen policy and chooses either high or low unemployment. The Fed prefers low inflation, but is willing to choose high inflation if this leads to lower unemployment. Regardless of what inflation policy is chosen, the representative consumer always prefers low unemployment. For illustrative purposes we will suppose that the policymaker's payoff is the sum of an unemployment term and an inflation term, and that the policymaker gets 2 for low unemployment, 0 for high unemployment, 1 for low inflation, and 0 for high inflation. The representative consumer gets 1 for low unemployment and 0 for high unemployment.

The Phillips curve game has two different types of Nash equilibria. It is an equilibrium for the representative consumer to always choose low unemployment and for the Fed to choose low inflation. However, it is also a Nash equilibrium for the consumer to follow a strategy of "respond to low inflation by choosing high unemployment and high inflation by choosing low unemployment, and for the Fed to choose high inflation in response. Why should the consumer choose high unemployment when we said low unemployment is preferred? The rationale behind this second outcome lies in a technicality in the definition of Nash equilibrium. Because the Fed is choosing *high inflation* in response to the consumer strategy, the way in which the representative consumer responds to low inflation is purely hypothetical—it is "off the equilibrium path." In effect, Nash equilibrium asks: would you choose high or low unemployment in response to low inflation? And the representative consumer answers: it does not really matter to me because I don't expect to see low inflation in my lifetime. And the representative consumer is correct as the Fed is choosing high inflation. As a technical matter Nash equilibrium allows this possibility. Game theorists have developed two responses.

1) Fix the technicality. The requirement of subgame perfect equilibrium strengthens Nash equilibrium by requiring that players should choose best responses to all contingencies, whether or not these contingencies are expected to occur. In the example, subgame perfection requires that the consumer makes the optimal choice in response to low inflation even if the consumer never expects to see low inflation. Nash equilibrium makes no such requirement. However, there are issues with subgame perfection. In more complex games than the example used here, subgame perfection requires that players have extensive knowledge about opponents' responses to hypothetical contingencies. For example, it can require that a player who has never seen opponents play a particular coordination subgame believe that the opponents will coordinate on one of the equilibria of that subgame and that the particular equilibrium that is coordinated on can be correctly forecast. Moreover, subgame perfection is often not robust to even small amounts of payoff uncertainty (Fudenberg, Kreps, and Levine 1988; Myerson 1978).

2) Take learning more seriously. An alternative story we can tell about the Phillips curve game is that the representative consumer always chooses low unemployment. However, the Fed chooses high inflation and incorrectly believes that if it were to choose low inflation, the representative consumer would choose high unemployment. If the Fed does not have detailed knowledge of consumer behavior and preferences, then when the Fed chooses high inflation it receives no feedback about the consequences of low inflation, and so has no basis on which to discover that its beliefs are incorrect. This leads to the concept of self-confirming equilibrium, which weakens Nash equilibrium by only requiring that player's beliefs about other player's strategies are consistent with what they observe when the game is played, and so allows players to have incorrect beliefs about how opponents would play.

The story then that explains the misguided Fed beliefs of the 1960s is that it was stuck in a non-Nash self-confirming equilibrium in which the consumers would choose low unemployment in response to low inflation but the Fed mistakenly thinks they would choose high employment instead. Believing that low inflation would lead to high unemployment, the Fed in the 1960s and into the 1970s chose high inflation, and it took time to learn that its belief was wrong. However, while self-confirming equilibrium may be a good short-run description, it may not be a good long-run description, because players may eventually get enough evidence about off-path play to correct their mistaken beliefs.

The Hijacking Game

We turn now to a case where Levine (2012) points out that learning was breathtakingly fast. In response to changed circumstances, an equilibrium that involved millions of air passengers and had lasted for decades changed to an opposite equilibrium, and the switch took place spontaneously and in less than half an hour.

We start with a game-theoretic model of air hijackings with two players: hijackers and passengers. There are two types of hijackers: mild and severe. The hijackers' type is private information, but the probabilities are common knowledge. The game proceeds sequentially. First, the hijackers decide to stay out or to hijack the plane. If they stay out, the game ends and everyone gets utility of 0. If the plane is hijacked, then the passengers must decide whether to fight or acquiesce. If the passengers fight, the hijackers are defeated with severe hijackers getting −1 and mild hijackers getting −2; because fighting generates a chance that the plane crashes, the passengers get an expected payoff of −2. If the passengers acquiesce, then the hijackers get +1 and the amount that the passengers get depends on the type of hijacker. If the hijackers are of the mild type, the passengers are eventually released and get −1. If the hijackers are of the severe type the passengers may be killed, and we set payoff of the passengers to be −3.

Suppose initially all hijackers are mild, so there is no private information. Then there are two Nash equilibrium outcomes: either the hijackers stay out or they enter and the passengers acquiesce. The latter is the unique subgame perfect equilibrium.

What if an exogenous change in circumstances drops the probability of mild hijackers to 25 percent? Then hijack/acquiesce is no longer a Nash or even a self-confirming equilibrium, and the only Nash equilibrium is for the hijackers to stay out and for the passengers to fight with at least 50 percent probability. Over time, the passengers learn that it is now better to fight, and when the hijackers in turn learn that passengers are choosing to fight, hijacking would diminish and we would reach the stay-out equilibrium. Formal learning models, as well as experimental studies involving unraveling in the finitely repeated prisoner's dilemma, suggest that this process would take some time. That, however, is not how it happened.

The 1990s saw roughly 18 aircraft hijackings a year. Flight crews were trained in the rational and government-approved "Common Strategy." Hijackers' demands should be complied with, the plane should be landed safely as soon as possible, and security forces should be allowed to handle the situation. Passengers should sit quietly, and nobody should play hero. This advice was well established, rational, successful, and validated by decades of experience. This was the hijack/acquiesce equilibrium. Most hijackings ended peacefully, and the longer a hijacking persisted, the more often there was a peaceful ending.

Circumstances changed on September 11, 2001, when hijackers used the aircraft for suicide attacks on ground targets. The theory predicts that the equilibrium should shift from hijack/acquiesce to stay out/fight. This indeed has been the case: there have been very few hijackings since September 11, 2001, and in those very few cases the passengers have always resisted. But in this example, learning was extremely fast (National Commission on Terrorist Attacks on the United States 2004). American Airlines Flight 11 crashed into the North Tower of the World Trade Center at 8:42 am on September 11, 2011. Forty-two minutes later, United Airlines Flight 93 was hijacked. Only 29 minutes later, passengers and the flight crew on United Airlines Flight 93 assaulted their hijackers. A dramatic regime change happened on a plane already in the air based on limited information obtained through a few dozen telephone calls that relayed second-hand experience.

Of course, some ingredients are missing in the simple model. For example, one thing that was clear to the passengers, although it might not have been to a computer program implementing simple learning rules, that the other severe hijackings of the day made it virtually certain that their hijackers were of the severe type, too: after all, it would be a cosmic coincidence if severe hijackers had seized two planes and the third plane was seized by an independent group of mild hijackers. This highlights one problem with learning theory, namely that people are smart and sophisticated in ways it is hard to model.

Passive Learning

The basic concept of Nash equilibrium describes a situation where further learning about opponents' strategies is not needed and cannot occur. That is, since everyone is doing the best they can given the play of the others, nobody will ever discover a better action than the one they are using. As noted earlier, players in a game observe only what actually happens ("the equilibrium path") and not generally all the strategic choices of the other players.

However, in static simultaneous move games such as Cournot or Bertrand duopoly, the strategies are simply choices of actions. In this situation, observing the realized actions of others is enough for a player to determine what the outcome would have been had that player used a different strategy, so the question of "what would the opponent have done if I'd done something else" does not arise. To put it another way, all learning is "passive" in this situation, meaning that because what players do has no impact on what they see, players have no incentive to change their actions to gain additional information.

There are two main models of passive learning. The first, called *fictitious play*, was introduced by Brown (1951) and analyzed by Shapley (1964), Fudenberg and

Kreps (1993), and Monderer, Samet, and Selta (1997), among others. In the first period, players make an arbitrary choice; no data has been received, no learning has taken place. Subsequently, players keep track of the frequency with which their opponent has played different actions. It is straightforward to show that if the actions of both players converge, they must converge to a Nash equilibrium, and only a bit harder to show that the same is true if the empirical marginal distributions of actions converge to a pair of mixed strategies (Fudenberg and Kreps 1993). The exact rule for forming beliefs does not matter for this result; all that matters is that (asymptotically) players choose actions that are a best response to the empirical distribution of play. Economists tend to think of learning in terms of Bayes' law, and fictitious play can be interpreted in this way.

However, fictitious play raises two difficulties as a model of learning. First, fictitious play involves a deterministic best response based on the information collected, which can open a player up to exploitation by a clever opponent (Blackwell 1956; Fudenberg and Kreps 1993). Second, from a purely descriptive point of view, the exact best response of fictitious play implies that a small change in beliefs can lead to a discontinuous change in response probabilities, which seems implausible. Indeed, even when we see convergence to Nash equilibrium in experimental data, the play of individual players is quite noisy and is better described by a random response.

In response to these concerns, Fudenberg and Kreps (1993) replaced the exact best response of fictitious play with the assumption that payoffs are subject to independently distributed, privately observed payoff shocks. Introducing a degree of randomness means that the strategy is no longer deterministic and therefore is harder to exploit. More generally, this approach replaces the exact best response function of fictitious play with a smooth approximation to it, called "smooth fictitious play," which is both a better approximation of how players act and also has other analytical advantages. The resulting "Nash distribution"—the distribution over actions induced by the introduction of randomness—has over time become known as a "quantal response equilibrium" (McKelvey and Palfrey 1995).

The second class of passive learning models, *reinforcement learning models*, were drawn from the psychology literature and applied to learning in games by Roth and Erev (1995). These models do not deal with beliefs but rather directly update a measure of the utility of each action—called a "propensity"—and derive probabilities so that actions with higher propensities are more likely to be played. For certain models of choice and certain parameters for converting expected utility into probabilities of play, this model can be formally equivalent to smooth fictitious play.

In the original Roth and Erev (1995) formulation, utility weights are updated only for the action that was chosen. This is the reinforcement learning idea: the action chosen is reinforced according to how well it did. After many years of study of experimental data using variations of this model (for example, Cheung and Freedman 1997; Camerer and Ho 1999; Salmon 2001), Ho, Camerer, and Chong (2007) proposed "self-tuning experience-weighted attraction," which they report does a good job of fitting a variety of experimental data. In this model, weights are updated for every action that would have done at least as well as the action that was chosen, although the utility of actions that are not used is depreciated. (Learners may depreciate the utility of unused actions by less when the data indicates a high degree of certainty about the environment, as in Fudenberg and Levine 2014 and Block, Fudenberg, and Levine 2016.) This method of updating has the property that if players are playing bad strategies they behave much as they would in fictitious play, while if they are playing a good strategy they play much as they would in a pure reinforcement learning model. Ho, Camerer, and Chong view this as a model of limited attention: people are more "likely to focus on strategies that would have given higher payoffs than ... [those] actually received, because these strategies present missed opportunities."[1]

The Cobweb and Recency

The discussion of passive learning models up to this point has assumed that current and past observations are weighted the same. *Recency* is the idea that recent observations might get more weight than older observations.

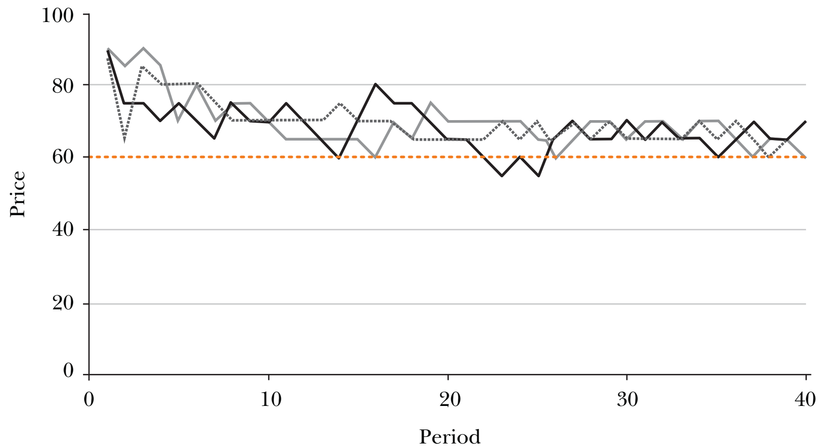
An extreme example of recency is to update using only data from the most recent period. Depending on the parameters, this can give rise to cycles, as in the famous "cobweb" first described in Kaldor (1934). Sutan and Willinger (2004) investigated this possibility. They studied a Cournot oligopoly market with five suppliers with increasing marginal costs, where the Cournot equilibrium is at a price of 65. The effects of recency can be demonstrated in such a setting by using the simplifying assumptions that players assume today's price will be the same as yesterday's and that they ignore their own market power. This leads to the conclusion that if producers expect a low price, they produce 0, which causes the price to rise to 100, so the next period there is overproduction and a low price, leading to 0 output the period after that, and so on and so on. However, the laboratory investigation of this Cournot oligopoly market found that experimental participants converged rather quickly to about 65, as shown in Figure 2.

This experiment (along with many others such as Hommes, Sonnemans, Tunisstra, and Van De Velden 2007) shows that extreme recency is not a good model. Interestingly our calculations show that if participants were to use an average of the prices in the last two periods, rather than just the last period, prices do converge, and the rate of convergence matches that in the experimental data rather well, as things settle down nicely after ten periods.

When and why should we expect people to give recent observations more weight? If the process that is generating observations undergoes unobserved regime shifts, then older observations may indeed be less informative than recent ones. Psychologists talk of "recency bias" because sometimes people do this even when they are told the environment they face is stationary (for example, Erev and Haruvy 2016).

[1] In the Ho, Camerer, and Chong (2007) approach, agents are homogeneous. Wilcox (2006) argues that agents are heterogeneous, and that assuming homogeneity biases the estimates of the learning parameters against belief learning and in favor of reinforcement learning.

Figure 2
Experimental Results from a Cournot Oligopoly Game



Source: Sutan and Willinger (2004).
Notes: Each solid line shows results from a group of five players playing a Cournot oligopoly game. The competitive price in this market is at a price of 60. The Cournot equilibrium is at a price of 65.

There are two approaches to modeling recency. One is to develop explicit Bayesian models of changing environment. This approach is not widely used because models of this type are quite complex.[2] Instead, most models of recency have instead focused on simple rules of thumb. A starting point is to modify the fictitious play/reinforcement learning specification to specify that older observations receive exponentially less weight (as, for example, in the econometric specification of Cheung and Freedman 1997; see also the theoretical work of Benaïm, Hofbauer, and Hopkins 2009; Fudenberg and Levine 2014).

In lab experiments, a recency model often does well in describing some learning paths. But in general, the discount rate placed on recency varies from experiment to experiment, and may well vary from subject to subject. However, when subjects get stochastic feedback, recency can lead to a distribution of play that is very different than any Nash equilibrium. Fudenberg and Peysakovich (2014) provide evidence on this point: in their experiment, subjects face a "lemons" problem in which the computer chooses a value v uniformly distributed on the interval [0,10] and the value of the object to the buyer is $v + k$, where k is a known parameter. The buyer makes a take-it-or-leave-it offer, which the computer accepts exactly when its value is below the offer. In one treatment (when $k = 3$) the Nash equilibrium is 3, while the actual mean bids converged to 5.18. However, in another treatment, the

[2] An example is hidden Markov models. Chen, Chen, and Levine (2015) develop techniques for simulating learning in models of this sort—but the algorithms used to solve the hidden Markov model cannot be used to generate analytic results.

Nash equilibrium bid is 6 while the actual mean bids converged to a bit less than that value. These outcomes can be matched by simulations with a high degree of recency, and in the data, even after some 20 rounds of play, participants appeared to place most of their weight on the most recent two observations.

Unfortunately, we do not yet have satisfactory models of recency. Here's an example of one of the complications. It may seem intuitive that if things have been stable for a while, but then seem to have changed, then you use greater recency. This insight is similar in spirit to work that assumes people act "as if" the world is stationary unless the data looks "too non-stationary" as in Fudenberg and Kreps (1994), Sargent (1999), and Cho and Kasa (2015). However, this intuition is incomplete. When we are surprised, we do not just put weight on more recent data, but we also re-evaluate our previous interpretations of old data. When the economy experienced an unusually severe recession as in 2007–2009, many analysts stopped looking for comparisons in post–World War II recessions and instead went back further to look for relevant lessons in the experience of the Great Depression.[3]

A thought experiment about the coordination game of driving on a certain side of the road helps to illustrate the difficulties. Imagine that you are driving on a deserted road and you encounter a driver who is on the wrong side. The next driver you encounter is also on the wrong side, and so is the next. Even so, you probably still would not conclude that the equilibrium had changed, but would instead contemplate the possibility that there was something unusual about this road at this particular time. The answer to the question of how many drivers in a row would you have to encounter before you concluded that the equilibrium had changed and all drivers everywhere were driving on the wrong side of the road is not obvious. Moreover, this example also highlights that real-world players are not operating in a vacuum. After encountering two or three wrong-side drivers in a row, you might well start listening to the radio or call someone on the phone, and ask if they had heard about anything funny going on.

From the Laboratory to the Field

There is a concern that the laboratory evidence on recency may not capture how real-world decisions are made. For example, Fudenberg and Peysakovitch (2014) find that when they give players a group of ten observations, the players display recency and the specific game does not converge to Nash equilibrium. However, if they give players a summary of those ten observations in the form of an

[3] One promising approach is the self-tuning experience-weighted attraction model of Ho, Camerer, and Chong (2007), which proposes a way to endogenize the "window" of time that players use in looking back. In this model, the window is taken to be the number of actions in the support of Nash equilibrium. The concept of the window seems an essential conceptual building block. However, it seems questionable to base a learning equilibrium on computations of Nash equilibrium by players. The approach is not consistent with evidence about recency, which sometimes seems to take into account longer or shorter windows. It is unclear how the idea of a window takes the re-evaluation of older experience into account. Also, it is unclear how this approach is to be applied when there is more than one Nash equilibrium.

average, then the players no longer exhibit recency, and the game does converge to Nash equilibrium.

Are real-world decision makers more likely to be seeing a series of data or some summary of that data? Federal Reserve decisions, for example, are taken by a committee that looks a bit at specific data from last week or last month, but mostly uses sophisticated econometric models using data going back a long way. Investment banks do sophisticated analysis of the term structure of interest rates and look for arbitrage opportunities using historical data series. Some part of how people learn to play games should be conceived of as choosing between model *A*, model *B*, model *C*, and others because people learn about which model should be used in addition to learning the parameters of a specific model.

Active Learning

Learning about Off-Path Play

In some settings, a passive learning approach will not gather information about the outcomes of alternative strategies because much of the game is "off the equilibrium path." Yet players must still infer causality: if I were to cooperate, would my opponent reward me? If so, for how long? For this reason, players in a dynamic game may choose to experiment with actions that they think might prove to be suboptimal, just to learn more about their consequences.

This perspective sheds additional light on the Sargent, Williams, and Zha (2006) analysis of the Federal Reserve and the Phillips curve game discussed earlier. If the game is fully understood by all players, then backward induction leads to the low inflation/low unemployment outcome. However, there is a self-confirming equilibrium in which the policymaker chooses high inflation due to a mistaken belief that low inflation leads to high unemployment. Sargent, Williams, and Zha argue that self-confirming equilibrium cannot adequately explain either the accelerating inflation of the 1970s nor the dramatic fall in inflation in the 1980s. They provide a more detailed model of active Bayesian learning that takes into account that some relevant data is revealed even in the high inflation regime, and argue that this learning model can explain many details of US monetary policy and inflation during 1970s and 1980s.

In incorporating learning about off-path play into learning models, several key issues must be addressed. First, the patience of the players matters—that is, time preference or discounting—because a patient player will be more willing to risk short-term mistakes in pursuit of better performance in the long run. Second, there seems to be a role here for random play. Remember that even in the passive models of fictitious play, random play helped in avoiding a situation where strategy choices became predictably exploitable by other players or unrealistically discontinuous. Here, randomness can also serve as a mechanism for learning about off-path play. Third, if the potential risks from experimentation are large and negative, then less of it will occur. Finally, some games may include many information sets, and thus it would potentially require a lot of experimentation to figure out what was going on. A crucial case in point is that of repeated games, to which we turn our attention next.

Cooperation in Infinitely Repeated Games

The relations of consumers and businesses usually involve an important element of repetition, as do employment relationships, family relationships, and others. When games are repeated over time, the possibility of creating incentives through rewards and punishments arises. However, learning in these games is complicated by the need to infer causality "off the equilibrium path." To focus thoughts, we begin with the classic repeated prisoner's dilemma game. In each period, two players play each other in a *stage game* and decide whether to cooperate C or defect D. Typical payoffs are given by the payoff matrix:

	C	D
C	2,2	0,3
D	3,0	1,1

Each player has the defect choice D as the unique dominant strategy when the game is played only once. However, the infinitely repeated case, which can be considered as an idealized representation of settings without a commonly known ending date, is quite different. Consider the "grim trigger strategy" of cooperating in the first period and up until the other player defects, and then defecting forever afterwards. In this situation, if players do not have too high a discount rate on future payoffs, they will find it optimal to cooperate. This is a special case of the celebrated "Folk Theorem" as developed by Auman and Shapley (1992), Friedman (1971), Fudenberg and Maskin (1986), and Fudenberg, Levine, and Maskin (1994), among others: any payoff vector that is individually rational for the players is a subgame perfect equilibrium provided that the players are sufficiently patient (and assuming some technical conditions are satisfied). Although repeated games allow the possibility of cooperation in which incentives are established through future rewards, they allow many other possibilities as well.

What predictions should we make about repeated games with patient players? A common assumption in applied theory and theoretical industrial organization is that people cooperate whenever there is a cooperative equilibrium. Moreover, that prediction can be derived from various evolutionary game theory models, as in Axelrod and Hamilton (1981), Fudenberg and Maskin (1990), Binmore and Samuelson (1992), and Dal Bó and Pujals (2015). Unfortunately, there is little hard empirical support for this prediction, and laboratory evidence leans against it. Moreover, the laboratory provides a way to better understand what does happen in repeated games, and suggests that learning plays a key role.

Dal Bó (2005) relaunched the experimental study of repeated games by having participants play 7–10 iterations of the repeated game, with a different partner each time, as opposed to past work such as Murnighan and Roth (1983) in which each subject played just once. There have now been a great many experimental studies of infinitely repeated games; there are 11 of them with 28 conditions in the meta-analysis of Dal Bó and Fréchette (2015). One main takeaway is that the discount factor matters much more once participants have played the game a few times. Another is that laboratory participants do respond to game parameters such as continuation probability and the payoff matrix in the direction suggested by theory, with the tendency to cooperate increasing in the gains from doing so, but it is not the case that players always succeed in cooperating whenever there is an equilibrium that supports cooperation.

Yet another take-away is that in contrast to predictions based on equilibrium analysis, the loss a cooperator incurs when the other player defects does matter. That is, whether an equilibrium exists in which players cooperate every period is theoretically independent of the loss a player incurs when that player cooperates and the other defects, because in an equilibrium where players always cooperate, no player ever expects that his opponent would be the first to play the defect choice *D*. In contrast, the loss that arises when one player cooperates and the other defects matters in practice because participants cannot be sure what strategies their partners are using, and even in treatments where most participants eventually cooperate, some of them do play the defect choice *D*. To try to capture the effect of this "strategic uncertainty," Blonski, Ockenfels, and Spagnolo (2011) look at risk dominance in an associated game where the only strategies are "Tit for Tat," which is repeating the choice just made by the other player, and "Always Defect" (Axelrod and Hamilton 1981). The payoff matrix is:

	Tit-for-Tat	Always Defect
Tit-for-Tat	2, 2	δ, $3(1-\delta)+\delta$
Always Defect	$3(1-\delta)+\delta$, δ	1, 1

They propose that players will only cooperate if the risk of a Tit-for-Tat choice dominates Always Defect choice, which in our example requires $\delta \geq 2/3$, so that for $2/3 > \delta \geq 1/2$, they would predict little or no cooperation. This criterion does a fairly good job of matching the data in the Dal Bó and Fréchette (2015) meta-study. To get more precise predictions, Dal Bó and Fréchette relate cooperation to the size of the "basin" of Tit-for-Tat, which is the probability of the opponent playing Always Defect that leaves the player just indifferent between Tit-for-Tat and Always Defect. However, even in "cooperative treatments"—where the payoff matrix and discount factor should lead to a high rate of cooperation—Dal Bó and Fréchette estimate that about 10–20 percent of the participants use Always Defect. There are similarly large shares of Always Defect in the "cooperative treatments" of the noisy prisoner's dilemma in Fudenberg, Rand, and Dreber (2012), who also compute the payoffs of the estimated strategies against the estimated distribution and find that the Always Defect players do substantially worse than the conditional cooperators who use Tit-for-Tat. This heterogeneity of play does not seem to reflect social preferences, and is uncorrelated with how the same participants play in a dictator game (Dreber, Fudenberg, and Rand 2014), so we interpret it as showing that people find it hard to learn which strategies will perform well, both because of the size of their own strategy space and because of the many possible strategies their opponents might be using.

What Constitutes a Good Theory?

Game theory has become a basic working tool for economists—and not just for theoreticians, but for empirical investigation. So where do we go from here? We have argued here that improved models of learning can lead to a better theory. To see why, let us review what we would like to see in a good theory.

First, we would like precise and valid predictions. Our impression is that existing game theoretic methods often do pretty well on validity, at least when researchers use appropriately robust versions of the theory. However, precision means that the theory generates precise statements about what will happen: for example, specifying which of several possible equilibria will occur. In some settings, for example in repeated games, game theory does not do well on this score. In other settings, equilibrium models have proven useful in structural estimation; see Bajari, Hong, and Nekipelov (2013) for a survey of recent work. In settings where equilibrium theory does not yield precise predictions, theoretical analysis of learning models has a great deal of promise both in explaining which equilibria are more likely to be observed and how initial conditions may matter. The extensive literature on evolutionary games with random shocks is a step in this direction. Early work both in discrete time models (Kandori, Mailath and Rob 1993; Young 1993) and in continuous time (Foster and Young 1990; Fudenberg and Harris 1992) gave conditions under which risk dominant equilibria are likely to be observed, and subsequent work such as Johnson, Levine, and Pesendorfer (2001) extended the idea that random shocks generate equilibrium selection to the case of dynamic games. These results are likely to expand, as there has been a recent resurgence of interest both in traditional evolutionary models, such as Levine and Modica (2016) and in fast learning, such as Kriendler and Young (2013) and Ellison, Fudenberg, and Imhof (2016). Applications of some of these recent results can be found in Block, Fudenberg, and Levine (2016).

Another way to use learning models to generate better predictions is by the use of simulations. For example, Brandts and Holt (1996) use this approach to argue that a form of myopic fictitious play fits experimental play of signaling games; Dal Bó and Fréchette (2015) used simulations of a belief-based learning model to predict how play in their repeated game experiment would have changed if subjects had played more games; and Fudenberg and Peysakovich (2014) argued that simulations of a model of learning with recency fit their data better than either Nash or the "cursed equilibrium" of Eyster and Rabin (2005). More generally, while theory is useful for building insight and intuition into how models work, and crucial for understanding the generality and robustness of various conclusions, simulations have proven to be useful for generating conjectures, and can be essential for developing quantitative results.

Second, we need theoretical simplicity. As time goes on, game theory may be able to deal with more sophisticated models of human behavior, but it is likely always to be the case that simple models will be helpful for providing understanding and intuition about how more elaborate models work. Of course, theories of learning are more complicated than static theories of equilibrium. However, existing models such as variations on fictitious play are quite tractable. We may hope that the analysis remains tractable after adding important features such as events that trigger re-evaluation of models.

Third, we need breadth. A single unified theory is subject to a great deal of possible testing and falsification. On the other hand, a theory specifically tailored to explain only one fact cannot be tested at all. Game theory, both static and the theory of learning dynamics, fares well on this score.

Finally, we would argue for the methodological value of conservatism. There is no point in introducing, say, a new theory of social preference and fairness that explains exactly one experiment and is inconsistent with many other facts for which we already have common and coherent explanations. The theory of Nash equilibrium has proven useful and accurate. Adding learning theory to the mix preserves the basic results and insights of Nash equilibrium, while also adding greater precision to prediction in many cases and offering new predictions about the speed of learning.

■ *We are grateful to Juan Block, Michele Boldrin, Marco Casari, Pedro Dal Bó, Anna Dreber, Rohan Dutta, Ben Golub, Guillame Fréchette, Gabriel Kreindler, Salvatore Modica, Andrea Mattozzi, David Rand, and members of the EUI Theory Reading Group. This essay is based on our longer paper "Whither Game Theory" (Fudenberg and Levine 2016), which can be found at http://www.dklevine.com/archive/refs4786969000000001307.pdf.*

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Journal of Economic Perspectives—Volume 30, Number 4—Fall 2016—Pages 171–198

The View from Above: Applications of Satellite Data in Economics

Dave Donaldson and Adam Storeygard

Photographic images of the Earth from above have been recorded since the late 19th century, initially by cameras attached to balloons, kites, or pigeons. This remotely sensed information has been used for economic analysis since at least the 1930s; for example, Monmonier (2002) discusses how several dozen photographic crews started flying over US farmland in the 1930s to study production and conservation, and by 1941 had recorded images of more than 90 percent of total acreage. However, the past decade or so has seen a dramatic change in the way that economists can learn by watching our planet from above. A revolution has taken place in remote sensing and allied fields such as computer science, engineering, and geography. Petabytes of satellite imagery have become publicly accessible at increasing resolution, many algorithms for extracting meaningful social science information from these images are now routine, and modern cloud-based processing power allows these algorithms to be run at global scale. This paper seeks to introduce economists to the science of remotely sensed data, and to give a flavor of how this new source of data has been used by economists so far and what might be done in the future.

We group the main advantages of such remote sensing data to economists into three categories: 1) access to information difficult to obtain by other means; 2) unusually high spatial resolution; and 3) wide geographic coverage.

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† For supplementary materials such as appendices, datasets, and author disclosure statements, see the article page at
http://dx.doi.org/10.1257/jep.30.4.171 doi=10.1257/jep.30.4.171

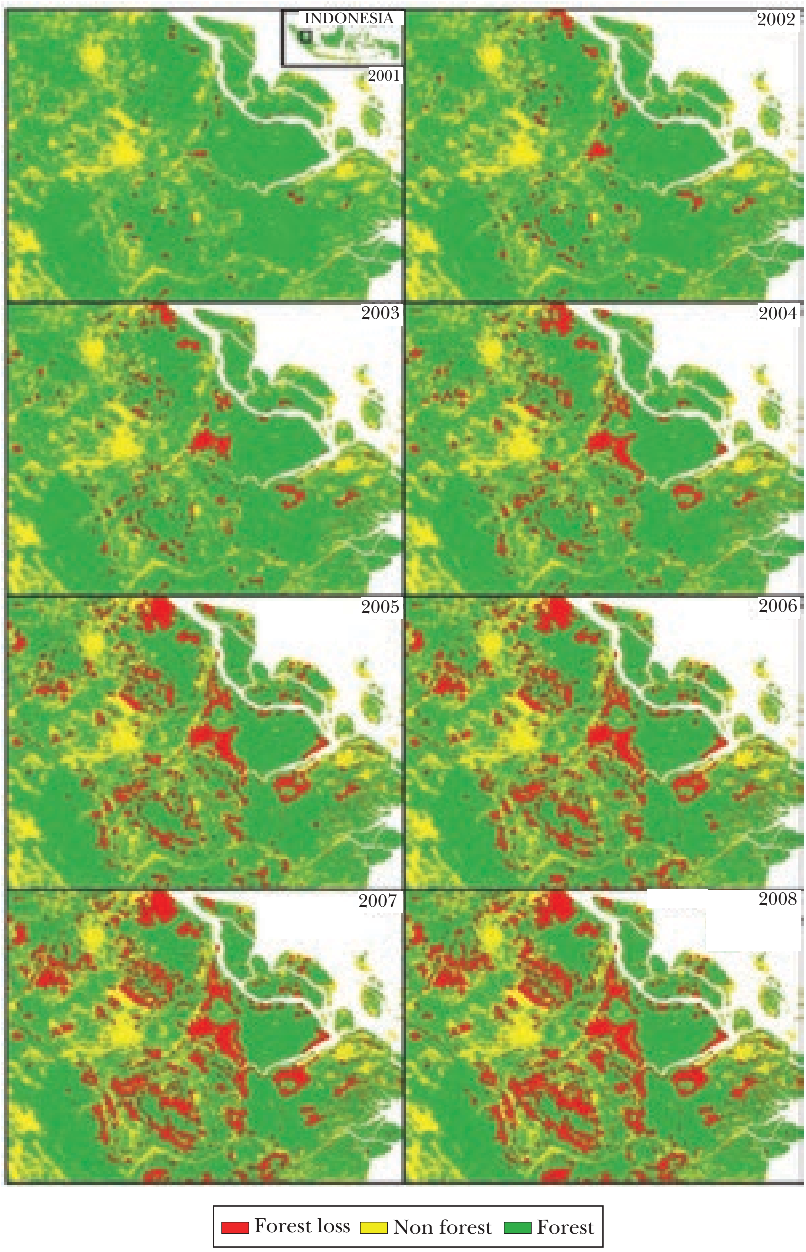
The first advantage is simply that remote sensing technologies can collect panel data at low marginal cost, repeatedly, and at large scale on proxies for a wide range of hard-to-measure characteristics. We discuss below economic analysis that already uses remotely sensed data on night lights, precipitation, wind speed, flooding, topography, forest cover, crop choice, agricultural productivity, urban development, building type, roads, pollution, beach quality, and fish abundance. Many more characteristics of potential interest to economists have already been measured remotely and used in other fields. Most of these variables would be prohibitively expensive to measure accurately without remote sensing, and there are settings in which the official government counterparts of some remotely sensed statistics (such as pollution or forestry) may be subject to manipulation.

As an example of this first advantage, access to previously unavailable data, consider Burgess et al. (2012), who study deforestation in Indonesia. Forestry is highly regulated in Indonesia, but local officials are sometimes bribed to overlook illegal logging. Thus, administrative statistics, produced in collaboration with such officials, are subject to concerns about misreporting. Satellite data allowed Burgess et al. (2012) to measure deforestation—an example of which can be seen in Figure 1—in an objective manner, and thereby to shed new light on the political economy of natural resource appropriation. Consistent with Cournot competition across jurisdictions, these authors find that each additional district created in a province induces an 8.2 percent increase in the province's deforestation rate. In principle, with higher spatial and temporal resolution, enough satellites and improved algorithms, future work could track forest cover or agricultural output (even at the level of individual plots) globally.

Figure 2 illustrates a second example where novel satellite data made an important study possible. Jayachandran (2009) estimates the impact of air pollution (particulate matter) resulting from Indonesia's devastating late-1997 forest fire on infant and fetal mortality. Using daily satellite sensor readings about airborne smoke and dust, Jayachandran measures the spread of pollution and estimated that this two-month event caused 16,400 infant and fetal deaths. New technologies are already being developed in order to measure other pollutants such as methane, a major greenhouse gas, perhaps even with the ability to resolve individual plumes.

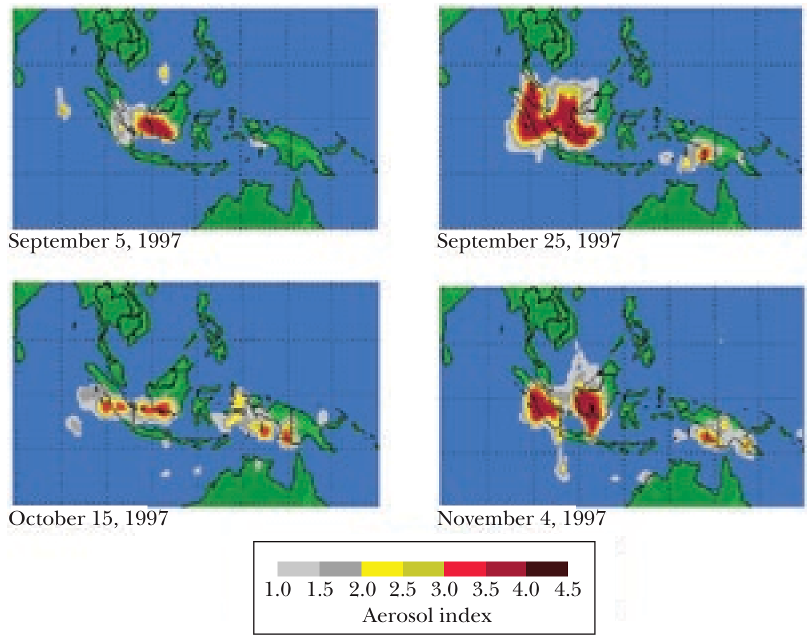
The second advantage of remote sensing data sources is that they are typically available at a substantially higher degree of spatial resolution than are traditional data. Much of the publicly available satellite imagery used by economists provides readings for each of the hundreds of billions of 30-meter-by-30-meter grid cells of land surface on Earth. Many economic decisions (particularly land use decisions such as zoning, building types, or crop choice) are made at approximately this same level of spatial resolution. But since 1999, private companies have offered submeter imagery and, following a 2014 US government ruling, American companies are able to sell imagery at resolutions below 0.5 meters to nongovernment customers for the first time. This is important because even when a coarser unit of *analysis* is appropriate, 900 1-meter pixels provide far more information available for signal extraction than a single 30-meter pixel covering the same area. In addition, some

Figure 1
Forest Cover over Time in Riau Province, Indonesia



Source: Burgess et al. (2012).
Note: Readers of the printed journal can check out the color versions of this figure in the article at the journal website.

Figure 2
Aerosol Index of Particulate Air Pollution in Indonesia during Massive Wildfires in 1997



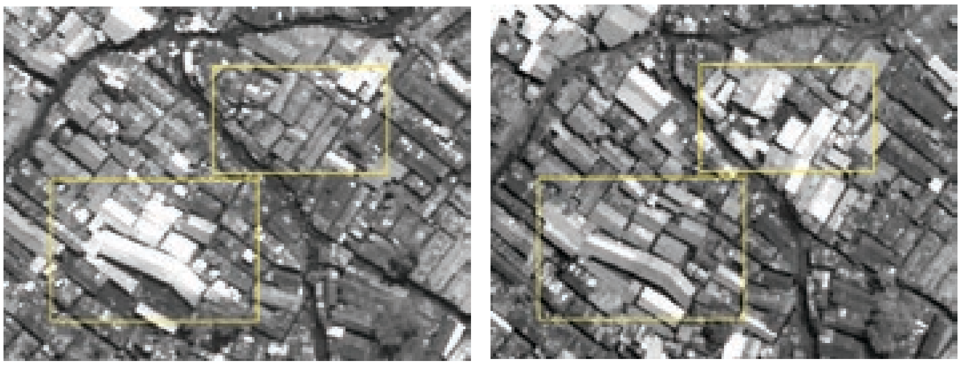
Source: Jayachandran (2006).

innovative identification strategies used by economists exploit stark policy changes that occur at geographic boundaries; these high-spatial-resolution research designs rely intimately on high-spatial-resolution outcome data (for example, Turner, Haughwout, and van der Klaauw 2014).

One example of this second advantage—high spatial resolution—offered by remote sensing comes from Marx, Stoker, and Suri (2015), who use 0.5-meter resolution imagery to measure a proxy for dwelling investments in a Nairobi slum. Figure 3 contains an example. In a context where most houses have corrugated iron roofs, newly replaced or improved roofs are more reflective than older, more rusted ones. These authors refined algorithms that can detect such differential reflectivity and used the resulting data to better understand the role of ethnic favoritism in residential markets in this setting. Market research firms similarly use imagery at this spatial resolution to count cars in parking lots to estimate retail demand, and in principle related algorithms could be used to measure automobile traffic or to count crowds at political rallies. With more high-resolution sensors and improved algorithms, these tasks could be done continuously and at low cost. Relatedly,

Figure 3
Roofs in Kibera, Nairobi

A: July 2009 B: August 2012



Source: Marx, Stoker, and Suri (2015).
Notes: This is a 50-cm resolution panchromatic image from Kibera, Nairobi. Roofs in the lower left rectangle dulled over time, while those in the upper right rectangle were replaced.

one could imagine trying to improve worldwide measures of building stocks and construction activity from the observed materials and height of built structures.

Of course, high spatial resolution is a relative concept. Even the 1-kilometer resolution NASA data on nighttime lights (Elvidge et al. 1997; Henderson, Storeygard, and Weil, 2012) offers a proxy for settlement patterns and wealth at substantially higher spatial resolution than is typically available. This has enabled creative studies of the spatial distribution of economic activity such as Bleakley and Lin (2012), who document the enduring persistence of US economic activity at sites of early commerce. Prior to the widespread use of canals or railroads, travel inland from the US southeast coast was impeded at the point where rivers cross a geomorphological feature known as the "fall line." Further navigation necessitated portage—reloading of cargo, overland, from one boat to another—and the sites at which such portage took place are almost without exception thriving cities to this day, well over a century after portage became obsolete. Figure 4 shows how this remarkable example of high-spatial-resolution path dependence in urban location is clearly visible in the pattern of night lights, while this relationship would be obscured by conventional US data sources at, for example, the county level.

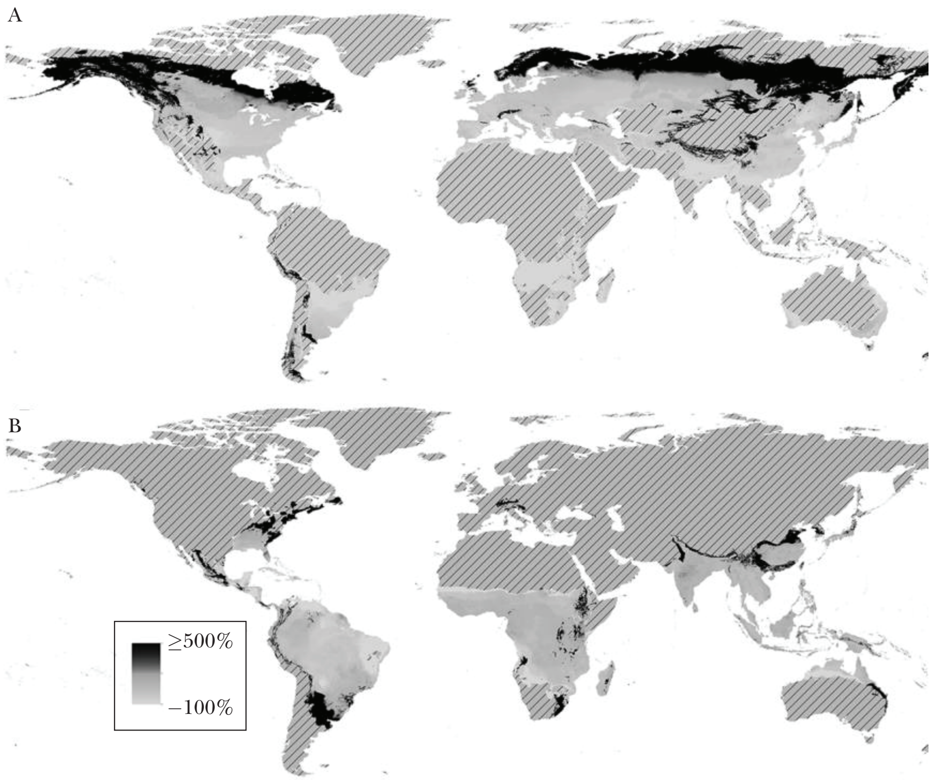
The third key advantage of remotely sensed data lies in their wide geographic coverage. Only rarely do social scientists enjoy the opportunities, afforded by satellites, to study data that have been collected in a consistent manner—without regard for local events like political strife or natural disasters—across borders and with uniform spatial sampling on every inhabited continent. Equally important, many research satellites (or integrated series of satellites) offer substantial temporal coverage, capturing data from the same location at weekly or even daily frequency for several decades and counting.

Figure 4
Night Lights in the United States and the Fall Line

Source: Bleakley and Lin 2012.
Notes: The figure shows night lights across part of the United States in 2003, illustrated with rivers (dotted lines) and the fall line (solid line). Substantial cities on the fall line, starting from the northeast, include Trenton, Philadelphia, Washington DC, Richmond, Augusta, Columbia, Little Rock, Fort Worth, Austin, and San Antonio.

An example of this third feature—global scope—can be seen in work on the economic impacts of climate change in agriculture by Costinot, Donaldson, and Smith (2016). These authors draw on an agronomic model that is partly based on remotely sensed data. The agronomic model, when evaluated under both contemporary and expected (2070–99) climates, predicts a change in agricultural productivity for any crop in any location on Earth. For example, the relative impact for two of the world's most important crops, rice and wheat, is shown in Figure 5. Costinot, Donaldson, and Smith feed these pixel-by-pixel changes into a general equilibrium model of world agricultural trade and then use the model to estimate that climate change can be expected to reduce global agricultural output by about one-sixth (and that international trade is unlikely to mitigate this damage, despite the inherently transnational nature of the shock seen in Figure 5). Given the rate at which algorithms for crop classification and yield measurement have improved in recent years, future applications of satellite data are likely to be particularly rich in the agricultural arena.

Figure 5
Predicted Yield Changes due to Climate Change for (A) Wheat and (B) Rice, Based on Global Agro-Ecological Zones (GAEZ) Models



Source: Costinot, Donaldson, and Smith (2016).
Note: Percentage change in predicted yield (between current baseline and the 2070–2099 period) in the GAEZ model. Areas with diagonal stripes indicate regions for which predicted changes are zero.

As these five examples illustrate, economists have learned a great deal from satellites in recent years. In addition to the three advantages described above, this is in no small part due to the fact that imagery from prominent satellites is publicly available, that platforms such as Google's Earth Engine dramatically ease the process of accessing and analyzing such data, and that there is a robust community of remote sensing users from which one can rapidly learn. In the next two sections, we describe the basics of remote sensing technologies and techniques, and then offer a summary of the many areas where satellite data have advanced the study of economics to date.

It is important to keep in mind that, while the science of remote sensing has advanced enormously since the pigeon era, serious challenges remain. A human who looks at a picture can tell whether the image is of an empty field, a pile of rocks, or the roof of an apartment building. It is no surprise that small-scale applications of remote sensing—for example, to monitor China's construction of military installations on islands in the South China Sea or Boko Haram's destruction of Nigerian villages—have recently enjoyed such prominence. But the more ambitious scale required of typical economics applications requires teaching a machine to make these distinctions, and that is no simple feat. We describe these and other challenges and potential pitfalls below. Ultimately, we believe that we are only at the beginning of a remote sensing data and software revolution, and that as these tools develop they will be of increasing importance to economists. We conclude with some speculative examples that we hope will help the reader to think of the possibilities that lie ahead.

A Primer on Remote Sensing For Economists

What do economists need to learn about remote sensing concepts?[1] In the broadest sense, remote sensing data are collected from above the Earth's surface using aircraft or spacecraft. Here we focus predominantly on satellite data, though a wealth of information is also collected from other spacecraft (such as the International Space Station and the Space Shuttle), as well as from planes and drones. We describe the essentials here, moving from the paths that satellites traverse, to the data that they can collect, to the ways in which these data can be processed and interpreted.

Orbits

Most remote sensing satellites operate in one of two orbits: geostationary or sun-synchronous. *Geostationary* satellites orbit the Earth in a way that keeps them directly above a fixed point on the Equator. Thus, they have the advantage of continuously observing the same area of the Earth's surface at all times—a key feature for national weather services, for example—and the corresponding disadvantage of not observing the rest of the world. Also, the physics behind geostationary orbits means that such satellites must locate approximately 36,000 kilometers above the Earth's surface, which means that their images are relatively low resolution.

Sun-synchronous satellites orbit typically within 6,000 kilometers and often much more closely. As their name implies, they observe the whole Earth at approximately the same time each day, ensuring constant solar illumination (conditional on latitude) at a given time of the year. Sun synchronous orbits are a type of (nearly) polar orbit, so named because they operate in a plane that (nearly) contains the North and South Poles. As a sun-synchronous satellite passes the equator on successive overpasses, the Earth has rotated to the east, and thus the satellite passes above an area to the west of its previous overpass. Sun-synchronous satellites can orbit Earth between 7 and 16 times per day, depending on their altitude. The lowest altitude

[1] A more comprehensive treatment can be found in remote sensing textbooks, including Jensen (2006); Campbell and Wynne (2011); Lillesand, Kiefer, and Chipman (2015); and Tempfli, Kerle, Huurneman, and Janssen (2009).

(and highest frequency) sun-synchronous satellites fly at an altitude of 282 kilometers, with an orbital period of 90 minutes.

The area covered in a given overpass of a satellite or other sensor is known as its "swath." This is essentially the width of the sensor's field of vision as it looks down at the Earth. With a wide enough swath, a sensor can record the whole Earth surface every day. Perhaps the easiest way to think of orbital swaths is through an analogy. If one were to cover a ball with a thin ribbon, one could do so as follows. Starting at the North Pole, wrap to the South Pole, and back around to the North pole, so that the ribbon has completed one orbit (circumference). Now rotate the ball about its axis and wrap again. Repeating this process in a way that minimized overlap at the equator, one would fully cover the ball after $C/2w$ wraps, where C is the circumference of the ball, and w is the width of the ribbon. With a wider ribbon (or swath), fewer orbits would be required to cover the ball.

A tradeoff arises here: holding constant other aspects of satellite and sensor design, the higher the frequency of repeat coverage, the lower the resolution. Thus, given current technology, satellites providing imagery at 1-meter resolution take weeks to obtain full Earth coverage, while kilometer-resolution sensors can provide daily global coverage. More regular coverage can be important. For example, Burgess et al. (2012) used 250-meter Moderate Resolution Imaging Spectroradiometer (MODIS) data with near-daily overpasses—unlike many other studies of deforestation based on 30-meter Landsat data with 16-day repeat overpasses—because they focused on rain forests that are covered by clouds most of the time. A given plot of land in such an environment might not have a cloud-free Landsat image for a year or more.

Sensors and Bands

A remote sensing satellite (or other platform) hosts one or more sensors, each of which may generate one or more independent data streams. A given sensor can observe energy in one or more bands, or ranges of the electromagnetic spectrum, corresponding to segments of the spectrum known as microwaves, infrared, ultraviolet, or visible light. Sensors emphasizing spectral resolution may record information about dozens (multispectral) or hundreds (hyperspectral) of bands. By comparison, the human eye can sense three bands, centered in the red, blue, and green regions of the spectrum.

Different bands, and combinations thereof, have different useful properties, as we will discuss in the applications below. As one example, plants reflect at different sets of frequencies at different stages of their life cycle. For this reason, functions of reflectance in specific portions of the visible and infrared spectra can provide information about vegetation growth. This insight is used to produce the commonly used Normalized Difference Vegetation Index (NDVI). Infrared data can also be used to measure temperature and, indirectly, precipitation when applied to clouds (for example, Novella and Thiaw 2012).

Most sensors used by social scientists are "passive," meaning that they observe energy emitted directly from the Earth or, more typically, reflected off the Earth from the Sun. In contrast, "active" sensors, such as radar and LiDAR, emit radiation and record some property of that radiation when it is reflected back, typically its transit time. Radar is the technology behind the Shuttle Radar Topography Mission (SRTM), a common source of global elevation data recorded by the Space Shuttle in 2000. LiDAR is a technology similar to radar that uses reflectance of laser emissions rather than sound. Especially on aircraft, LiDAR is used to precisely measure elevation and building heights.

Intermediate Processing

Social scientists almost never use raw satellite data. Extensive processing is typically required to make data comparable and interpretable, and there is an active remote sensing literature developing and refining these methods and applying them to new and existing datasets. In remote sensing parlance, raw data are called Level 0 data, while data providers often release Level 1 or Level 2 data, with each higher level reflecting further processing. We briefly describe some key steps here.

Within a given swath, a satellite views the locations it is passing directly over (at nadir) from a right angle, but it is simultaneously viewing other locations at different angles. "Orthorectification" transforms the resulting images to account for these differences in angles, as well as an analogous distortion due to elevation differences. Similarly, raw data are typically in a reference frame corresponding to a swath, but they can be projected to the user's geographic projection of choice. The most common projection for distributing global remote sensing data, as well as many other datasets, is Plate Carrée—sometimes referred to as "latitude-latitude," or, confusingly, "unprojected" or "geographic"—in which a spherical degree of longitude is assigned the same Cartesian length as a degree of latitude. Of course, no projection of a spherical surface to a plane can preserve distances, areas, and directions. Plate Carrée distorts East-West distances (and therefore areas) in proportion to the cosine of latitude. In general, any such re-projection necessarily involves combining information from multiple input pixels.

Data for a given region of interest may be drawn from multiple overlapping swathes. Such data can be combined in a process sometimes known as "mosaicking," which can help in reducing random error (noise) or other unwanted features. For example, when investigating land cover, areas covered in clouds do not contain useful information (in bands for which clouds are opaque). Multiple images, captured on several different days, may be combined (that is, averaged or mosaicked) in order to obtain a cloud-free composite image.

Interpretation

While some applications discussed below involve relatively direct conversion of sensed quantities for individual pixels to physical quantities of interest (such as night lights, greenness, elevation, particulate concentration, or temperature), many others instead involve classifying pixels, each of which is a vector of quantities in different bands, into a discrete set of land cover categories. More complex forms of classification use contextual information (that is, information on neighboring pixels) to help classify a given pixel. This potentially allows algorithms to identify shapes consisting of multiple pixels, typically known as objects, and find edges between them.[2] Objects might include cars, buildings, or agricultural plots. For any given object size, higher spatial resolution, more bands in relevant spectra, and a more frequent repeat cycle all provide more information to help with identifying the object.

Classification is generally subjective, in the sense that the same underlying data can be summarized in substantially different classifications. At the same time, classification is guided by decades of prior art in the remote sensing and computer science literature. While much of this work has been done on individual scenes on the order of hundreds or thousands of square kilometers, global datasets are increasingly common.[3] One broad distinction is between *unsupervised* classification, in which the data are partitioned into clusters without additional information, and *supervised* classification, which relies on training datasets to assign data to pre-specified classes. As an example of supervised classification that is particularly intensive in the use of external information, the Vogelmann et al. (2001) land cover data (used by Burchfield et al. 2006, as discussed below) supplements satellite data with aerial photography and census data to classify land cover and land use.

Sophisticated supervised classification systems increasingly rely on machine learning techniques. A critical input to these and other methods is the availability of training data on the variable of interest that assigns ground truth values to sample sites. For example, delineating imaged urban neighborhoods as residential, or even more specifically as slums, requires first providing a set of areas pre-defined as slums by other means. Doing so well requires a training dataset that reflects the full diversity of distinct neighborhoods within the category of slums. This is especially challenging when the object of interest is heterogeneous or imprecisely defined. But even for well-defined land cover, such as an individual crop species, differences in density, growth stage, solar angle, cloud cover, and neighboring land cover will generate a variety of signals, so that ground truth data reflecting the full heterogeneity will improve classification accuracy. Relatedly, training data should ideally be as close to the desired final outcome as possible. One could imagine economists using remotely sensed information on buildings to estimate a region's capital stock; in such a case, the ideal training data would concern building values instead of building types.

Because these training datasets are used to define the classes underlying a classification algorithm, they must be produced outside the algorithm. Thus, they are typically a labor-intensive analog constraint on a technology that otherwise can operate with all the scale benefits of computer processing.

[2] These methods are related to those used in image analysis more generally. See Glaeser, Kominers, Luca, and Naik (2015) and Naik et al. (2015) for two recent examples of economic analysis drawing on Google Streetview images.

[3] For a review of recent work in human-related land cover classification at the global scale, see Small and Sousa (2016).

Prominent Existing Data Sources

Economists have used data derived from many different satellites and sensors. Table 1 lists a few of the most prominent. A comprehensive database of essentially all declassified and unclassified remote sensing satellites ever launched except for the very smallest, complete with information on onboard sensors and application areas, can be found in the World Meteorological Organization's OSCAR database: http://www.wmo-sat.info/oscar/. A series of eight satellites in the Landsat program have been collecting data since 1972. The MODIS sensor has flown on two satellites since 1999. It provides coarser resolution data than Landsat, but has been useful in producing high-frequency imagery, and data on important phenomena including particulate pollution and fires. Night lights data from the Defense Meteorological Satellite Program–Operational Linescan System (DMSP-OLS), and Visible Infrared Imaging Radiometer Suite (VIIRS) sensors are even coarser, spatially and spectrally, but their simplicity has made them easy for economists to use. The 2000 Shuttle Radar Topography Mission (SRTM) provides the most comprehensive elevation data to date. Finally, a rapidly increasing trove of high-resolution images is being captured by private sector firms, including Spot Image and Digital Globe and, more recently, Planet and Terra Bella.

Auxiliary Gridded Datasets

Remote sensing datasets are typically recorded and stored in the form of large grids of pixels, with each pixel corresponding to a geographic location. Grids are more efficiently stored than points because once one corner, the cell size, and the overall dimensions are defined, no pixel-specific location information is required. Several other datasets, not collected by satellite, have been organized in the same gridded fashion to facilitate analysis in combination with the satellite data. For example, Gridded Population of the World is a lightly modeled population surface, while LandScan and WorldPop are more heavily modeled population datasets. G-Econ offers a set of modeled GDP estimates (Nordhaus 2006), while the FAO-IIASA's Global Agro-Ecological Zones (GAEZ) project from the Food and Agriculture Organization and the International Institute for Applied Systems Analysis has seen widespread use among agricultural economists.[4]

Applications of Remote Sensing Data in Economics

We now discuss a series of applications of remote sensing data that have been used in the economics literature to date—though our remit is to provide examples rather than to be comprehensive. For ease of reference, we organize our discussion

[4] See the Gridded Population of the World (GPW) at http://sedac.ciesin.columbia.edu/gpw/; LandScan at http://web.ornl.gov/sci/landscan/; WorldPop at http://www.worldpop.org.uk/; and Geographically based Economic data (G-Econ) at http://gecon.yale.edu/; and Global Agro-Ecological Zones (GAEZ) http://gaez.fao.org/.

Table 1
Main Satellite Data Sources Used in Economics

Source	*Economics applications*	*Highest resolution*	*Pricing*	*Availability by year*	*Examples*	*For more information*
Landsat	Urban land cover, beaches, forest cover, mineral deposits	30 m	Free	1972– (8 satellites)	Foster and Rosenzweig (2003); Faber and Gaubert (2015)	http://landsat.usgs.gov/
MODIS	Airborne pollution, fish abundance	250 m	Free	1999– (Terra); 2002– (Aqua)	Foster, Gutierrez, and Kumar (2009); Burgess et al. (2012)	http://modis.gsfc.nasa.gov/
Night lights (DMSP-OLS, VIIRS)	Income, electricity use	~1 km	Free digital annual (DMSP- OLS) and monthly (VIIRS) composites	Digital archive 1992–2013+ (VIIRS 2012–; film archive 1972–1991)	Henderson et al. (2012); Chen and Nordhaus (2011)	http://ngdc.noaa.gov/eog/
SRTM	Elevation, terrain roughness	30 m	Free	2000 (static)	Costinot, Donaldson, and Smith (2016) via Global Agro-Ecological Zones (GAEZ) data	https://lta.cr.usgs.gov/SRTM
DigitalGlobe (including Quickbird, Ikonos)	Urban land cover, forests	< 1 m	Not free	1999– (6 satellites)	Marx, Stoker, and Suri (2015); Jayachandran, de Laat, Lambin, and Stanton (2016)	https://www.digitalglobe.com/resources/satellite-information

around the type of physical phenomenon being considered in each application. In each case, the work of economists is based on decades of work on sensor and algorithm design and interpretation by researchers and practitioners in the remote sensing community. For brevity, we generally limit discussion to a few papers on each topic in the economics literature, and encourage interested readers to seek out the relevant remote sensing literature cited in those papers.

Night Lights

Total visible light emitted from Earth's surface at night has become a commonly used proxy for local economic activity. These data have been obtained primarily from the DMSP-OLS sensor, which offers nominal 1-kilometer resolution, and are now easy to access and process. They can plausibly be used as a proxy for economic activity under the assumption that lighting is a normal good. In this sense, the use of lights data follows the same logic behind a great deal of earlier work that uses data on consumption decisions to proxy for income under the assumption that Engel curves are stable (for example, Bils and Klenow 2001; Costa 2001; Young 2012).

While the cross-sectional correlation between lights and human activity has been noted since shortly after declassification of these data in 1972 (Croft 1973; Doll, Muller, and Morley 2006), the use of lights data expanded dramatically after the development of new processing methods and the distribution of a digital archive by the National Oceanic and Atmospheric Administration (NOAA) in the 1990s and 2000s (Elvidge et al. 1997). The accuracy of lights as a proxy for economic growth has been the subject of formal econometric scrutiny only recently, starting with Henderson, Storeygard, and Weil (2012). In an annual panel of countries from 1992 to 2008, as well as the corresponding long difference, these authors estimate a lights-GDP elasticity of 0.28 to 0.32, with no evidence of nonlinearity or asymmetry between increases and decreases in lights. In the long difference, the lights-GDP relationship has a correlation coefficient of 0.53. Under a range of assumptions about measurement error of GDP in countries with good data, they estimate a structural elasticity of lights growth with respect to GDP growth of between 1.0 and 1.7.[5]

Henderson, Storeygard, and Weil (2012) focused on aggregate country-level lights in order to make comparisons with traditional GDP data, harnessing the independence of errors between the two data sources. By contrast, a subsequent and innovative literature has used lights as a proxy for economic activity within fine geographic units for which no alternative data source is available. Such units include cities (Harari 2016; Storeygard 2016), ethnic homelands (Michalopoulos and Papaioannou 2013, 2014), subnational administrative units (Hodler and Raschky 2014), larger uniform grid squares (Henderson, Squires, Storeygard, and Weil 2016), and around natural features such as rivers (Bleakley and Lin 2012, as discussed earlier). Lee (2016) has also used the night lights data to estimate economic activity in North Korea, whose government produces no credible economic statistics. The many additional novel uses of night lights data in recent work are too voluminous to fully capture here.

Thus, even one of the most rudimentary sources of satellite data (luminosity at night, aggregated to annual frequency, with 1-kilometer resolution, at best, and just one useable band) has enabled economists to answer important questions in new and convincing ways. This only serves to underscore the great potential that lies ahead for the use of remote sensing data in economics.

Climate and Weather

A vast literature in economics has studied the impact of short-run weather fluctuations and longer-term climate trends on human activity (for a survey, see Dell, Jones, and Olken 2014). This weather–economy relationship is both of interest in its own right (for example, as an input into an improved understanding of the impacts of climate change) and as a source of plausibly exogenous income or cost variation in agricultural or resource-dependent settings.

[5] Chen and Nordhaus (2011) develop an alternative method and arrive at more pessimistic view of the lights data. For a bibliography of early lights work at NOAA, see http://ngdc.noaa.gov/eog/pubs_new.html.

But in many parts of the world, data-collecting weather stations are extremely sparse. Thus, researchers estimate measures of interest by combining three ingredients: weather data from meteorological stations (when available); remotely sourced readings that are available for a wider range of locations, such as cloud-cover and cloud-top temperature; and a climate model. In effect, the researcher uses a climate model and remotely sensed readings about certain meteorological phenomena that are not of direct interest (cloud-top temperature, for example) to interpolate intelligently between station-level readings of direct interest (on rainfall, for example).[6]

Two examples of recent work on Africa draw particularly strongly on the fine spatial resolution of this weather data. First, Harari and La Ferrara (2015) combine 1-degree gridded weather data with data on conflict events in Africa (the PRIO/Uppsala Armed Conflict Location and Event Dataset). The within-country spatial resolution of such datasets allows these authors to estimate spatial spillovers of conflict—how drought in one cell can cause armed conflict both in that cell and in other cells nearby—that are surprisingly large relative to the existing literature that had used country-level data. For example, these authors find that every conflict event in one subnational grid cell causes the risk of conflict in each of the eight adjacent grid cells to rise by 3.6 percentage points. Naturally, an additional advantage of satellite-sourced weather data in this setting is that ground-based weather reporting may be jeopardized during periods of conflict. Second, Kudamatsu, Persson, and Stromberg (2016) match weather data to the Demographic and Health Surveys in all 28 African countries in which GPS coordinates were recorded for individual survey clusters. This allows them to conduct a detailed investigation into the extent to which infant mortality in Africa is related to weather variation; in fact, the spatial precision involved allows them to estimate the extent to which weather affects infant mortality through particular channels such as malaria or malnutrition.

A number of other innovative weather attributes derived from satellite imagery have been used by economists. These have been incorporated into studies of the impact of flooding (Guiteras, Jina, and Mobarak 2015) and cyclones (Yang 2008; Hsiang and Jina 2014), as well as the use of wind speed and direction as a creative source of variation in predicting colonial settlement patterns (Feyrer and Sacerdote 2009) and the extent to which oceanic trade routes were disrupted by the adoption of steam shipping in the late nineteenth century (Pascali 2015). Guiteras, Jina, and Mobarak (2015) make the surprising observation that households do not recall inundation events very accurately, especially in areas where floods are routine, thereby highlighting the importance of the objectivity that satellites can provide.

Topography

High-resolution maps of elevation—and hence a reasonable approximation to topography—commonly known as “digital elevation models” (DEMs)—have

[6] Auffhammer, Hsiang, Schlenker, and Sobel (2013) provide details about these climate models and derived weather products, particularly as used by economists.

seen many recent applications to economic questions. Easily accessible DEMs have been produced globally at 30-meter resolution using remote sensing instruments, including the Shuttle Radar Topography Mission (SRTM) and the satellite-based Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER).[7] Such DEMs superseded an earlier generation of DEMs that were built from decades of aerial photography (via stereophotogrammetry) and centuries of surveying, providing globally uniform high resolution.

One prominent application of a digital elevation model comes from the urban literature. Following Burchfield et al. (2006), Saiz (2010) measures the geographic constraints on expansion that US cities face.[8] Drawing on data from the US Geological Survey, Saiz calculates the fraction of area within a 50-kilometer radius of a city that neither has a slope greater than 15 percent nor is covered by a body of water. This measure is important in its own right, but its widest use to date has been to provide a source of exogenous variation in urban land supply for the large literature that aims to estimate determinants of urban housing demand. Recent examples include Mian and Sufi (2014) on the extent to which housing decline caused unemployment and Hsieh and Moretti (2015) on the aggregate misallocative consequences of housing supply regulations.

Topographical variation can also be applied to study the economic impact of large infrastructure investments. For example, Duflo and Pande (2007) seek to estimate the effects of large dams in India, which are used for both irrigation and hydropower. In order to isolate plausibly exogenous variation in the spatial placement of dams, these authors argue that dams are most likely to be viable when they are built in locations in which the course of a river is neither too shallow nor too steep—locations that that can be identified using a digital elevation model. This geographical measure, interacted with further time-series determinants of the rate of dam-building, is indeed highly predictive of where dams were built in India over the past 50 years. The authors' resulting instrumental variable estimates of the impact of dams on poverty and agricultural productivity reveal that these controversial projects do not appear to generate enough economic benefit to justify their (substantial) construction costs. Dinkelman (2011) and Lipscomb, Mobarak, and Barham (2013) developed refinements of this approach in their studies of the impacts of electrification in South Africa and Brazil, respectively.

Remotely sourced topographic data also serve as an indirect input into a large body of work on the economics of agriculture. A number of studies model a production possibilities frontier, which requires that the researcher be able to predict the suitability of a given crop at a given location, regardless of whether that crop is actually grown in that location. Conventional output data cannot be used for such

[7] SRTM data are not available at high latitudes, beyond 60 degrees north and 54 degrees south. Prior to 2014, the US government only released SRTM data outside the United States at 90-meter resolution, but they are now available at full 30-meter resolution globally. ASTER elevation data are newer and have different limits and advantages, including availability at high latitudes.

[8] Pioneering work by Qian (2008) and Nunn and Puga (2012) also aims to understand how a region's terrain ruggedness impacts its economic characteristics.

a purpose but agronomic models, such as GAEZ, enable such predictions by using characteristics of the location (including its topography, from a remotely sourced digital elevation model) and crop as modeling inputs. The result is a prediction about the yield that could potentially be achieved for any crop at any location on Earth. As discussed above, Costinot, Donaldson, and Smith (2016) draw on such predictions about the global agricultural production possibility frontier (both in the current climate and in the future climate predicted by climatologists) to study economic consequences of climate change in an integrated world economy. Earlier versions of the GAEZ data were used in Nunn and Qian's (2011) study of the impact of the discovery of the potato in the New World on Old World living standards and Alesina, Giuliano, and Nunn's (2013) test of the hypothesis that modern-day gender roles have roots in traditional agricultural practices such as the use of the plough. In both cases, the GAEZ model provides a unique input into the agricultural possibilities of any given location, regardless of whether those possibilities are being exploited at a given point in time.

Agricultural Land Use and Crop Choice

Satellite data have been used with rapidly improving accuracy to measure aspects of agricultural land use. Two recent studies draw on the USDA's Cropland Data Layer (CDL), which classifies 30-meter pixels throughout the United States into crop-specific categories, to evaluate some of the incentives that American farmers face. First, Scott (2014) investigates how US agricultural policy alters dynamic incentives for the preparation of land for crop agriculture. Given the lumpy nature of dynamic cultivation decisions, this question would be far more challenging without such high spatial precision. Holmes and Lee (2012) harness the CDL's crop-specific nature to estimate the extent to which crop choice patterns within land ownership parcels are more correlated than those across such parcels, as would be expected if economies of density at the farm level are substantial.

Another area of focus aims to measure the volume of agricultural output at a location. The simplest such efforts—used, for example, by the Kudamatsu, Persson, and Stromberg (2016) study referred to above—aim to capture a broad measure of agricultural productivity, which is typically done by measuring a normalized difference vegetation index (NDVI). The challenge here is that remote sensors capture increase in greenness, which may include growth in nonagricultural plants that are not the user's focus. For this reason, the use of NDVI data in agricultural applications can be enhanced with land-use classification that identifies cropland. Improved measures of remotely sensed yield measurement—such as those used in the production function estimates from Nebraska by Farmaha et al. (2016)—suggest that future applications in this area could be particularly rich.

Urban Land Use

Perhaps the starkest distinction in land use is between urban and nonurban areas. Small, Pozzi, and Elvidge (2015) and Small, Elvidge, Balk, and Montgomery (2011) carried out early work on urban extent using the night lights data. In a path-breaking study of the determinants of urban sprawl, Burchfield et al. (2006) draw on two datasets, Vogelmann et al. (2001) and US Environmental Protection Agency (1994), that classify US land cover in 1992 and approximately 1976, respectively. After careful integration of the two datasets, these authors can track both urban (residential, commercial, and industrial development and transportation networks) and nonurban (water, bare rock and sand, forest, range and grassland, agricultural land, and wetlands) land cover categories over time. The resulting 30-meter data allow Burchfield et al. (2006) to document the striking extent to which recent US urban development has taken place in grid cells in close proximity to previously developed cells. Urban growth appears to have taken place with very little spatial "leapfrogging" across undeveloped cells.

Another classic topic in urban economics concerns the incidence of land use regulation policy. Turner, Haughwout, and van der Klaauw (2014) use the satellite-derived (30-meter resolution) National Land Use and Land Cover dataset (NLCD) in order to measure the impact of municipal land use regulations in the United States (as measured by the Wharton Land Use Regulation data). From a spatial regression discontinuity analysis across straight-line municipal boundaries, these authors conclude that a one standard deviation increase in regulations reduces land values by about one-third. In addition, the richness of the data allows Turner, Haughwout, and van der Klaauw (2014) to estimate spatially decaying spillover effects of land regulations (which appear to be small).

Building Types

An active research frontier is using remote sensing data to identify individual buildings, and to classify these buildings by type. For example, Casaburi and Troiano (2016) highlight an innovative use of aerial photography by the Italian government to find buildings not registered for property tax collection. Though these authors do not use the photographs directly, their analysis draws on the resulting counts of unregistered buildings obtained from aerial photographs to study the political ramifications of the intensity with which this program was used to prevent tax evasion.

Two recent studies from Nairobi have made important progress with extremely high (0.5-meter) resolution imagery. First, as described above, Marx, Stoker, and Suri (2015) use satellite data to detect the new, or better maintained, corrugated iron roofs that are indicative of higher-quality housing. Interestingly, even though these authors had also conducted a household survey with rich attribute information, they find that the satellite-derived measure of housing quality is a useful additional measure because it is not subject to recall bias. Second, Henderson, Regan, and Venables (2016) rely on imagery spanning multiple years to consider a dynamic model of city land use with formal and informal sectors. These authors combine data on building heights and imagery from aerial photography and satellites on building and road footprints in order to consider changes in building volumes in the data-poor environment of this low-income city. This study is unique because the novel data employed allow the authors to test the implications that urban models typically have for building density with direct data about buildings, rather than with indirect proxies such as population.

Natural Resources

Large-scale deforestation has been quantified via satellite since at least Skole and Tucker (1993). But the first application of such data in an economic model came from work by Foster and Rosenzweig (2003), who harnessed three decades of Landsat data in seeking to understand the rise in forest cover that India (in common with many other countries) has seen since the late 1950s. These authors combine satellite data with village-level survey data to document that forest growth appears to be caused by growth in the demand for forest products (such as wood fuel) due to income growth, and not by supply-side factors (such as land and labor prices) in the forestry sector.

Other work has focused on the ability for satellite data to monitor illegal logging activity, as discussed in our introduction. Two recent studies have used innovative research designs in this context. First, Burgess, Costa, and Olken (2016) demonstrate, via a spatial regression discontinuity design using 30-meter resolution satellite data, just how suddenly Brazil's 2006 anti-deforestation policy affected land use choices there. Second, Jayachandran, de Laat, Lambin, and Stanton (2016) combine a randomized controlled trial with bespoke satellite images (commissioned from the QuickBird satellite by the authors) and algorithms that are sufficiently rich as to detect individual trees owned by farmers in Uganda. In doing so, they document the powerful impact of a payment-for-ecosystem services program in reducing deforestation.

The possibilities for tourism are another resource that can be inferred from remotely sensed data. Faber and Gaubert (2016) pursue such a strategy in order to estimate the effect of tourism on economic development. They isolate plausibly exogenous variation in tourism supply across municipalities in Mexico by focusing on a metric of beach quality, which can be constructed by isolating the distinctive features (in six Landsat bands) of four of Mexico's top-ranked beaches in an industry journal, and then searching for other areas of coastline with similar spectral characteristics. This measure of beach quality is a strong predictor of the relative extent of tourism along Mexico's coastline (excluding the top four beaches) today. A surprising result that emerges when the authors use this variation is that tourism appears to have positive effects on the size of even tradable, nontourism sectors (such as manufacturing) in the same municipality.

Finally, Axbard (2016) documents a connection between income shocks due to reduced fishing opportunities and increased piracy in Indonesia using remotely-detected data on chlorophyll and building on the established correlation (in the marine biology of this study region) between chlorophyll and fish abundance. This sea-based data proves useful in this study because it varies in a way that is orthogonal to land-based incomes and policies. Furthermore, chlorophyll does not have a direct effect on other actors; critically in the context of studying piracy, it does not directly constrain sea travel for cargo or enforcement.

Pollution Monitoring

Environmental monitoring is another promising research area, particularly involving air conditions. Ground-based air pollution monitoring stations are not widespread in developing countries, and they are potentially subject to government manipulation. For this reason, as discussed above, Jayachandran (2009) draws on remote sensing work establishing the relationship between aerosol optical depth from the satellite-based Total Ozone Mapping Spectrometer and standard measures of airborne particulate matter in order to measure the air pollution caused by forest fires in Indonesia. Foster, Gutierrez, and Kumar (2009) document the effect of air pollution, measured similarly using MODIS data, on infant mortality, using an instrumental variable based on a voluntary certification policy applied to manufacturing firms. Chen, Jin, Kumar, and Shi (2013) and Bombardini and Li (2016) evaluate potential causes of air pollution (government policy and international trade patterns, respectively), and are able to compare the satellite data with ground-based monitoring systems in a context where pollution is a politically contentious matter.

Combinations of Sources

An exciting research avenue concerns the use of broad sets of satellite data, combined with techniques from machine learning, to obtain predictors of a phenomenon of interest. This type of work has not yet seen much application in economics. But in one important recent example, Xie, Jean, Burke, Lobell, and Ermon (2016) develop high-resolution predictors of household income, wealth, and poverty rates in five African countries. Their algorithm combines information from a standard image classification database (drawing on both night lights data and 3-meter resolution daytime imagery) with real measures of consumption and assets, available for larger spatial units, from national-level Demographic and Health Surveys and the Living Standards Measurement Survey. This method has the potential to provide estimates of economic well-being at spatial and temporal frequencies that are an order of magnitude higher than those that are commonly available. These estimates could then be used as dependent or independent variables in future research, at least subject to the caveat that these estimates would be problematic for use in a study involving any variable that was itself used as an input into these well-being estimates.

Potential Pitfalls in the Use of Remote Sensing Data

Economists who use these and other remote sensing data will face some challenges that are unique to these data, and some that arise in other settings as well. Here, we focus on issues concerning dataset size, spatial dependence, measurement error, and privacy concerns. For an overview of the econometric issues associated with spatial data and large datasets, useful starting points are Gibbons, Overman, and Pattacchini (2015) and Varian (2014), respectively.

One set of challenges arises from the complexity of many remote sensing datasets. The land area on Earth can be subdivided into hundreds of billions of 30-meter grid cells, and hundreds of trillions of 1-meter cells. Such high-dimensional data can be difficult to model, even with the simplest linear functions. Yet remotely sensed dependent variables are often discrete or truncated in some way, so linear analysis is unlikely to be appropriate. Relatedly, part of the excitement of the new remote sensing data lies in its promise for informing and disciplining economic theory, but solving even simple models with the sort of spatial heterogeneity afforded by enormous datasets will require advances in the tools that economists use to solve for equilibria in high-dimensional spatial models. Some recent progress has been made in this area, including Allen and Arkolakis (2014), Krusell and Smith (2015), and Desmet, Nagy, and Rossi-Hansberg (2015).

Satellite data often display substantial spatial dependence: local correlation among nearby units. Here an important distinction is whether the data are being used as a dependent or independent variable. When spatial dependence appears in the dependent variable, then the error term in a multivariate regression that seeks to explain that variable will no longer be distributed independently. As a result, statistical inference should be conducted with attention to the dependence across units; for example, Pinkovskiy (2013) discusses how this can be done in the context of regression discontinuity designs when using remote sensing data.

When the remote sensing data is used as an independent variable, then estimates of all the regression coefficients are potentially biased (if one hopes to use them to make counterfactual predictions), unless adjustments are made to allow for the possibility that treatment in one spatial unit could have a causal effect on outcomes not just in that unit, but also on other units. For example, as Bleakley and Lin (2012) show, the causal effect of historical portage sites on the location of economic activity today is clearly evident from Figure 4. But, as these authors make clear, it would be wrong to conclude from this evidence that aggregate US economic activity would be higher today if only there had been more sites for portage in 1800—it is far more likely that when activity concentrated at portage sites, it displaced activity elsewhere. In more technical terms, the problem of spatial dependence here is a violation of the so-called "stable unit treatment value assumption," as in Rubin (1990). Recent examples of strategies for addressing this bias include Crepon et al. (2013), Acemoglu, Garcia-Jimeno, and Robinson (2015), and Donaldson and Hornbeck (2016).

These concerns about spatial dependence arise in many kinds of geographical data, but they are likely to be more acute at high spatial resolution. For example, for most questions that arise in spatial economics, the spatial dependency between the cities of Boston and New York is likely to be weaker than that between two neighboring 30-meter grid cells within Boston. In an agricultural context, if a region faces a completely inelastic demand curve for a given crop, then the total amount of that crop produced in the region will be fixed by the demand side, implying that any increase in production by one grid cell must displace, one-for-one, production by some other grid cell in the region.

Related to the issue of spatial dependence is the importance of understanding the nature of spatial relationships in any gridded dataset. There can be a tendency to equate dataset resolution with information density, but this intuition may not hold true in certain cases, especially for derived products that combine input data sources with multiple resolutions.[9] Relatively raw data can also exhibit mechanical spatial correlation. For example, the commonly used night lights data are distributed as a grid of cells that are one kilometer wide at the Equator and decreasing with the cosine of latitude, but each of these cells records light for a footprint roughly 3–5 kilometers in diameter, so in practice measurements are autocorrelated at that distance.[10]

Derived products combining multiple inputs also require care in overall interpretation. For example, across various literatures in natural and social science journals, nighttime lights have been used as inputs to gridded maps of income, poverty, electricity, impervious surface, in-use metal stocks, carbon emissions, and rice consumption. While each of these quantities is surely positively correlated with night lights, at least at the national level, the assumptions underlying each use are different and not always explicitly spelled out.

Measurement error raises a different set of concerns. Classification methods are generally subjective data reduction exercises, albeit ones refined by decades of algorithm development. False positives and false negatives are to be expected from any such exercise. While assessing and minimizing such errors is the stock-in-trade of remote sensing science, it is important to recognize that the types of errors that would seriously jeopardize a typical economic application of remotely sensed data are not always a main concern of the remote sensing community. Such issues can arise even when the relevant data product reports a relatively well-defined physical quantity. For example, the elevation recorded in the SRTM dataset generally corresponds to a point in the tree canopy, rather than the ground, in areas where tree cover is particularly dense (Hofton, Blair, and Rabine 2006). Thus, in applications for which ground elevation differences on the order of tree heights matter, there is a potentially problematic correlation between the measurement error in elevation and the type of local tree cover.

[9] An example from agriculture is the M3 Crops Database (Monfreda, Ramankutty, and Foley 2008). This product combines the best publicly available data on agricultural output (by crop) for relatively large subnational land units (for example, counties in the US case) with satellite data on the location of crop agriculture (relative to noncrop agriculture). Assuming that production is allocated proportionally (within each crop) to each grid cell within each subnational unit, this dataset provides interpolated estimates of output by crop at the resolution of the satellite data. The MapSPAM database (You et al. 2014) goes further and uses the GAEZ model described earlier, along with FAO price data at the national level, to assign crop totals to grid cells by revenue-maximization rather than pure proportionality. The result in both cases is a high-resolution proxy for crop-level output around the world, but neither dataset presents raw data by crop at the grid cell-level.

[10] A newer generation of sensor, the Visible Infrared Imaging Radiometer Suite, launched on the Suomi National Polar Partnership satellite in 2011, has a true sub-kilometer footprint and has the potential to overcome some other limitations of the DMSP-OLS sensor, though current versions have more noise, and the overpass time is much later, at roughly 1:30 AM (Elvidge, Baugh, Zhizhin, and Hsu 2013; Chen and Nordhaus 2015).

Even within the same data product or class of products, successive overpasses of the same location will in general be at (at least) slightly different times of day, angle of view, solar angle, and atmospheric conditions. The orbit of an individual satellite generally decays over its lifetime, sensors degrade, and replacement sensors, even within the same series, operate with subtle differences. Whether these differences affect interpretation will depend on the nature of the study. On the plus side, there are many contexts where error in remotely sensed measurements is plausibly orthogonal to error in human-collected data, so that the two can be used to instrument for each other to reduce measurement error. And while the continuous data underlying discrete datasets are often not made available, in principle they could be, enhancing economists' ability to consider classification error in an econometric framework.

Overall, it is essential for economists using remote sensing data to understand, and be skeptical of, the data and assumptions underlying them. Increased communication, and in some cases active collaboration, between economists and remote sensing scientists will be important in ensuring that the next wave of this kind of economics research is fruitful.

Finally, we note that at very high (submeter) resolution, satellites increasingly provide information that, if disclosed, might violate reasonable expectations of privacy. If such information comes from an image that a researcher orders from a satellite data provider (as opposed to purchasing from an inventory of already public images), thereby making it (potentially) public, this raises ethical and regulatory concerns related to human subjects research.

Concluding Remarks: The Promise of Satellite Data for Research in Economics

The cheap availability of high-resolution satellite imagery has already become a powerful tool in economics, just as it has in other research fields and in the private sector.[11] And costs are likely to continue to fall as entry in the satellite sensing industry has accelerated of late. Cheaper microsatellites (up to 70 or 100 kilograms), nanosatellites (up to 10 kilograms), and even picosatellites (up to 1 kilogram) are becoming more prevalent and more useful due to increasingly powerful lightweight components. Even among the mostly larger satellites covered in the OSCAR database, launches have been steadily increasing from the 5–7 launches per year that were common in the 1970s and 1980s to 15–18 launches per year from 2010–2015 (World Meteorological Organization OSCAR database at http://www.wmo-sat.info/oscar/). Indeed, such launches are becoming commonplace—within 48 hours of the date in September 2016 on which we happen to be writing this

[11] For example, Nagaraj (2015) shows—remarkably—that regions of the world with high idiosyncratic cloud cover at the instants the heavily used Landsat satellite was overhead have seen less local gold discovery in recent decades.

sentence, 11 satellites, each with best resolution near or below one meter, operated by two firms, are scheduled to be launched on three different rockets.

As the data collected by these orbiting machines increasingly offer greater spatial, temporal, and spectral resolution, and the algorithms and processing power used to interpret these data become more and more sophisticated, new potential applications are increasingly becoming feasible. We conclude with a few such examples.

In studying urban areas, aerial photography and some satellites can be used to count crowds of people and cars at events such as protests, political rallies, or peak shopping periods (for example, Kearns 2015; Swanson 2015). Similarly, traffic volumes could be measured from snapshots of car densities. This approach might be especially useful in areas including border controls and ports. Facebook is in the process of producing a map of buildings for several countries as a proxy for population density using billions of 0.5-meter resolution images as inputs (Simonite 2016). Measurements of disturbed soil or impervious materials could potentially track construction on an annual or even monthly basis.

In agricultural and resource economics, higher spectral resolution and continued algorithm development might allow for more automated distinctions between crops and noncrop vegetation, and increased temporal frequency may allow tracking of crop growth within seasons (Xie, Sha, and Yu 2008; Lobell 2013). NASA's GRACE satellite provides spatially coarse (1-degree) measures of soil moisture and groundwater depletion, via small changes in the local gravitational field. Economically important minerals located at the Earth's surface also have distinctive spectral and topographic properties that are routinely exploited in geology (for early and more recent reviews, see Goetz and Rowan 1981 and van der Meer et al. 2012, respectively).

New opportunities in environmental economics will also become available. Pollutants other than particulates, such as nitrogen dioxide, can be detected remotely (Geddes, Martin, Boys, and van Donkelaar 2015). Invasive plant species might be detected much like crops (Huang and Asner 2009). Precise trends in global forest cover change can be used in climate modelling (Hansen et al. 2013). Changes in sea level and its effects on coastal communities and ecosystems can be monitored from space.

As one example of many other possibilities, satellite imagery has been used for real-time conflict monitoring, for example in Darfur and Sri Lanka (UNITAR 2011), but not yet in long-term analysis of conflict, as far as we are aware. This research agenda for economists and other social scientists based on remote sensing data has made great strides in the last decade, but it seems safe to say that the real excitement lies ahead.

■ *We thank Treb Allen, Neeraj Baruah, Hoyt Bleakley, Jonathan Colmer, James Fenske, Matthew Gentzkow, Raymond Guiteras, Jon Hersh, Seema Jayachandran, Yongsuk Lee, David Lobell, Mushfiq Mobarak, Ben Olken, Henry Overman, Elias Papaioannou, Nancy Qian, Christopher Small, Matt Turner, and the editors of this journal for helpful comments on an earlier draft.*

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Journal of Economic Perspectives—Volume 30, Number 4—Fall 2016—Pages 199–220

Village and Larger Economies: The Theory and Measurement of the Townsend Thai Project

Robert M. Townsend

I have spent close to 20 years cataloging transactions between households in Thai villages, along with a research team. Just this past summer, we documented a number of ways in which even relatively poor villages have money markets not dissimilar in some ways from New York financial markets, with borrowing and repayment passing along links in credit chains. In another project, we have been looking at month-by-month school attendance, grade level completion, and graduation for children in these villages, following them from birth to graduation. This article tells the story of how I ended up in such endeavors.

First of all, why villages? Villages can be viewed as economies—not closed and self-contained economies, of course, but spatially concentrated units that trade with other villages and with the larger regional and national economy. More broadly, a set of villages may be connected to each other in the way that households within a village are connected to each other. For me, starting with villages made sense from the standpoint of general equilibrium theory. To some, general equilibrium theory may seem abstract and irrelevant. But in villages, the entire endeavor of modeling actual economies comes to life. In particular, assumptions about endowment, technology, and heterogeneity as well as contracts, markets, and institutions can be based on measured reality. Research on village economies has become commonplace in development economics, although often not proceeding from this general equilibrium perspective.

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† For supplementary materials such as appendices, datasets, and author disclosure statements, see the article page at
http://dx.doi.org/10.1257/jep.30.4.199 doi=10.1257/jep.30.2.199

I first studied medieval villages using historical data, and then studied villages in India using data from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Wondering myself if the three primary villages of the ICRISAT data were representative of the entire developing world, as it sometimes seemed from the existing literature, and having a personal attachment to Thailand through my wife, I set out from our home in Chiang Mai, in the north, in the early 1990s to study villages in that area.[1]

My approach in Northern Thailand might seem on the surface to have been a traditional anthropological method. Instead, it shows how I approach research and modeling. I went with a list of questions for the villagers, supplemented with open-ended and relatively unstructured interviews, while I was eating and sleeping in the villages over sustained periods of time. I would then retreat to my home base to review what I had learned, to ponder the puzzles that emerged, and then to rethink my models and predictions. This process was iterative and Bayesian.[2] Facts and assertions were sorted through the lens of theory, and then insights from theory were incorporated into new conversations in the field. Ultimately, final questionnaires were designed and administered to a small sample of households across ten villages in three distinct areas (Townsend 1995).

Starting in 1997, I decided to scale up this endeavor to four new provinces. After fielding the survey in these new provinces as a baseline, we selected a subset of villages to receive follow-up resurveys. In 1998, realizing that more fine detail could be developed with intensive monthly resurveys, we expanded our operations to a new but smaller sample of the baseline villages. Then, seeking to gain a better picture for the whole country, we extended the annual resurveys to more provinces and to urban areas within the previously selected and newly selected provinces. We are currently at 19 years of annual resurveys, 18 years of monthly resurveys, and counting. The Townsend Thai project is arguably the longest running panel anywhere in the developing world.

Although the Townsend Thai project collects a very broad range of data, concentrating on measurement would miss a substantial dimension of what makes the effort distinctive and fruitful. After all, government statistical agencies in low-income countries now carry out a substantial number of household surveys, including the Living Standards Measurement Surveys of the World Bank, the Family Life Surveys of Rand, and other unique, specialized databases used in development studies. The key contrast is that the Townsend Thai project is at its heart rooted in

[1] Christopher Udry (1995) and I were among the first of a new wave of development economists to actually do field research, though now of course it has become standard. At the time, some prominent development economists argued against going into the field to gather data, believing this should be left to country governments or international agencies. However, there is a grand tradition in agricultural economics to be on the ground and in touch with local populations.

[2] In general, the Bayesian approach to developing models offers an interesting perspective on randomized control trials, as well. A pure Bayesian armed with a prior, and seeking only to convince herself after compiling new evidence, will not choose to randomize (Banerjee, Chassang, and Snowberg 2016).

a drive to describe village economies through the lens of economic theory—specifically, the Arrow–Debreu model of an economy in general equilibrium—which has led to questionnaires and on-site data collection methods designed with theory very much in mind.

Moreover, I have a passion for realistic assumptions and panel data. Structure imposed on a model should be consistent with measured reality, and predictions should be free of functional form and distribution assumptions, as in nonparametric econometrics, in so far as possible. Both are ideals of course, and compromises must be made as practical considerations arise, but at least we are clear about the goal. The Townsend Thai project, in pushing this version of the structural approach, and in keeping the surveys running on the same households over time, might be said to have anticipated 20 years ago the current dynamic approaches to modeling household behavior.

In the following pages I will describe this underlying theoretical vision of the village as embodying an Arrow–Debreu economy. I review my earlier work on village economies, to set the stage for what I was seeking to accomplish with the Townsend Thai project. After a synopsis of the evolution of the Townsend Thai project, I describe research based on this data: the extent of risk-sharing within and across villages; how obstacles to trade vary across regions and by urban/rural status; taking advantage of natural experiments such as the effects of a Thai government program to provide microfinance; and using the longitudinal nature of the data to look at patterns like trends in returns and inequality. The concluding sections of the paper consider some of the advantages of long-term panel studies, the influence of this study on other research efforts, and some horizons for future research, both with these data and more generally.

Village Economies in Theoretical Perspective

An "economy" in the language of general equilibrium theory consists of a specification of the fundamental objects, as in Debreu (1959), Arrow (1964), and McKenzie (1959). This includes an underlying commodity space which includes consumption goods and other outputs; land, labor, capital and other inputs; locations; the passage of time to recognize dynamics; and states of the world to capture uncertainty. These commodity spaces can be chunky, as with indivisible goods (think of savings and loan rotating credit associations, which are winner-take-all, or an investment that requires a minimal scale which limits entry). Commodities can be transformed into one another as in production, or moved from one point in space to another at a cost, as in the transport of goods.

After the commodity space comes a specification of the preferences of agents, such as the assumption that households may maximize expected utility. Ownership comes from endowments, including factors of production (land, labor, and capital) and access to the technologies of production, storage, and trade. All of these can be measured, in principle.

The tools of general equilibrium theory also allow us to take a view of a village in partial equilibrium, with some balance of payments constraint on its relation with the outside world. The village economy can include fiat money which is valued as social currency, although typically not by the way it is used in the village, but rather by outside, economy-wide considerations. We can just extend the commodity space and include this currency as another good. Generalizing, one can include a potentially limited array of outside assets or liabilities, such as savings accounts or credit from external lenders.

One can then consider the allocations that are observed against a benchmark of economic efficiency. In the case of private information and/or other obstacles such as limited commitment, allocations will not be first-best, but rather will be, or at least should be, constrained Pareto optimal. To continue with the village metaphor, such allocations can be determined by maximizing a weighted sum of utilities of individuals and households in a village, subject to a variety of constraints: resources constraints (or open economy village-wide budget constraints); incentive compatibility constraints having to do with private information and moral hazard; constraints having to do with limited commitment; and so on. This maximization subject to constraints is a mathematics problem. Indeed, one can refer to this problem in a shorthand way as "the planner's problem," although the concept of a "planner" is really just a stand-in for the math problem that delivers the outcomes of the community of the whole.

In terms of implementation, one can suppose that allocations in a village will be achieved in a decentralized fashion, as with complete markets. But one need not make any such assumption. For example, the trading of Arrow–Debreu securities (that is, claims with payoffs contingent on the states of the world) is not necessary. Other institutions and mechanisms are allowed, and indeed are often one of the more interesting aspects of investigation. For positive economics, prediction comes from the premise that social forces will seek to move to an allocation in which some can be made better off while not making others worse off. For normative economies, if the allocation is not constrained optimal, then Pareto improvements are possible, hence providing natural guidelines for policy. There is some tension between the positive and the normative approaches, but the overall perspective is that models should be taken seriously, and they will talk back to us with conclusions that were not necessarily obvious a priori.

It may seem peculiar to some readers that a data-gathering project and accompanying empirical work should begin with an Arrow–Debreu theoretical perspective, but of course, drawing a distinction between theory and econometrics is fallacious. Koopmans (1947) offered a prominent statement of their connection in his "Measurement without Theory" essay, where he critiqued the National Bureau of Economic Research project of business cycle measurement (as discussed in Burns and Mitchell 1946). His main argument for the use of economic theory was that it allows economists to make predictions, especially counterfactual predictions to evaluate potential policy. In a more recent comment along the same lines, Rubin (2005, p. 3) notes: "There is no assumption-free causal inference, and nothing is wrong with this. It is the quality of the assumptions that matters, not their existence or even their absolute correctness. Good researchers attempt to make assumptions plausible by the design of their studies."

Some Village Research Antecedents

Thinking about villages in the context of Arrow–Debreu economies was the basis for my studies in economic history and in various countries. Because these predecessors shaped my thinking about the Townsend Thai project, it is helpful to consider them briefly.

The orientation of my work on the medieval village or estate economy was to explain observed institutions through the lens of theory, or establish puzzles that could not be so explained. The theory part is clear from the subtitle to that book, "A study of the Pareto mapping in general equilibrium models" (Townsend 1993). The book focused on risk and its many sources, both aggregate and idiosyncratic. For example, idiosyncratic risk was a force behind one of the most salient institutional features: fragmented land holdings. A typical farmer could hold 50–60 spatially separated strips of land scattered through the village, as a hedge against risk. Yet despite low cross-crop and cross-plot correlations that apparently drove this fragmentation, the variation in aggregate yields was so high that episodes of starvation occurred approximately every 12 years. Storage, either in the bin or as seed in the ground, had an incredibly low return. This research offered a calibration of a macro model that could rationalize the observed patterns of crop variability, carryovers, and planting decisions. Labor supply came in large part from duties and works supplied to the lord of the manor as a function of landholdings. We have no record of actual consumption, and thus no ability to link consumption directly to landholdings. However, land division was apparently a more useful method of sharing risk than a system of transfer payments to offset idiosyncratic risk. This is built into a moral hazard model that seeks as part of the math problem to limit transfers and thus showed how the number and location of initial "endowments" of land would matter. The model predicted a substantial part of the high degree of observed land fragmentation. This theoretical basis for decisions about location, and the condition of plots, became a basis for considerable subsequent work, some of which is touched on below.

The measurement used in this study of the medieval village came from historical material, like the accounts of the Bishop of Winchester, reported in Titow (1972) and other sources gathered and studied in McCloskey (1976). It would not be misleading to refer to many of the sources as government administrative data. I used virtually all available data to calibrate the models.

Following this work, I turned to village India to bring this analysis of risk and insurance to a more contemporary context. In this research (Townsend 1994), the focus was on taking the theories of Wilson (1968) and Diamond (1967) of the optimal allocation of risk bearing to the consumption and income data gathered by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). For an efficient outcome, aggregate risk at the village level—in the form of what is left of crops after intertemporal smoothing—should be shared among households. Put more dramatically, controlling for the aggregate shocks, the idiosyncratic variations in household-specific income should not influence consumption at all. Analysis of the panel data revealed that this benchmark for efficient outcomes could not be rejected in many specifications, and in the cases where it was rejected, the coefficient on how idiosyncratic household income affected consumption was typically small. The implication was that desperately poor households in undeveloped villages achieve, or come close to achieving, a high degree of risk-sharing, as if the markets (or other social institutions) for risk-sharing were complete, or almost complete. This remarkable finding and the resulting controversy helped to fuel interest.[3] The view here is that the extent of risk-sharing should not be based on a theoretical presumption, but instead should everywhere and always be treated as an empirical question.

In the early 1990s, the ICRISAT data were one of the few panel data sets available anywhere in the world containing consumption and income data for the households living in villages in low-income countries over time. In those early days, a researcher wanting access to this data was required to visit the Institute near Hyderabad, India, and from there proceed to visiting the sampled villages. The journey could be arduous, but it did teach researchers about the potential importance of context—and sometimes there were serendipitous events that shape careers.

For example, during one of these trips, co-author Ned Prescott discovered a fascinating institution: cropping groups in which multiple tenants jointly farm the land of a single landowner. Theory was developed to understand this corporate form and its internal incentives, as well as how it could coexist with both single tenancy and a spot market for bullocks (Townsend and Mueller 1998; Mueller, Prescott, and Sumner 2002; Prescott and Townsend 2006). This same theory can be applied in many other contexts, including complex financial institutions and the role of agency in New York's financial markets. This experience with cropping groups reinforced the idea that data collection and measurement in village economies needed to include contracts and institutions, which in turn needed to be spelled out in baseline forms with possible variations for labor employment contracts, credit, land rental, and so on. It also showed that data is needed on the environment, on allocations as outcomes, and on these contracts and institutions.

My work on Northern Thai villages added to this historical and contemporary experience (Townsend 1995). The selected villages are described in the language of technology and endowments: crops and their varieties; plots and their location, slope and soil characteristics; variability in crop yields; and mismatches in the timing

[3] A parallel literature developed around the same time in the United States, with some accepting the null and others rejecting it, using different datasets and different methods. For examples, see Altonji, Hayashi, and Kotlikoff (1992), Attanasio and Davis (1996), Mace (1991), Cochrane (1991), and Altug and Miller (1990).

of good and bad years. Responses to shocks included labor supply and potential borrowing and lending. In other villages, I was left with risk-response variations across households which suggested that Pareto improvements would be possible, which made me think more deeply about policy. In sum, the Northern Thai village study reinforced the importance of measurement at the village level, and fruitful ways of doing that measurement. It pushed me toward the idea of a further, larger-scale but comparative study of villages near to one another, in small sampling areas, but with variation across provinces that differed in development and openness. It made me determined to do this in a way that held potential to contribute to economic policy.

Synopsis of Townsend Thai Project

To begin, we conducted an initial, baseline survey in 1997 that included villages from four provinces: two in the relatively poor agrarian Northeast and two in the developed Central region near Bangkok. The selection of provinces was based on a pre-existing socioeconomic income and expenditure survey by the Thai government, so that we could take advantage of existing government data. The idea, roughly, was to use the cross-sectional variation as a substitute for the passage of time; we had no idea then that the project would last for so long. Within each of these four provinces we chose 12 tambons (a small subcounty region) per province. The tambons were chosen at random but with an environmental stratification (as discussed in Binford, Lee, and Townsend 2004). The idea was to end up with a sample in which there would be idiosyncratic regional shocks, so that risk-sharing could be better tested. Landsat imagery classified the types of ground cover. The idea was to distinguish environmental variation from historical institutional variation by having a constant underlying environment for clusters of villages. Finally, four villages per tambon were selected randomly.

Within each village, households were selected at random from rosters held by the headman. The 1997 household survey thus totaled 2,880 households (15 households for each of 192 villages). There are also survey instruments for the 192 headmen, as well as for 161 pre-existing village-level institutions (such as production credit groups or rice banks) and 262 joint liability groups (that is, they underwrite the risk of each other's loans) for customers of the Bank for Agriculture and Agricultural Cooperatives (BAAC). There are as well 1,920 sets of soil samples with measurements of organic matter and cation exchange capacity (which is the soil's ability to hold on to nutrients) from 10 of every 15 households per village. The first collection of these data was in April/May of 1997, constituting the baseline survey for rural areas.

When the unanticipated Thai financial crisis erupted in July of 1997, we wanted to assess the impact of what seemed like an aggregate shock. Thus, we began in 1998 the first of many subsequent rural annual resurveys in four tambons in each of the original four provinces, chosen at random from the original baseline sample. These surveys are done regularly, once a year, with teams of hired enumerators.

Also in 1998, an additional tambon per province was selected for fielding an intensive monthly survey, starting in August of that year, to get the details on labor supply, use of cash, and many other features that are only possible to obtain accurately with frequent recall, high-frequency data. The subsample was chosen to be consistent with the aforementioned environmental specification—that is, with similar environments across villages—but with variation in a priori formal and informal institutions (as they appeared in the 1997 baseline instrument). The detail of the monthly crop production data is a revealing example, used in Felkner, Tazhibayeva, and Townsend (2009) to assess the impact of climate change. We have measurements of short-term inputs (seed/seedling, fertilizer, pesticides, herbicides, hired labor and exchange labor, and rented capital equipment), and outputs (harvests). We distinguish production by stages (planting, maintenance, harvesting) and have obtained, as noted earlier, measurements of the soil as in the annual data and also weather shocks (measured with village-level rainfall gauges, temperature, and soil moisture readings). For the monthly environmental and socioeconomic data, gathered continuously throughout the year, we use local enumerators who are in permanent residence in the area and who use the above-mentioned anthropological-type methods when doing interviews.

The scale of the survey expanded, so as to be more nationally representative: two more provinces were added in the South in 2003 and two more in the North in 2004. Subsequently, one province was dropped in each region: one in the South became too dangerous because of an insurgency, and one in the North was dropped for budget reasons. An urban baseline and subsequent annual urban resurvey were added beginning in 2005 in all six remaining provinces, so as to compare urban neighborhoods to rural villages within in the same province, and to think about a province as a regional economy. In 2013, we added monthly surveys in urban areas in the original four provinces. While we do not have as long a duration for any of these latter surveys, we have achieved a larger scale. As of the last reporting period, the Townsend Thai project includes 3,890 households.

This synopsis emphasizes the breadth and depth of the Thai project data. However, the importance of the theoretical base for collecting and organizing the data should not be lost. Collecting these data has been key to the types of analyses that can be performed. Indeed, we have been able to model the entire Thai national economy and its internal labor migration and flow of funds based on the selected samples.

Risk Sharing

The optimal allocation of risk bearing suggests that consumption and other variables should be sensitive to aggregate shocks, but not to idiosyncratic shocks. Using the monthly panel data from the Townsend Thai project, in Chiappori, Samphantharak, Schulhofer-Wohl, and Townsend (2014), we seek to test this benchmark allocation of efficiency, taking advantage of the unusual length of the panel.

Again, theory suggests that household consumption should depend on time fixed effects that capture village aggregate risk/consumption. The long panel allows us to estimate heterogeneity in risk aversion: household consumption should move with aggregate village consumption, but more risk-tolerant households should absorb more of any aggregate risk. With 84 months of data, we were able to estimate these time fixed effects and heterogeneous coefficients. We found substantial variation across villages in the aggregate shocks that are inferred from the data, with a monthly standard deviation of 13 percent. We also found significant diversity in how aggregate shocks are borne across households, which suggests differences in risk preferences across households. Interestingly, these risk preferences turn out not to be related to wealth (which is also an implication of the as-if-complete-markets model). The bottom line was that we cannot reject the benchmark model's null hypothesis that household-specific idiosyncratic income risk does not influence household-specific consumption. Idiosyncratic risk is quite well pooled, essentially smoothed away to zero.[4]

The findings also offer a policy punchline. We conducted a hypothetical intervention, looking through the lens of theory. Consider the possibility of pooling across many villages so that what were aggregate shocks at the village level are now idiosyncratic and insurable shocks in the larger regional or national level. To put this point another way, we introduce in the thought experiment an indexed insurance product that, if actuarially fair, would replace observed variation in a village's aggregate shock with its mean. Such insurance would help the more risk averse. For example, risk-averse households in some of the villages are willing to accept up to a 3 percent consumption loss on average and still find such an intervention to be welfare-improving. But on the other side, such an intervention would actually harm the more risk-tolerant households in the same villages, who have implicitly been providing insurance to their more risk-averse village neighbors and receiving an implicit premium for doing so. These risk-tolerant households require up to 4 percent higher consumption on average, post-intervention, to be compensated. This lesson seems important, especially with continued efforts worldwide to introduce new types of insurance products, like ones indexed to rainfall, as if there were nothing indigenous already out there. Such well-intended interventions could actually harm some risk-tolerant households (again there is no correlation of risk aversion with wealth, and so the more risk-tolerant are not necessarily more wealthy).

The implications of informal risk-sharing arrangements as a community insurance mechanism keep showing up in work on other topics. For example, we can return to the observation that markets for the physical assets of households are relatively thin. Obviously, households in low-income countries are not trading equity

[4] In related work (Chiappori, Samphantharak, Schulhofer-Wohl, and Townsend (2013), we also estimate risk preferences with a less demanding portfolio choice model. In that paper, assets with uncertain returns are chosen by each household to satisfy intertemporal optimization in consumption and returns, and we do not have to take a stand on cross-household risk sharing. Nevertheless, the findings are similar—that is, the measures of heterogeneous risk preferences across the two studies are well-correlated.

claims on the production projects associated with these assets in a formal village-level securities market (not yet, anyway). There is no stock market and no market in state-contingent securities. Nevertheless, one can extend the risk-sharing theory to get implications for the portfolio of projects held by households and the associated rates of return across households, as in Samphantharak and Townsend (2016). In this paper, a rate of return can be computed each month for each household, as the flow of profits during the month and average physical assets held during the month. We then have returns over all sampled households and all months. The principal residual risk in the village economy is at the village-aggregate level, so what matters, and cannot be diversified away, is the covariance of a household's return on assets—profits divided by capital—with the village average return. The higher the covariance of the household's return with the aggregate return, the higher the risk, and so the higher must be the expected (average) return, to compensate for that risk. Likewise, according to the theory, idiosyncratic risk can be shared in principle within the village, and can be pooled away. With the relatively long panel of the Townsend Thai data, means, variances, and covariances of returns can be measured reasonably well and so these implications of the theory can be tested.

We found that idiosyncratic risk dominates total risk, with the percentage of the total ranging from 55 to 88 percent. However, in terms of risk premia—that is, deviation from the risk-free rate as compensation for risk—covariate risk is what matters most. The aggregate risk premia range from 67 to 80 percent of the total in three of the four provinces where the model fits well. An "autarky model" where households have no method to insure against risk would imply that covariate and idiosyncratic risk enter symmetrically into risk premia, but this model is soundly rejected in the data. Idiosyncratic shocks do show up in risk premia, because they do influence consumption, but by much less than the autarky model would imply.

The benchmark model and our risk decomposition guide us to a salient policy conclusion: namely, adjusting for idiosyncratic and aggregate risk separately—as dictated by our theoretical framework and the data—makes a large difference to inferences about underlying rates of return. Poor households are more exposed to village aggregate risk than their more wealthy neighbors, and thus the poor have high unadjusted rates of return. But poor households with high returns are not necessarily credit-constrained within their current set of activities on the intensive margin—that is, in wanting to expand but unable to get the credit to do so. Richer households have risk-adjusted returns which are higher than the risk-adjusted returns of the poor in the Central region, and no lower in the Northeast. The relatively poor households are constrained in a different sense, on the extensive margin, unable apparently to enter occupations and sectors of the relatively rich.

Within the village, or within the larger tambon, family and financial networks seem to be the informal institutional mechanism underlying many of these insurance results. In Kinnan and Townsend (2012), an initial census for the monthly data enumerated all structures, where each individual eats and sleeps, and kinship ties through three generations. Though the sample of households within a village is drawn at random, transactions of the sampled households with transaction partners identify those partners for all village residents (that is, mapping even to those households that were in the original census, but not resampled in the monthly surveys). We are able to exploit this in-depth knowledge by extending the basic risk-sharing regression to include the interaction of idiosyncratic income with whether a household is in an active financial network of gifts and loans, now actually measured, or whether or not a household is in a kinship network in the village. We found that these networks are helpful in at least partially insuring idiosyncratic risk. Measured gifts also showed up in Samphantharak and Townsend (2016) as smoothing much of the idiosyncratic shocks.

One particularly striking institutional mechanism works like a refinancing credit chain, as noted at the outset of this article. A household borrows from a formal source (outside government bank or village fund), has difficulty in paying this off in a bad year, borrows short-term from informal sources (family, friend, moneylender) to pay off the formal loan, is then in good standing and so borrows again formally, and finally pays off the informal bridge loan (Sripakdeevong and Townsend 2016). Such patterns should serve as a reminder to policymakers that informal (and typically unmeasured) arrangements can be important. They also make the point that markets in village economies can be quite sophisticated in their functioning.

Identifying Obstacles to Household Interactions

Interconnections among households are likely to matter, whether in an informal network of loans and gifts or in the sense of registering to underwrite the risk of someone else's formal sector loan. Because obstacles to trade will matter for observables, we can consider theoretical models that include different obstacles, and then infer which obstacles are most likely given the patterns that emerge from the data. A variety of studies taking this general approach suggest consistent conclusions about the obstacles to trade and how such obstacles vary by rural/urban status.

In Ahlin and Townsend (2007), we take this approach in work on joint liability loans given by the Bank for Agriculture and Agricultural Cooperatives (BAAC). Cooperation is modeled as the ability to commit costlessly to a set of actions that is Pareto optimal within the borrowing group. We considered a range of models in the existing literature, not previously tested, each of which embodies a different obstacle to trade: moral hazard, limited enforcement, information limits on screening borrowers, and others. The implications of these models for repayment of loans will vary. In the case of moral hazard, the ability to act cooperatively leads to less risk-taking by eliminating a borrower's ability to free ride on a partner's safe behavior. Thus, cooperation raises the repayment rate. However, in a model with limited enforcement, cooperation can lower repayment by making possible binding agreements not to use excessively harsh penalties. Overall, the limited enforcement model does best in the poorer, low-infrastructure Northeast. The screening model does best in the wealthier Central region. The patterns suggest that strategic default may be a more prevalent problem in low-infrastructure areas, while information problems may be more prevalent in more developed areas.

In an approach that combines data on occupation choice and the financing of investment, in Paulson, Townsend, and Karaivanov (2006), we look at the entry decisions of households into business. We also modify the full information full risk-sharing benchmark to accommodate a variety of potential obstacles to trade with moral hazard in effort or the ability to default/walk away. We found that the quantitative mapping implied by a moral hazard model fits best in the Central region, whereas either a limited commitment model or a mixed financial regime with both limited commitment and moral hazard in combination fits best in the Northeast. Likewise, as assets increase, borrowing decreases in the Central region, probably because increased wealth means more self-financing and less moral hazard; however, as assets increase, borrowing increases in the Northeast, as those at a binding collateral constraint can increase borrowing when collateralized assets increase.

In Karaivanov and Townsend (2014), we extend this work, focusing on households running businesses over time, rather than the entry decision, and also expanding the variables to include consumption, income, capital, and investment. Using the rural monthly panel, we apply dynamic programming, linear programming, and maximum likelihood methods to find that a relatively simple borrowing-lending regime fits the overall data best. However, when we compare the rural to the urban data, a moral hazard model fits the capital stock transitions best.

This body of research papers, using distinct data and models, leads to consistent findings. If the policy goal were to try to alleviate the obstacles to cooperation noted here, then making contracts more complete and alleviating collateral constraints would be the suggested policy in rural areas, but mitigating information problems would be the suggested policy in urban areas. To put this more dramatically, a one-size-fits-all reform is likely to be unproductive, or even counterproductive, in either rural or urban areas.

Microfinance: A Natural Experiment Example

One advantage of fielding a long-term survey over many years is that the sample experiences natural experiments. We cannot do experiments in which capital is injected at random in the cross-section of villages. Yet in 2001, the government of Prime Minister Thaksin introduced a village-level saving and loan association, funding each with one million Thai baht (roughly $24,000), which was intended to make micro-finance loans within these villages. With five years of data in hand, this presented an exquisite opportunity for a quasi-natural experiment. Each village got the same amount of funds, yet the number of households in a village varied considerably, leading to random variation in the size of the intervention when measured on a per household basis. Moreover, that number of households is largely unrelated to any measured economic variable we can find in our own or in secondary data. At the time of the policy intervention, there were roughly 77,000 villages in Thailand,

and so the total used for funding was roughly 1.5 percent of GDP, making it one of the largest microfinance programs ever.

In several papers (Kaboski and Townsend 2011, 2012), we investigated the effects of this experiment with reduced form nonstructural statistical models, as a preliminary fact finder, and with a structural model. We also used the parameters to carry out alternative, counterfactual experiments, as if the program had been designed differently. The nonstructural reduced form paper (Kaboski and Townsend 2012) used the annual panel data and inverse village size as the instrument. An increase in total short-term credit increased consumption (by more than credit), increased agricultural investment and income growth, but decreased overall asset growth. We also found in the monthly data a positive effect on wages. However, some of these effects are attenuated over the years. Short-term credit remains high, but the effect on consumption and income becomes lower. Default may have increased but with a lag, the year after borrowing.

Consistent with the inferred obstacles to trade and in the work just mentioned above, we take these facts and construct a structural model, specifically a buffer stock model with a credit limit and a lumpy investment possibility (Kaboski and Townsend 2011). Parameters of preferences and technology are estimated on the five years of pre-intervention data, and then the structural model is used to predict what would happen over the next few years if the credit constraint were loosened. We use the same methods on the model-generated data as in the nonstructural paper, and the predictions compare well to what happened subsequently in the data. The point here is that the model provides an interpretation: A surprise increase in future credit availability causes households to run down buffer stock savings and increase consumption. But this jump cannot be sustained in the long term. In general, long-term impacts are something that shor-term randomized controlled trial studies, with baseline and endline, have trouble picking up. However, when Bannerjee, Breza, Duflo, and Kinnan (2015) carried out a longer-term resurvey of additional credit in in Hyderabad, their results complemented what we report here.

These studies and others are also picking up the importance of heterogeneity. In Kaboski and Townsend (2011), we can distinguish various types of households: for example, those near default, hand-to-mouth credit-constrained households, and households on the margin of investing. Some households actually lose with more liberal credit limits, because they can borrow at interest to cover loans coming due and are no longer allowed to default to a reasonably high level of consumption. Other households reduce consumption to co-finance investment. All of this is in contrast to work which imagines one or two types of households only. Again, we are using the lens of the model to understand more clearly this heterogeneity and what happened.

As a counterfactual policy, we evaluate the impact of lump sum grants costing the same amount to the Thai government, and find that this alternative is preferable for many households, though not all. Likewise, some households would gain more, relative to the original program, from credit that is stipulated to finance investment, as ironically this takes away the welfare loss that the would-have-been defaulting borrowers experienced in the original program. New work and other studies find that households that experience the greatest impact from micro credit interventions on the production side are those already in business and that have higher total factor productivity (Banerjee, Breza, and Townsend 2016). Yet the allocations of loans by the village fund committee arguably appears random if not inefficient (Vera-Cossio 2016). In hindsight, and in thinking about future interventions, one could have designed a better mousetrap.

Constructing Regional and National Economies

Given the strong theoretical roots in the Townsend Thai project and extended sampling ultimately designed into the surveys, it becomes possible to construct and estimate larger model economies based on the measured micro underpinnings.

In Samphantharak and Townsend (2010), we provide a key starting point, by using the monthly data to create a complete set of financial accounts for the sampled households. In effect, we envision these households as corporate firms, each with an income statement, balance sheet, and statement of cash flow. Then, following the steps outlined from the US Bureau of Economic Analysis, in Paweenawat and Townsend (2012, 2014), we use these accounts, aggregate up, and create village-level national income and product accounts—including savings/investment accounts, balance of payments accounts, and flow of funds accounts.

In turn, these accounts can be used to disentangle real and financial factors. In these papers, we establish that there is within-village and across-village sharing of consumption risk, though the latter seems worse than the former. The smoothing mechanisms are also different. Within-village, there is greater use of gifts, but in a typical village's relationship with the rest of the economy, there is greater use of cash and formal borrowing. Regarding investment, we explore the Feldstein and Horioka (1980) relationship of domestic saving to domestic investment. Here we find that investment is not sensitive to savings at the village level, a sign of good cross-village intermediation, but is sensitive once incoming (net) remittances are included in the saving variable. In short, village economies can take investment opportunities even when short of internal funds, by relying on external funds. Likewise, work by Srivisal (2014) uses the flow of funds accounts data at the village level and analyzes the impact of monetary policy, generated at the national, aggregate level but impacting the villages differentially.

Given that obstacles to trade seem to vary systematically by region or by rural/urban stratifications (as discussed earlier), in Moll, Townsend, and Zhorin (2016), we construct and compute steady-state solutions to a model of the national economy with two sectors, limited commitment in the rural sector and moral hazard in the urban sector, as in the micro data and those earlier studies. We then calibrate the model economy parameters around measured differences in the constructed financial accounts across these two sectors, that is, differences in income, consumption/income, capital/income, and wealth, and in the incidence of enterprise. Parameter estimates for preferences, technology, and the degree of constraint from limited commitment are consistent with parameter values in the literature. At these calibrated values, the model predicts substantial flows of capital from rural to urban areas: 23 percent of capital utilized in urban areas is imported and rural areas lose 39 percent relative to capital utilized. At the same time, there are huge flows of labor in the same direction: 75 percent of labor in the urban sector comes from this migration and rural areas lose 86 percent. Equivalently, the urban sector is 79 percent of the economy's capital and 65 percent of the economy's labor, even though the urban sector is only 30 percent of the population. In other words, we can explain a national economy model with urban concentrations similar to those we see in the data that are based only on varying obstacles to trade across rural and urban areas. Obviously there are other forces behind urbanization, but this surprising effect comes from the integrated model and its calibration, again based on differential obstacles alone.

At the micro level, we see that predictions across sectors are largely consistent with micro facts in the data that gave us the variation in financial obstacles across sectors in the first place. Over the relevant range, credit is strictly increasing with wealth in the rural/Northeast sector and nondecreasing with wealth in the urban/Central sector, as in Paulson and Townsend (2004), and there is much more persistence of capital stock levels in the rural sector than in the urban, as in Karaivanov and Townsend (2014). The model in Moll, Townsend, and Zhorin (2016) also offers some predictions that are validated when checked in the data. The growth of net worth is more concentrated in the urban/Central region than in the rural/Northeast, and distribution of firm size by capital in the moral hazard sector has a skewed right tail relative to the limited commitment sector, as does the Central region relative to the Northeast in the micro data. This line of research shows the value and relevance of constructing a macroeconomic model built on measured micro underpinnings. In particular, the model performs better and parameter estimates are more sensible when respecting this diversity across regions, rather than imagining underpinnings are held in common across all villages and towns.

These models allow the assessment of repressive policies that promote regional isolationism. In Paweenawat and Townsend (2014), we fit a small open economy model with collateral constraints to the rural data. We then conduct counterfactual experiments to determine gains and losses from potential restrictions on trade and on capital flows, separately and in combination. The effects can be substantial. For example, limiting capital outflows can lower interest rates, leading to more capital-intensive production and thus the hiring of more labor, thereby raising wages. But the low interest rate hurts those with savings. However, the same policy in another region can generate different numbers even using the same model, because baseline local conditions and calibration to locally observed paths produce different counterfactual predictions.

In a yet more explicit model, in Ji and Townsend (2016), we not only consider local markets within the Thai national economy—1,220 of them—but also the integration of these markets domestically into the economy as a whole, as well as opening that economy up to observed international capital flows. The Townsend Thai data has its variables on cash holdings and loan-to-collateral ratios, and both credit and savings are an explicit part of the model. These can be used in conjunction with secondary data sources and then loaded onto a "geographic information system" (GIS) with other key variables: roads; the locations of bank branch openings from the Bank of Thailand; wealth, population, and other village characteristics from Community Development Department village census; the Thai National Population and Housing Census which helps identify municipal populations; and the Socio-Economic Survey which measures income and wages. The model allows us to distinguish the effect that branch expansion vs. international capital flows have on growth, inequality, and credit access.

Longitudinal Studies

The long-term trends revealed in our 18 years of monthly data on Thai villages are dramatic. Inequality falls, for example, with the bottom 50 percent having an increasing share of the wealth. Rates of return on household enterprise converge, rising for the rich, from 5 to 10 percent, and falling substantially for the poor, from 28 to 12 percent per year.

In Pawasutipaisit and Townsend (2011), we establish some of the underlying mechanics within the Thai context. Low-wealth households have higher overall rates of return, including risk premia, and those coupled with higher own-savings rates (investing profits back into their own businesses) boosts their income over time on average and lowers inequality. This autarky-like mechanism takes many years to play out.

In ongoing work (Ru and Townsend 2016), we suggest an effect from financial intermediation as well. Gifts seem to play a role not only in smoothing consumption deficits, but also in financing investment. With that in mind, we try out a costly state verification financial/information regime, combining the multiperiod contracts in Townsend (1982) with the costly state verification model of debt in Townsend (1979). This model has the property that debt can be used to finance investment despite repayment problems: When low profits make repayment difficult, a cost is incurred, so that the state of an investment project is made known to creditors. With multiple time periods, there are also gains to enduring relationships, paying more from returns when profits are high with the advantage of getting more favored treatment later when returns are low. This multiperiod costly state verification regime fits the overall data best for relatively poor households in villages. Indeed, consistent with earlier results, the costs of verification are lower for households with kin in the village. Finally, though this finding is only suggestive, this mechanism may have improved with the advent of the village funds, as the simpler borrowing and lending financial regime fits best for everyone, including the poor, before the intervention, but the multiperiod costly state verification regime fits best for the poor afterwards and does not attenuate over time. One speculates that the quasi-formal village funds were somehow a catalyst, improving the performance of the pre-existing informal sector.

As we continue to gather panel data, we become able to address life-cycle research topics. We can see children born, school attendance, and soon a sufficient number of children who have grown up to have jobs and wages, as noted at the outset. We can see middle-aged households initially in their most productive years now quasi-retired, and others with disabling health shocks reduced to zero income at earlier ages. The longer we stay in the field and gather the data, the more the research possibilities grow.

Advantages of Long-Term Studies and Measurements

The longevity of the surveys and the repeat interviews build trust and thus reliability. Interviews are conducted in a conversational style and do not seem to be tedious for households. Enumerators have largely memorized the questionnaires, and of course take extensive notes during the interview, so that specific modules can be filled in afterward. This approach allows for eye contact and one-on-one back-and-forth during the interview, allowing sensitive topics to be revisited as conversations proceed. Our re-interview rates are quite high. For the monthly surveys, our resurvey rate has been over 99 percent per year: 602 out of the 710 original households starting in 1998 were still being resurveyed in 2014. For our annual survey, the average resurvey rate has been 98 percent during the last five years.

There is also a human story to the logistics of fielding the survey, the experience among enumerators, supervisors and staff from headquarters. These experiences are recounted in *Chronicles from the Field* (Townsend, Sakunthasathien, and Jordan 2013), a book aimed at both a general interest audience and providing supplementary material for anyone teaching a course on survey design and implementation. Rules matter in doing a survey, but additional human and logistical aspects must also be taken into account.

Another advantage to longevity is that enumerators remain in the field and in contact with the households, thus allowing researchers to follow-up both with individual households and to field systematic supplemental questions. For example, follow-up has been used when the numbers in the financial accounts appear as outliers. Supplemental questions have been asked concerning individual health insurance histories, behavior and attitudes toward discounting and commitment, and reconstruction of payment histories that distinguish deposits of cash from electronic deposits.

These benefits of long-term high-touch interviewing come with costs. Our interview techniques do not accommodate computer-assisted personal interview techniques, so we deal with mounds of paper and printing costs. We worry about the representativeness of the remaining sample, because even low attrition rates accumulate over time. There is chronic worry about funding, along with grant proposals to write and rewrite and also developing contingency plans. Any serious gap in funding would likely undo the long-term panel. As a cautionary example, the original ICRISAT sample had very low attrition, but many households were lost in the gaps between restarts. At present, new funding from the Bank of Thailand and the Thailand Research Fund along with continuing grants from the US National Institute of Child Health and Human Development (NICHD) will cover the costs for the next two years of field research, and there are discussions about going further.

Creating a local organization called the Thailand Family Research Program, with my close collaborator Sombat Sakunthasathien, enabled us to field the surveys and helped to keep down some of the costs associated with a research endeavor of this kind. TFRP kept a lean budget and fully 75 percent of its budget went to direct personnel costs, mostly the small army of enumerators, field editors, and coders who run the operation on the ground. Even so, the costs are significant, with about 31 full-time office staff and a larger number of field staff, around 70 enumerators, working part-time but year round.

Influence on Projects Elsewhere

The rarity of projects of this length and scale give the impression that such projects are difficult to conduct, but here are a few somewhat comparable projects. The above-mentioned ICRISAT studies on villages in India were conducted in 1975–1984, 1989, 2001–2009, and 2009–present. But for perspective, the ICRISAT second-generation survey has 500 questions from 9 modules, but the Townsend Thai monthly has 3,500 questions from 24 modules. The annual resurveys with more villages and urban neighborhoods are less intensive, but add to these totals.

Other roughly comparable projects are the large-scale multi-year panel surveys in Ghana and Tamil Nadu, India, being carried out by Yale's Economic Growth Center (EGC). These nationwide panel surveys will ultimately span 15 years each, with resurveys occurring every three years, providing depth across years and spotlighting socioeconomic mobility. They are not location-based per se, but rather track migrants who would otherwise be eliminated from the samples. Another ambitious endeavor is the Kavli Human Project, which plans to survey approximately 10,000 residents in about 4,000 New York City households over the next several decades.

But with these larger projects duly noted, smaller projects are easier to carry out. We generated many useful research papers from the 1997 baseline and first few years of annual resurveys. Even if we had stopped at that point, we would have learned much. The Thai modules have served as prototypes for others. For example, in Chile, a survey of small household businesses (*Encuesta de Microemprendimiento*) began in 2009, which complements the Central Bank of Chile household surveys. In Mexico, a study of BANSEFI credit unions used both the Townsend Thai project institutional and household questionnaires. I was recently in China as an advisor to help implement key add-ons to an ongoing survey modeled after University of Michigan's Panel Study of Income Dynamics. The household financial accounts created as part of the Thai project have been brought back to United States and are now being integrated with payments diaries and surveys from the Federal Reserve Bank of Boston (Samphantharak, Schuh, and Townsend 2016). The GIS database archive developed as part of the Townsend Thai project is being adapted and implemented in Brazil and China.

The Townsend Thai data have been continuously cleaned and uploaded to Dataverse (at https://dataverse.harvard.edu/dataverse/rtownsend). This data also contains the relevant secondary data sources. While application must be made for access to the subset of secondary data that is proprietary, the primary, cleaned, data are available to all. At last count there have been 90,000 downloads of the public data. In addition to my collaborators and co-authors, numerous other researchers have found the Townsend Thai data to be a useful tool, with almost 50 papers citing the use of the data, including at least 11 graduate students utilizing the data in their dissertations.

Conclusion

The Townsend Thai project is a theory-based data collection endeavor, measuring and mapping village and larger economies into general equilibrium frameworks. Theory determines key questions to ask of households, about contracts and mechanisms, for example. Theory can guide sample selection, so as to ensure data are adequate for tests of null hypotheses. In turn, observations from the field and findings from theory-based analysis of the gathered data can lead to new questions.

This way of doing research has given rise to a literature on village economies, and then extends to thinking about models of regional and national economies based on detailed micro underpinnings. The discussion in this paper has reviewed a number of findings, implications, applications, and lessons learned. What are the next steps? Among the many, we can single out here three leading examples of where I believe progress can be made.

A first key area has to do with an even better understanding of informal financial networks. We know in the Thai data that these networks are playing crucial roles in the reallocation of risk. But many questions remain unanswered. How have households managed to come up with these institutions, turning bilateral trade into functioning multilateral links that resemble sophisticated money markets? How aware are households of how these networks are functioning? Are there costs in coordination or perhaps missed opportunities? How do these networks change with increases in external financial development? Are informal and formal financial sectors substitutes or complements for each other? What are the implications for regulation?

A second area for further research concerns the industrial organization of financial service providers. Does the private sector compete with the public sector, deliberately partitioning itself off from the mainstream by targeting the poor, or rather does it act in concert with the public sector, driven by political or altruistic motives? Is the overall outcome efficient? How do we integrate the theory of contracts into the supply side, making both contracts and the location of branches an endogenous outcome, with tools that allow this conceptualization to be taken to data? What is the actual degree of competition among commercial banks? Methodologically, the exciting prospect here is a synergistic merger between development economics and industrial organization to address economies in transition.

A third area for research concerns bringing the kinds of models, data, and analysis from the Townsend Thai villages project to US communities. This line of research received great impetus from the US financial crisis. Considerable localized data is available at the zip code, census block, Metropolitan Statistical Area, commuting zone, county, and state level. The contributors to the US literature use creativity and determination to take advantage of this data. Yet these data are not yet organized systematically the way they would be when coming from the standpoint of integrated financial accounts. Moreover, the US data have not yet been mounted on a comprehensive geographic information system archive such as what is underway in Thailand, China, and Brazil. I am convinced that developing these models and data would bear much fruit in allowing us to think about local communities, how the larger US economy is put together, and implications for policy.

What remains is to find the right balance as we move forward in this world filled with these and other new possibilities. One dimension emphasized here is to be eclectic about the various possible measurement techniques, adopting what is needed to measure what is key and to elicit accurate and enduring responses. Another dimension is the use of the research in policy, either taking advantage of quasi-natural experiments or doing counterfactual experiments within the estimated models themselves. This experimental view can bring researchers together and arbitrages across subfields, unifying micro and macro with theory and data in the context of applied general equilibrium analysis.

■ *Research support from the Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD) (grant number R01 HD027638), the National Science Foundation (grant number 0649302), the John Templeton Foundation (grant number 12470), the Consortium on Financial Systems and Poverty at the University of Chicago (funded by Bill & Melinda Gates Foundation under grant number 51935), the Centre for Economic Policy Research (CEPR) and the Department for International Development (DFID) under grant MRG002_1255, and the Ford Foundation are gratefully acknowledged.*

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Journal of Economic Perspectives—Volume 30, Number 4—Fall 2016—Pages 221–242

Diversity in the Economics Profession: A New Attack on an Old Problem

Amanda Bayer and Cecilia Elena Rouse

The economics profession includes disproportionately few women and members of historically underrepresented racial and ethnic minority groups, relative both to the overall population and to other academic disciplines. In the United States, of 500 doctorate degrees awarded in economics to US citizens and permanent residents in 2014, only 42 were awarded to African Americans, Hispanics, and Native Americans and 157 to women (although this double-counts the 11 minority women who earned economics doctorates in 2014). This underrepresentation within the field of economics is present at the undergraduate level, continues into the ranks of the academy, and is barely improving over time. It likely hampers the discipline, constraining the range of issues addressed and limiting our collective ability to understand familiar issues from new and innovative perspectives.

In this paper, we first present data on the numbers of women and underrepresented minority groups in the profession. We then offer an overview of current research on the reasons for the underrepresentation, highlighting evidence that may be less familiar to economists. We argue that implicit attitudes and institutional practices may be contributing to the underrepresentation of women and minorities at all stages of the pipeline, calling for new types of research and initiatives to

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† For supplementary materials such as appendices, datasets, and author disclosure statements, see the article page at
http://dx.doi.org/10.1257/jep.30.4.221 doi=10.1257/jep.30.4.221

attack the problem. We then review evidence on how diversity affects productivity and propose remedial interventions as well as findings on effectiveness. We identify several promising practices, programs, and areas for future research. The *Journal of Economic Perspectives* last addressed underrepresentation by women and racial and ethnic minorities in the economics profession over ten years ago (Ginther and Kahn 2004; in this journal, see also Leeds 1992; Kahn 1995; Collins 2000). Given the growing evidence that diversity matters, it is time for a renewed focus on increasing the diversity of the economics profession.

The Gender and Racial/Ethnic Composition of the Economics Profession

We focus on groups that have been historically underrepresented in the economics profession and in the United States: women, African Americans, Hispanics/Latinos, and Native Americans. Underrepresentation in the economics profession by these groups is longstanding and there is a growing literature addressing its scope and possible remedies. Of course, this list does not encompass all dimensions of diversity, and the problems facing various underrepresented groups differ in some ways. But as we learn about barriers faced by members of these groups and interventions to address them, we hope to develop insights that are transferrable to facilitating the inclusion of the best people and ideas from all groups.[1]

According to the most recent survey conducted by the American Economic Association, 23.5 percent of tenured and tenure-track faculty in economics are women.[2] As such, gender diversity in the academic economics profession is as poor as both the male-dominated tech industry and the Academy Awards nominating committee, where only 30 percent of the Silicon Valley workforce and 24 percent of Oscar voters are female. By rank, women represent 15 percent of full professors in economics departments and 31 percent of economics faculty at the assistant level.

The gender gaps in tenure and promotion rates in economics are much greater than those in the social sciences overall: specifically, Ginther and Kahn (2014) report a 20 percent gender gap in achieving tenure and a 50 percent gap

[1] This paper examines disparities by race/ethnicity and gender, but independently. We acknowledge, but do not examine here, the complicated intersectionality of race, ethnicity, and gender (Brewer, Conrad, and King 2002).

[2] Statistics on economics faculty are authors' calculations from the *Universal Academic Questionnaire*, a survey conducted annually by the American Economic Association (Scott and Siegfried 2016). The questionnaire asks respondents to report gender for all faculty members and race/ethnicity only for US citizens and permanent residents. The data must be interpreted with caution due to a low response rate (about 50 percent) and missing data. Nevertheless, the magnitudes are consistent with those produced in other years and in other surveys. The survey likely mismeasures gender, race, and ethnicity, because it does not use self-identification (department chairs list the gender and race of department members) and because the AEA survey relies on a gender binary (in contrast, for example, to the American Sociological Association's six gender response options).

in promotion to full professor among economists compared to 12 percent and 25 percent, respectively, in the social sciences overall. More sobering, economics boasts the largest (or only) gender gaps in tenure rates, salaries, and job satisfaction compared to other math-intensive fields (Ceci, Ginther, Kahn, and Williams 2014). Moreover, Ceci, Ginther, Kahn, and Williams (2014) find that female full professor salaries in economics as a proportion of male salaries dropped from 95 percent in 1995 to less than 75 percent in 2010. In an analysis of published scholarly research across 21 academic disciplines, women accounted for 13.7 percent of authorships in economics since 1990, barely above the 12.0 percent in philosophy and well below the overall average of 27.2 percent (West, Jacquet, King, Correll, and Bergstrom 2013).

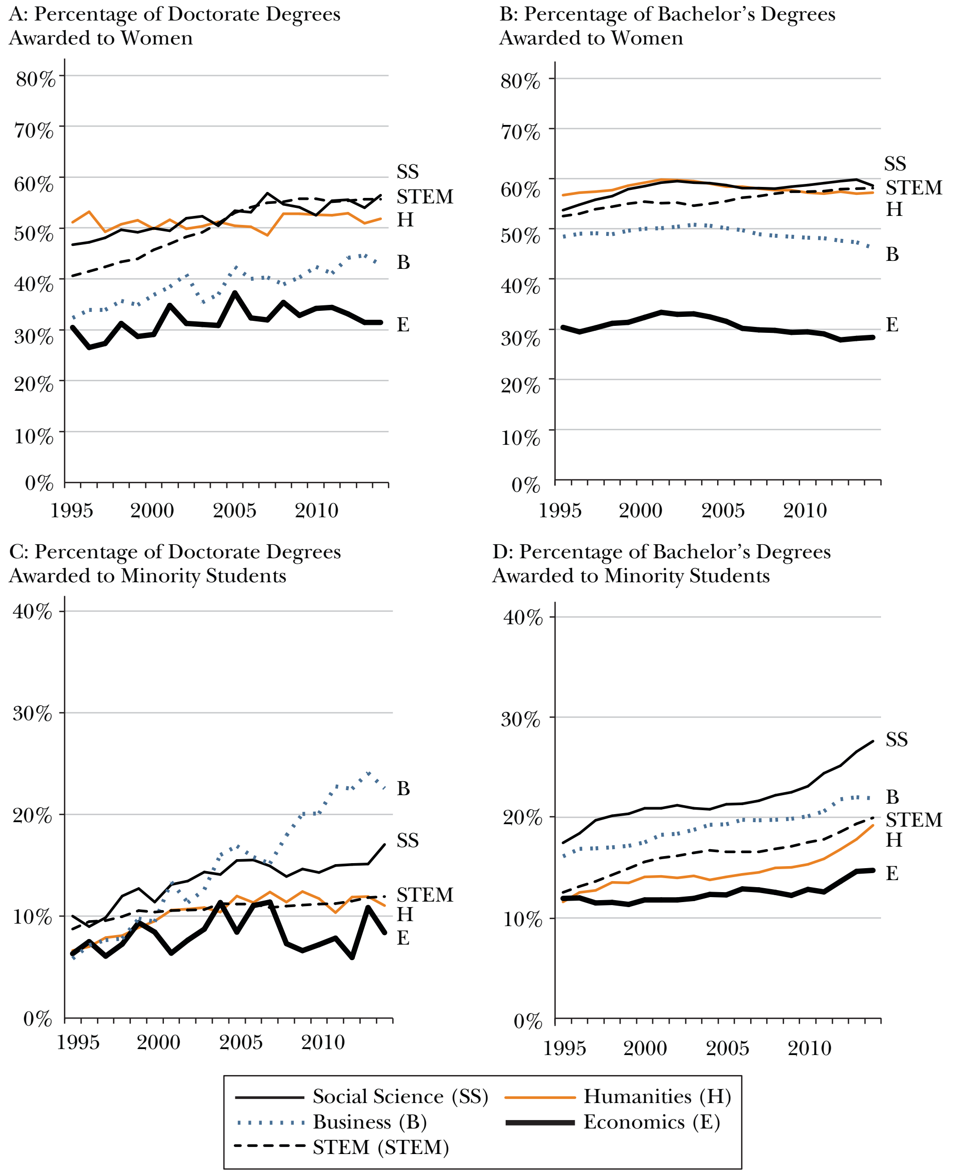
Minority academic economists are even rarer. While about 30 percent of the US population is black or Hispanic, only 6.3 percent of tenured and tenure-track economics faculty is identified as such (only 4.0 percent of full professors and 8.1 percent of assistants).[3] Price (2009) reports that in 2006, only 44 black economists were on the faculties of the 106 PhD-granting economics departments ranked by the National Research Council, and six of those black economists were employed at Howard University, a historically black university.

The pool from which economics departments pull new faculty members is not much different. Figure 1 shows the percentage of doctorate degrees awarded to women (panel A) and to minorities (panel C) between 1995 and 2014, using data on US citizens and permanent residents only, as collected by the National Center for Education Statistics. Figure 1A shows that while there was some progress in the representation of women between 1995 (when women represented 30.5 percent of new PhDs) and 2005 (when women represented 37.2 percent of new PhDs), some ground has been lost as just 31.4 percent of doctorates in economics were awarded to women in 2014. Even when including temporary-resident students, the percentage of doctorate degrees awarded to women, regardless of citizenship status, is only slightly greater (34.2 percent in 2014) and varies considerably across institutions. (For example, within the top ten programs, the percentage of doctorates awarded to women over the last three years ranges from a high of 40.8 percent to a low of 4.9 percent.) Figure 1A also shows that the percentage of women earning doctorates has stagnated in economics, while it has increased in other social science fields, humanities, business and management, and also in STEM (science, technology, engineering, and math) fields.

Figure 1C shows that the story is mostly similar when we look at the percentage of doctorates awarded to minorities (meaning black, Hispanic, or Native American) between 1995 and 2014. Between 1995 and 2007, there was steady improvement in the percentage of new doctorates in economics awarded to minorities, from 6.3 percent in 1995 to 11.4 percent in 2007. Since then, the percentage of new doctorates awarded to minorities has dropped substantially to only about 7 percent,

[3]Another 13 percent of tenured and tenure-track faculty is identified as US citizens or permanent residents of Asian ethnicity. About 5 percent of the general population in the United States is Asian.

Figure 1
Degrees Awarded to Women and Underrepresented Minorities



Note: Data are authors' calculations from the Integrated Postsecondary Education Data System (IPEDS) at the National Center for Education Statistics, using data on US citizens and permanent residents only. Economics degrees are classified as those with IPEDS Classification of Instructional Program codes for "Economics, General," "Agricultural Economics," "Applied Economics," "Econometrics and Quantitative Economics," "Development Economics and International Development," "International Economics," and "Economics, Other." We use the National Science Foundation definition of STEM (Science, Technology, Engineering, and Math) subjects, but exclude the social sciences to present that series separately. "Social Science" indicates social science fields but excludes degrees in economics. "Business" denotes business and management disciplines. Minority students are those who self identify as Hispanic or Latino, American Indian or Alaska Native, or Black or African American.

although in 2014, 8.4 percent of new doctorates were awarded to minorities. (When including temporary-resident students, US minorities earned 3.5 percent of all economics PhDs awarded in the United States in 2014.) Further, Figure 1C shows that progress in increasing racial and ethnic diversity has been faster in other fields.

These disparities are evident at earlier stages in the pipeline as well. Figures 1B and 1D show the percentage of bachelor's degrees awarded to women and to minorities in various fields between 1995 and 2014. Again, there is little progress in increasing the percentage of female students graduating with bachelor's degrees in economics over the past two decades, with 28.4 percent (30.9 percent when including temporary residents) of degrees awarded to women in 2014. While there has been progress in other fields—including STEM—business and management displays the same lack of progress seen in economics.

Finally, while there has been some improvement in the percentage of minority students graduating with a major in economics, from 12 percent in 1995 to 14.7 percent in 2014, this rate is still far below the prevalence of this population among college students (22 percent of bachelor's degrees were awarded to minorities in 2014) and also below the 20 percent of bachelor's degrees awarded in STEM fields.

Overall, the economics profession has made little progress in the last two decades in diversifying the profession in key dimensions of gender, race, and ethnicity. These patterns stand in contrast to the robust and increasing representation of foreign-born individuals in US departments of economics. For example, the percentage of all US economics doctorate degrees awarded to temporary visa holders increased from 49 percent in 1995 to 59 percent in 2014, with half of these degrees going to temporary visa holders self-reporting Asian ethnicity on the NSF Survey of Earned Doctorates. (Simultaneously, the percentage of all US economics doctorate degrees awarded to non-Hispanic Asian citizens and permanent residents decreased from 6.6 percent in 1995 to 5.0 percent in 2014.) Though many of these students do not stay in the country after graduation, about one-third of new PhDs holding temporary visas have definite employment commitments in the United States (NSF Survey of Earned Doctorates, Table 51). So while the profession may not have made progress in all dimensions of diversity, it has in some. Nevertheless, concern with racial and ethnic diversity is inextricably linked to the history of race and ethnicity in the United States and to the pervasive and persistent barriers faced by African Americans, Hispanics, and Native Americans in this country. While students and faculty who come to the United States from abroad explicitly to study or teach economics have certainly faced challenges of their own and will face many more here as well, their experiences are fundamentally different from those of people who have lived a good portion of their lives in the country.

The relative absence of women and members of racial and ethnic minority groups in economics begins at the undergraduate level and then continues through doctoral education and beyond. The lethargic trends, along with the significant disparities that continue to exist throughout the pipeline from economics majors to economics professors, suggest that change is unlikely to be sustained—or perhaps to occur at all—without purposeful action.

Barriers to Diversity

Why are there relatively few women and certain racial/ethnic minorities in the economics profession? We start by summarizing the literature on factors that affect the supply of individuals choosing economics as a field of study or profession, such as mathematics preparation and prior exposure to the field. We then turn to a review of evidence, some of it newer and less familiar, on the role of the demand side. We emphasize that by "demand side," we refer to the behavior of economists at all points along the pipeline, not only when hiring new PhDs but also at points before, such as attracting undergraduates to the major, and after, as careers are advanced or not.

Supply-Side Factors

The evidence in the previous section makes a prima facie case that the reason for the underrepresentation of women and minorities among PhD economists traces back to decisions made at the undergraduate level. Thus, a small, but growing, number of articles attempt to understand the factors that affect the decision to study economics, particularly by undergraduates. Common hypotheses focus on the effects of math preparation or aptitude, prior exposure to economics, performance in economics relative to other courses, and instructor race or gender. Most of this literature is based on correlational regression analysis of surveys or administrative data, either from an individual college or from a subset of colleges for which data were available. This research suggests that some explanations are more likely than others, without reaching a definitive conclusion.

For example, the level of math preparation does not seem to explain the underrepresentation within economics. The research generally finds that prior math preparation (as proxied by SAT/ACT scores or by questions that ask about comfort level with math), while affecting the decision by any student to take a class or major in economics, explains, at best, a small part of the underrepresentation in economics by women and minority students. In one study, Emerson, McGoldrick, and Mumford (2012) analyze a database with extensive information on undergraduate courses for 11 large state universities and find that gender differences in taking economics courses after the introductory course are not accounted for by measures of aptitude, or by an array of other variables. This conclusion is consistent with Integrated Postsecondary Education Data System (IPEDS) data showing that in 2014 women earned 42.6 percent of bachelor's degrees in mathematics and statistics, far beyond their 28.4 percent share in economics.

Several studies consider the role of prior exposure to economics in the decision to pursue further study. Dynan and Rouse (1997) find that women in their junior and senior years of college were more than twice as likely as men to report that they did not take economics in their first year because they "did not think that economics was interesting." This result is consistent with the findings of Calkins and Welki (2006) who report that perceived interest in the subject is a key factor in determining the choice of undergraduate major. Of course, such research raises questions of how perceptions of economics vary across undergraduates from different groups, which, if any, are accurate, and how we might provide better information about what economics is and the range of topics economists study.

Performance in early economics courses—such as introductory courses—and especially relative to performance in other courses may also be related to the decision to persist in economics. Rask and Tiefenthaler (2008), using 16 years of data from a liberal arts college where economics is a prominent major, find that women are more responsive to their relative grades in economics than are men. Of course, if this response exists across economics departments, it is likely related to the specific context of economics, including advising practices: if women were universally more responsive to relative grades, then they would also be more averse to majoring in math and science, where grades tend to be low (for example, see Butcher, McEwan, and Weerapana 2014, in this journal), but where female representation is higher than in economics.

Many point to the lack of role models in the profession as deterring both women and minorities from further consideration of economics. Instructor identity could affect student performance through a variety of possible mechanisms. Perhaps students are inspired by the role model or less subject to stereotype threat (Steele and Aronson 1995) in the presence of a stereotype-defying economist.[4] Alternatively, professors with different life experiences may talk about different economic issues and in ways that resonate with different students. While earlier evidence on the effects of same-gender and same-race instructors had been mixed, more recent studies find that instructor identity makes some difference. For example, Dynan and Rouse (1997) look at data from Harvard University and report that having a female teacher at the introductory economics level had only a small impact on the decision to subsequently major in economics. In contrast, Hale and Regev (2014) conclude that a larger share of women on the economics faculty of top universities leads to more female students entering economics PhD programs, using the number of resignations of male faculty members as an instrumental variable to capture exogenous variation in the share of women in the faculty. Carrell, Page, and West (2010) analyze data from the US Air Force Academy, where students are randomly assigned to professors, and find female students perform significantly better in introductory math and science courses if taught by female faculty, and they are more likely to pursue majors in science, technology, engineering, or math. Fairlie, Hoffmann, and Oreopoulos (2014) find similar effects for underrepresented minority college students at a large and diverse community college, whose short and longer-term outcomes improve from taking courses with underrepresented minority instructors.

[4] "Stereotype threat" is a robust and widely replicated phenomenon. A considerable body of research shows that "performance in academic contexts can be harmed by the awareness that one's behavior might be viewed through the lens of racial stereotypes" (Steele and Aronson 1995). Stereotype threat has been documented to diminish the academic performance of members of groups subject to negative stereotypes, including African Americans, Latinos, and women (Gonzales, Blanton, and Williams 2002; Inzlicht and Schmader 2012). White men are subject to stereotype threat on a math test when led to believe the test is being used to examine Asian superiority at math (Aronson et al. 1999).

Because these last two studies do not focus on economics, future research might investigate the effects within economics specifically, as well as how to reproduce the benefits of faculty role models before having sufficient numbers of women and minority economists in place.

Demand-Side Factors

Most academic institutions have policies that officially encourage diversity in outreach, hiring, and promotion, and most academics have sat in numerous meetings where such concerns were expressed. Thus, claims that explicitly discriminatory attitudes on the demand side of academia play a role are often met with skepticism. Explicitly discriminatory behavior and attitudes may occur less frequently than in the past, but that does not mean they no longer exist. Perhaps more importantly, researchers in the last 30 years have been investigating implicit bias, a form of discrimination based on unconscious attitudes or associations, which can produce behavior that diverges from the individual's own endorsed beliefs or principles. A common method for exploring unconscious attitudes is an "Implicit Association Test" (Greenwald, McGhee, and Schwartz 1998), in which subjects are instructed to make associations between various words or images very quickly and then see what patterns and connections emerge.[5] In contrast, most investigations by economists of demand-side causes of disparities—like models of taste-based discrimination and statistical discrimination—focus on situations in which the discriminator makes an explicit decision (for reviews, see Darity and Mason 1998 in this journal; Lang and Lehmann 2012). While much of the work on implicit associations and discrimination has not involved economists as subjects or as researchers, we believe the evidence has implications for the economics profession and for future economic research.

A substantial body of evidence documents the pervasiveness of implicit biases reflecting social stereotypes (for surveys of the evidence, see Greenwald and Banaji 1995; Greenwald and Krieger 2006). This work is consistent with the research in economics by Bertrand and Mullainathan (2004), which involved responding to newspaper help-wanted ads with fictitious resumes showing similar credentials but a mixture of names that potential employers were likely to associate with African Americans or with whites. White-sounding names were much more likely to get callbacks. Bertrand, Chugh, and Mullainathan (2005) discuss how such findings can result from implicit discrimination.

Implicit biases have been shown to affect professional judgment across a range of professions. For example, Schulman et al. (1999) describes a study in which

[5] Researchers hypothesize that the human brain uses implicit association to deal with bottlenecks in information processing; in the visual system, for instance, the retina receives information at an estimated rate of 109 bits per second (Kelly 1962), far beyond the 30 to 50 bits per second processing capacity of deep layers of the visual pathway (Sziklai 1956). Response latency tests, priming studies, and direct measurement of physiological and neurological reactions indicate that race, gender, and other perceived group affiliations operate as heuristics, with powerful, unconscious effects on judgments and actions. Try taking a test yourself at https://implicit.harvard.edu/implicit/education.html.

720 doctors watched videos of "patients" describing chest pain symptoms. Although the actors were scripted to convey a very similar range of information, the doctors were more likely to refer whites and men for cardiac catheterization than blacks and women. In an Internet-based study of the responses of 287 physicians at four medical centers to a hypothetical patient presenting with acute coronary symptoms, Green et al. (2007) find that physicians with greater pro-white implicit bias, as measured by an array of implicit association tests, were less likely to treat black patients with thrombolysis (an immediate treatment to dissolve blood-clots) relative to whites with the same symptoms, despite reporting no explicit bias in a survey about prejudice.

Research suggests that implicit bias affects interactions at all stages of the academic pipeline, in formal decisions, such as promotion and admission, and in routine interactions, such as advising students on courses to take or responding to questions and ideas from colleagues. In a study by Milkman, Akinola, and Chugh (2015), 6,500 professors in 89 disciplines across 259 US universities received an email with a request from a fictional prospective student, asking for a 10-minute meeting to discuss research opportunities prior to applying to a doctoral program. The student's name was randomly assigned to signal gender and race (Caucasian, Black, Hispanic, Indian, Chinese), but messages were otherwise identical. Across almost all disciplines, faculty ignored requests from women and minorities at higher rates than requests from Caucasian males, with large and statistically significant regression-estimated discriminatory gaps. In business, the discipline with the largest gap, 87 percent of Caucasian males received a response, compared to 62 percent of women and minorities. In the social sciences, which in this study pools economics with 18 other disciplines including sociology, communication, and gender and area studies, 75 percent of Caucasian males received a response, compared with 68 percent of women and minorities. Follow-up analyses revealed that discriminatory gaps were particularly acute in higher-paying disciplines and in private institutions. Moreover, there was no evidence that women benefited from contacting female faculty, nor that black or Hispanic students benefited from contacting same-race faculty.[6]

A variety of studies suggest bias in academic hiring. Specifically, a sample of 127 science faculty in research universities rated a male applicant for a lab manager position as significantly more competent and hirable than an identical female applicant based on looking at a job application from a hypothetical job candidate who was randomly assigned to be male or female. They also selected a 15 percent higher starting salary and offered more career mentoring to male applicants (Moss-Racusin et al. 2012). Male and female faculty members were equally likely to exhibit bias. Similarly, after evaluating a curriculum vitae that was randomly assigned a male or female name, a sample of 238 male and female academic psychologists

[6] Implicit bias also affects the experience of enrolled students. Dee, John, Baker, and Evans (2015) find that instructors of massive open online courses (MOOCs) are more likely to respond to forum posts by ostensibly white male students.

were more likely to hire the male applicant for a tenure-track job and had more positive evaluations of the male applicant's teaching, research, and service records (Steinpreis, Anders, and Ritzke 1999). In a study of high-achieving male professors in life sciences, Sheltzer and Smith (2014) find that they train 10–40 percent fewer women in their laboratories relative to others. Trix and Psenka (2003) analyze the content of 300 letters of recommendation for prospective faculty members at a large medical school in the 1990s, finding that letters for women are shorter, are more likely to use language that raises doubts, and reinforce gender stereotypes of women as teachers and men as researchers (for example, the phrases "her teaching" and "his research" are commonly used).

While we know of no experiments directly testing for bias amongst economists, a recent working paper by Sarsons (2015) provides evidence suggesting implicit bias in economics. Using data from the curricula vitae of economists who were up for tenure between 1975 and 2014 at the top 30 PhD-granting US universities, she documents that, while an additional coauthored paper for a man has the same effect on the likelihood of tenure as a solo-authored paper, women suffer a significant penalty for coauthoring, especially when their coauthors are men.

Women and minority faculty members can be subject to unconscious bias from evaluators other than colleagues, as well. Students rate instructors of online classes significantly higher when the instructors use a male identity than when they use a female identity, regardless of the instructors' actual gender (MacNell, Driscoll, and Hunt 2015; Boring, Ottoboni, and Stark 2016), and write gendered online reviews, using the word "brilliant" more often to describe male faculty and the word "annoying" to describe females, even in economics (see http://benschmidt.org/profGender). In a study of referee recommendations using a large sample of articles submitted to one economics journal, Abrevaya and Hamermesh (2012) find no evidence of relative favoritism by referees towards authors of their own gender. It is important to note, however, that regression analyses that assess discrimination using same-gender interaction terms cannot actually detect bias to the extent that both male and female evaluators are influenced by social stereotypes about women, as other studies have repeatedly shown.

Finally, there is a possibility of "institutional discrimination," which occurs when the rules, practices, or "nonconscious understandings of appropriate conduct" systematically advantage or disadvantage members of particular groups (Haney-López 2000). We use this phrase to describe the (not explicitly intended) discrimination that occurs when facially neutral policies and routines of an academic department or instructor have, in practice, a disparate impact by gender or race. For example, a de facto practice to hire candidates only from elite PhD programs (or to admit PhD applicants only from elite undergraduate institutions) may produce systematic disadvantage. Indeed, economists do in fact display a high propensity to hire from top ten graduate programs as compared to other disciplines (Wu 2005). Alternatively, the use of a decision rule eliminating all junior job candidates who took more than six years to complete their PhD would disproportionately impact members of racial and ethnic minority groups, and to some extent women, for whom longer times to PhD completion are more likely. More generally, a narrow vision of the appropriate route to excellence as an economist undervalues the alternative pathways taken by women and minorities towards academic careers (Turner and Myers 2000; Husbands Fealing, Lai, and Myers 2015).

Institutional policies can cause unplanned, but ultimately unsurprising, disadvantage. An analysis of data on all assistant professors hired at top-50 economics departments from 1985 to 2004 found that gender-neutral policies to stop the tenure clock for new parents substantially reduce female tenure rates while substantially increasing male tenure rates (Antecol, Bedard, and Stearns 2016). As another example, desire to have women and minority representation on committees may help explain why women faculty are asked to provide more service, as a survey of 1,399 members of US political science departments found (Mitchell and Hesli 2013). Indeed, women associate professors spend far more time on service than do male associates, with estimates of the differential ranging from two to five hours a week, in studies of faculty in science and engineering at top research universities (Link, Swann, and Bozeman 2008) and in various disciplines at a large public university (Misra, Lundquist, and Templer 2011).

As a broader example of unintended disparate effects, perhaps economists are not in the habit of implementing undergraduate curricula and teaching techniques that would make economics more inclusive and meaningful for groups traditionally underrepresented in our profession. To the extent that economists are ineffective teachers, whether due to competing priorities or to lack of training, we end up with a self-selected sample of student majors who come to our classes with prior interest, background, and encouragement in economics.

Of course, posing these demand-side explanations raises the question of whether they can help explain why economics has been slower to diversify than other fields. The existing evidence on this point is not conclusive. However, it is concerning that those who, like economists, are used to framing choices in terms of individual objective decision-making may also be less vigilant against discrimination. Stephens and Levine (2011) look at attitudes about gender discrimination in the labor force in a sample of stay-at-home mothers and undergraduate students, and find that framing actions in terms of individual choice increases expressed belief that society provides equal opportunities and that discrimination no longer exists. Uhlmann and Cohen (2007) analyze a group of 65 men who role-played a game about hiring a factory manager, in which they rated a job applicant who could randomly be male or female. Some of the men were "primed" in advance by being asked to answer a survey about whether they viewed themselves as objective and logical. Those who were "primed" in this way were more likely to favor male applicants.

Overall, the potential importance of demand-side considerations in economics is suggested by one of the findings in Ceci, Ginther, Kahn, and Williams (2014), who find that across most fields with a heavy focus on math skills, "the research indicates no significant sex differences in promotion to tenure and full professor." However, they also write: "Economics is an outlier, with a persistent sex gap in promotion that cannot be readily explained by productivity differences."[7]

Why Economists Should Care about Diversity

Why should economists care about the underrepresentation of women and members of minority groups in their profession? Broadening the pool from which professional economists are drawn is not just about fairness, important though this is. Two strands of recent research suggest that it is also necessary to ensure the profession produces robust and relevant knowledge.

First, opinions among economists about policy are not the same across different groups. In a survey of 143 AEA members with doctoral degrees from US institutions, May, McGarvey, and Whaples (2014) find that male and female economists have different views on economic outcomes and policies, even after controlling for vintage of PhD and type of employment. For example, relative to male economists, women economists are 21 percentage points more likely to disagree that the United States has excessive government regulation of economic activity; 32 percentage points more likely to agree with making the distribution of income more equal; 30 percentage points more likely to agree that the United States should link import openness to labor standards; and 42 percentage points more likely to disagree that labor market opportunities are equal for men and women. The prevailing range of views among economists is likely to be biased by the relative lack of women and minority economists.

Second, diversity changes group dynamics and decision-making, and the behavior of individual members changes with the mix of the group. A body of laboratory experiments on this point has been done with a wide range of players and tasks. In studies focusing on the effects of gender diversity, Woolley et al. (2010) recruited 699 people in Boston and Pittsburgh and put them to work in groups ranging in size from two to five on a series of problem-solving tasks. They find that the more successful groups display a "collective intelligence" that is based not on the intelligence of individual members, but on the social sensitivity of the group, in taking turns in conversation, and on the proportion of females in the group. Hoogendoorn, Oosterbeek, and van Praag (2013) randomly assign 550 undergraduate business students in Amsterdam to course project groups and find that mixed-gender groups display more intense mutual monitoring and produce better outcomes in a business-oriented scenario. Kamas, Preston, and Baum (2008) look at a group of 164 undergraduate students playing a "dictator"

[7] It is also worth noting that regression analyses attributing differences in outcomes to productivity-related factors likely underestimate discriminatory gaps, given the pervasive effects of gender and racial/ethnic biases. For example, in regressions explaining the likelihood of promotion to full professor, unconscious bias likely affects control variables such as course evaluations and publication record as well as the estimated coefficients on gender and race variables.

game in which they must split a sum of money between themselves and the American Red Cross. Women tend to give more than men, and a two-person male-female team gives more than the expected sum of what they would give playing alone.

In examples of studies looking at ethnic and cultural diversity, Phillips, Northcraft, and Neale (2006) show in an experimental setting with 216 undergraduate business students that racially diverse groups significantly outperform other groups in solving complex problems, as homogeneous groups perceive their information to be less unique and spend less time on the task. In a study with 200 jury-eligible Michigan community members, Sommers (2006) found that participants on racially diverse mock juries exchange more information, make fewer errors, deliberate longer, and consider a wider range of perspectives. Levine et al. (2014) conduct a laboratory experiment involving a scenario with potential price bubbles using groups of real world traders in two locations, one in Southeast Asia and one in North America. They find that traders in ethnically homogeneous markets place undue confidence in the reasonableness of others' decisions, which leads to price bubbles, while ethnic diversity can promote deliberation and disrupt conformity. Leung, Maddux, Galinsky, and Chiu (2008) offer a review of the evidence from the psychology literature that exposure to multiple cultures can enhance creativity.

The commonality of findings about diversity in many contexts is notable, but of course these studies are not directly about decision-making in academia. In a study that suggests that the creativity and productivity of mixed groups may also benefit academic research, Freeman and Huang (2015) examine 2.5 million research papers written from 1985 to 2008 in which all of the authors had US addresses. They find that papers written by ethnically diverse research teams receive more citations and are higher impact than papers written by authors from the same ethnic group. Although noncausal explanations of this pattern are possible, it suggests that greater diversity of authorship may lead to higher quality research.

If the ultimate goal of economic research is to develop and communicate lasting insights, this evidence suggests that the value and impact of the economics profession suffer from the lack of diversity in its ranks.

Moving Forward

We believe there are several promising directions for future initiatives and research.

Revise How We Present Economics to Undergraduates

The economics profession needs to attract a larger share of women and minorities into economics at the undergraduate level. We highlight several recommended approaches here. Much of the evidence behind these approaches comes from randomized control trial studies in science, technology, engineering, and math fields. We encourage economists to use and expand the body of research on best teaching practices in economics.[8]

Undergraduate economics continues to be taught primarily in a lecture format. Watts and Schaur (2011), for instance, show in survey data with about 400 academic economists as respondents that traditional lecturing, a practice that has been shown repeatedly to be inferior to other available methods, remains the dominant undergraduate teaching method among economists. The survey also shows that references to "gender, race, and ethnic issues" in undergraduate economics courses are rare. The alternative to a lecture format is active learning, in which instructors ask rather than tell, and students answer questions in discussions or with clickers, clarify concepts to each other via peer instruction, and discover principles through classroom experiments and labs. Freeman et al. (2014) carries out a meta-analysis of 225 studies comparing the effects of active and passive learning techniques in science, technology, engineering, and mathematics. They find that active learning increases exam scores and decreases failure rates relative to traditional lecturing, with particular benefit for students from disadvantaged backgrounds and for women in male-dominated fields.

Instructors can reduce stereotype threat with an array of empirically validated strategies, many of which suggest that what may seem like relatively small changes can have substantial effects. For example, Murphy, Steele, and Gross (2007) had 47 Stanford University undergraduates watch one of two videos about a math, science, and engineering conference. Some viewed a video in which men outnumbered women in a ratio of 3 to 1, while others observed gender balance in an otherwise identical video. Women who saw the gender-balanced conference felt more sense of belonging and desire to participate than those who saw the gender-imbalanced version. Purdie-Vaughns et al. (2008), in experiments involving African American professionals, show that cues conveying that diversity is valued, rather than a colorblind philosophy, can help reduce identity-related threat in low minority representation environments. Miyake et al. (2010) carry out a "values affirmation" exercise with 399 college students in an introductory physics class and confirm that the treatment group, which selected and wrote about values important to them in two 15-minutes exercises, ended up with a lower male-female performance gap for the course as a whole. Such exercises, although unrelated to course content, have been shown to reduce the effects of stereotype threat for racial minorities, too. With these examples in mind, sharing the new AEA video on careers in economics (at http://www.aeaweb.org/video/career_in_economics.php) may be a useful step toward encouraging women and minority students in economics.

Good teachers remind students that intelligence is not a fixed trait and that economic ability can be developed through hard work, making mistakes, and perseverance. For example, in an experimental study Aronson, Fried, and Good (2002)

[8] For a review of studies about undergraduate teaching in economics, although with little attention to the diversity issues that are the focus here, a useful starting point is Allgood, Walstad, and Siegfried (2015). For more guidance on the design of undergraduate economics curricula, see Allgood and Bayer (2016).

ask African American and white Stanford undergraduates to write to younger pen pals to emphasize, among other things, that intelligence is malleable, and they find that the treatment increases academic enjoyment, engagement, and performance for undergraduates in both racial groups, but particularly for African Americans. Departments making comprehensive changes can impact participation rates significantly. The Grinnell Science Project, the computer science program at Harvey Mudd College, and Princeton's Diversity Programs in Molecular Biology and Quantitative and Computational Biology use arrays of interventions to produce significant changes at the undergraduate and doctoral levels. Components include curricular reform, community building, student-faculty research, recruitment, holistic candidate review, and/or pre-orientation. At Harvey Mudd, the number of women computer science graduates quadrupled in six years (Alvarado, Dodds, and Libeskind-Hadas 2012).

There are a number of current projects to develop and evaluate best practices within economics. The AEA's Committee on the Status of Minority Groups in the Economics Profession sponsors an online resource, *Diversifying Economic Quality* at DiversifyingEcon.org, to help economics instructors and departments adopt inclusive, innovative, and evidence-based teaching practices (Bayer 2011). Another initiative is "The Undergraduate Women in Economics Challenge," directed by Claudia Goldin and funded by the Alfred P. Sloan Foundation, which provides guidance and significant funds to 20 treatment departments to explore and implement interventions designed to increase the number of women economics majors, while simultaneously tracking outcomes in a set of unfunded control departments. Other projects are using field experiments to evaluate the effectiveness of specific interventions intended to broaden participation in undergraduate economics. Through projects with rigorous experimental designs, we learn what works and what does not work in increasing the representation of women and minorities in economics, while also gaining greater insight into causal mechanisms and generating additional hypotheses to support future research and initiatives.

Support Early-Career Pipeline and Mentoring Programs

Pipeline programs help participants develop skills and networks critical to staying and moving forward in a field of study. The AEA supports several programs, and there now exists some credible evidence of their effectiveness. For example, the AEA's Committee on the Status of Women in the Economics Profession (CSWEP) sponsors a mentoring program for young female economists (CeMENT Mentoring Workshops) during which participants are placed into small groups based on their teaching and research and matched with a senior mentor to address issues such as effective teaching, navigating the journal publication process, balancing work and "life," and the tenure process. Blau, Currie, Croson, and Ginther (2010) conducted a randomized study of its effectiveness and report that the mentoring program had a positive effect on a number of professional outcomes, such as the number of top-tier publications, the total number of publications, and the number of successful federal grants earned by individuals randomly assigned a mentor compared to those randomly assigned to the control group.

Since 1974, the AEA's Committee on the Status of Minority Groups in the Economics Profession (CSMGEP) has sponsored a Summer Training Program aimed at improving diversity in the economics profession. The program, which has been hosted at a number of universities over time, runs about 7–8 weeks during which undergraduates take classes in microeconomic theory, math, and econometrics, and more recently have written research papers. The program has averaged about 25 students per year. Becker, Rouse, and Chen (2016) compared the outcomes of participants to those of unsuccessful applicants and find that Summer Program participants were significantly more likely to apply to and attend an economics PhD program, complete a PhD, and ever work in an economics-related academic job.

Both CSWEP and CSMGEP have other programs aimed at providing women and underrepresented minorities with greater mentorship (such as CSWEP's Mentoring Breakfast and CSMGEP's Mentoring Program) or opportunities to conduct guided research (such as the CSWEP/CSMGEP Summer Fellows Program). Another mentoring program currently housed at Duke University is the Diversity Initiative for Tenure in Economics (DITE), which aims to help untenured professors and economists outside of the academy to strengthen their research in order to attain tenure. Other recent efforts for early-stage economists include one-year pre-doctoral and master's programs, which are designed to enrich students' skills in math, economic theory, and econometrics to increase their likelihood of graduate program acceptance and success; the University of Wisconsin, the University of Texas at Austin, Duke University, Tufts University, the University of California at Los Angeles, Washington University, and Vanderbilt University currently offer such programs, to name a few. While these efforts have not yet been evaluated, well-designed bridge programs are used successfully in physics and other disciplines to increase the number of underrepresented minority students earning doctoral degrees (for example, Stassun et al. 2011). More generally, the economics profession would benefit greatly from additional studies with credible identification strategies to help estimate the effectiveness of these kinds of pipeline and mentoring programs.

Remove Implicit and Institutional Barriers

Research shows that implicit associations can be modified to produce outcomes more aligned with our values and intentions. In one prominent example, Pope, Price, and Wolfers (2014) show that racial patterns in personal foul calls by professional basketball referees disappeared following media attention to findings reported by Price and Wolfers (2010).

Laboratory experiments suggest that interventions can alter implicit attitudes. Devine, Forscher, Austin, and Cox (2012) study 91 nonblack undergraduate students who took a 12-week course to raise awareness of the existence and effects of implicit bias and to learn about an array of proven strategies for reducing bias. The students in the treatment group changed their scores on implicit bias tests about black-white associations, and the change persisted eight weeks after the end of the course. Research also suggests that altering decision-making procedures can limit the opportunity for bias to influence evaluations and behavior. A well-known example is the study by Goldin and Rouse (2000), which found that when auditions for professional orchestras occurred behind a screen, so that musicians were judged only on what they sounded like, the chances rose for women to be hired. More broadly, Soll, Milkman, and Payne (2014) review a range of literature on ways to "debias" judgments, which apply not only to attitudes about women and minorities in economics but also to the full array of behavioral decision biases. For example, we can create conditions for making less-biased evaluations by: removing identifiers, minimizing time pressure and distractions, discrediting feelings of connection or chemistry, committing to fair and relevant admissions or hiring criteria before learning applicants' race or gender, collecting more evidence on candidates' competencies, creating accountability, and strategically setting default options and other nudges. Efforts along these lines deserve further study and documentation.

Certain institutional features and practices that can act as barriers to diversity should be reconsidered. Conventional hiring and admissions standards—such as hiring exclusively (or almost exclusively) from elite PhD programs, getting referrals from traditional networks, and using test score cutoffs—may be better indicators of past background than of future potential. Indeed, using a minimum GRE score below which graduate school applicants are rejected without consideration of other information violates the test developer's guidelines (ETS 2015), and physicists are constructing alternative selection criteria more predictive of success in scientific research (for example, Miller and Stassun 2014). When developing criteria to evaluate candidates, colleagues, or students, the goal should be to set sufficiently broad and fundamental criteria to allow all types of candidates to reveal their strengths and potential. As colleagues, we can be allies to women and faculty of color by helping to relieve service burdens and making sure diverse types of work are valued. Using a combination of survey, field, and laboratory evidence, Vesterlund, Babcock, Recalde, and Weingart (2015) consider the allocation of "non-promotable tasks" (tasks irrelevant to advancement of an individual's career but necessary to the wellbeing of the group) and find that women more often are asked to do these tasks, and accept, due to commonly held beliefs that men are relatively less inclined to do them. More generally, the possibility of bias in the impact of the policies, shortcuts, and habits of individuals, departments, and administrations should be recognized and addressed.

In some ways, efforts to reduce bias ask nothing more than for academics to listen to the better angels of their nature. Fair and specific feedback, delivered with both an invocation of high standards and an assurance of the person's capacity to reach those standards, can counter stereotype threat and close racial gaps in perceived bias, motivation, and achievement, as Cohen, Steele, and Ross (1999) demonstrate in a study of 100 black and white Stanford undergraduates. A sensible, if untested, strategy to counter the everyday effects of unconscious bias is to crowd out micro-inequities with what Rowe (2008) calls "micro-affirmations," defined as small acts that occur, consciously or unconsciously, wherever people wish to help others to succeed. In interactions with colleagues and students, give credit to others, open doors to opportunity, listen, include, support, and encourage.

Conclusion

We hope that these insights and results about diversity, drawn from bodies of research in multiple disciplines, help to suggest promising directions for future interventions and research, by economists and others. The evidence seems clear that the field of economics is behind others in its progress on diversity concerns, and our sense is that attending to what we have characterized as demand-side issues could have great payoffs. Recent methodological advances, especially in analyzing cognitive biases and in the use of laboratory and field experiments, provide new insights and opportunities for research into the benefits, barriers, and steps to a more diverse and inclusive profession.

The social science discipline of economics will be strengthened if it is built on a broader segment of the population. In October 2014, the Federal Reserve hosted a National Summit on Diversity in the Economics Profession, bringing together presidents and research directors of the Federal Reserve Banks and chairs of economics departments from around the country to open a professionwide dialogue about diversity. In her remarks at this event, Federal Reserve Chair Janet Yellen (2014) stated, "[W]hen economics is tested by future challenges, I hope that our profession will be able to say that we have done all we could to attract the best people and the best ideas."

■ *We thank Disa Hynsjo, Samsun Knight, and Nikhita Luthra for expert research assistance, Charles Scott for providing additional data from the Universal Academic Questionnaire, and the Princeton University Industrial Relations Section for funding. Any errors in fact or interpretation are ours.*

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Recommendations for Further Reading

Timothy Taylor

This section will list readings that may be especially useful to teachers of undergraduate economics, as well as other articles that are of broader cultural interest. In general, with occasional exceptions, the articles chosen will be expository or integrative and not focus on original research. If you write or read an appropriate article, please send a copy of the article (and possibly a few sentences describing it) to Timothy Taylor, preferably by email at taylort@macalester.edu, or c/o *Journal of Economic Perspectives*, Macalester College, 1600 Grand Ave., St. Paul, MN 55105.

Smorgasbord

"More than 40 million people living in the United States were born in other countries, and almost an equal number have at least one foreign-born parent. Together, the first generation (foreign-born) and second generation (children of the foreign-born) comprise almost one in four Americans. It comes as little surprise, then, that many U.S. residents view immigration as a major policy issue facing the nation. Not only does immigration affect the environment in which everyone lives, learns, and works, but it also interacts with nearly every policy area of concern, from jobs and the economy, education, and health care, to federal, state, and local government budgets." That's the beginning of *The Economic and Fiscal Consequences of*

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† For supplementary materials such as appendices, datasets, and author disclosure statements, see the article page at
http://dx.doi.org/10.1257/jep.30.4.243 doi=10.1257/jep.30.4.243

Immigration, a National Academy of Sciences report edited by Francine D. Blau and Christopher Mackie. September 2016. A "prepublication copy" can be downloaded at https://www.nap.edu/catalog/23550/the-economic-and-fiscal-consequences-of-immigration. The report can be usefully read in combination with the "Symposium on Immigration" in this issue.

Olivier Blanchard asks, "Do DSGE Models Have a Future?" "For those who are not macroeconomists, or for those macroeconomists who lived on a desert island for the last 20 years, here is a brief refresher. DSGE stands for 'dynamic stochastic general equilibrium.' The models are indeed dynamic, stochastic, and characterize the general equilibrium of the economy. They make three strategic modeling choices: First, the behavior of consumers, firms, and financial intermediaries, when present, is formally derived from microfoundations. Second, the underlying economic environment is that of a competitive economy, but with a number of essential distortions added, from nominal ties to monopoly power to information problems. Third, the model is estimated as a system, rather than equation by equation in the previous generations of macroeconomic models. … [C]urrent DSGE models are best seen as large-scale versions of the New Keynesian model, which emphasizes nominal rigidities and a role for aggregate demand. … There are many reasons to dislike current DSGE models. First: They are based on unappealing assumptions. Not just simplifying assumptions, as any model must, but assumptions profoundly at odds with what we know about consumers and firms. ... Second: Their standard method of estimation, which is a mix of calibration and Bayesian estimation, is unconvincing. ... Third: While the models can formally be used for normative purposes, normative implications are not convincing. ... Fourth: DSGE models are bad communication devices. A typical DSGE paper adds a particular distortion to an existing core. It starts with an algebra-heavy derivation of the model, then goes through estimation, and ends with various dynamic simulations showing the effects of the distortion on the general equilibrium properties of the model. … I see the current DSGE models as seriously flawed, but they are eminently improvable and central to the future of macroeconomics." Peterson Institute for International Economics Policy Brief 16-11, August 2016, https://piie.com/system/files/documents/pb16-11.pdf.

Nadim Ahmad and Paul Schreyer of the OECD ask, "Are GDP and Productivity Measures Up to the Challenges of the Digital Economy?" From the abstract: "Recent years have seen a rapid emergence of disruptive technologies with new forms of intermediation, service provision and consumption, with digitalization being a common characteristic. These include new platforms that facilitate peer-to-peer transactions, such as AirBnB and Uber, new activities such as crowd sourcing, a growing category of the 'occasional self-employed' and prevalence of 'free' media services, funded by advertising and 'Big data'. Against a backdrop of slowing rates of measured productivity growth, this has raised questions about the conceptual basis of GDP, and whether current compilation methods are adequate. This article frames the discussion under an umbrella of the Digitalized Economy, covering also statistical challenges where digitalization is a complicating feature such as the measurement of international transactions and knowledge-based assets. It delineates between conceptual and compilation issues and highlights areas where further investigations are merited. The overall conclusion is that, on balance, the accounting framework for GDP looks to be up to the challenges posed by digitalization. Many practical measurement issues remain, however, in particular concerning price changes and where digitalization meets internationalization." *International Productivity Monitor*, published by the Ontario-based Centre for the Study of Living Standards, Spring 2016, pp. 4–27, http://www.csls.ca/ipm/30/ahmadandschreyer.pdf.

Theodore Talbot and Owen Barder discuss "Payouts for Perils: Why Disaster Aid Is Broken, and How Catastrophe Insurance Can Help to Fix It." "[T]he principle is simple: rather than transferring risk to a re-insurer, an insurance firm creates a single company (a 'special purpose vehicle', or SPV) whose sole purpose is to hold this risk. The SPV sells bonds to investors. The investors lose the face value of those bonds if the hazard specified in the bond contracts hits, but earn a stream of payments (the insurance premiums) until it does, or the bond's term expires. This gives any actor—insurer, re-insurer, or sovereign risk pool like schemes in the Pacific, Caribbean and Sub-Saharan Africa, which we discuss below—a way to transfer risks from their balance sheets to investors. … Tying contracts to external, observable phenomena such as Richter-scale readings for the extent of earthquakes or median surface temperature for droughts means that risk transfer can be specifically tailored to the situation. There are three varieties of triggers: parametric, modelled-loss, and indemnity. Parametric triggers are the easiest to calculate based on natural science data—satellite data reporting a hurricane's wind speed is transparent, publicly available, and cannot be affected by the actions of the insured or the insurer. When a variable exceeds an agreed threshold, the contract's clauses to payout are invoked. Because neither the insured nor the insurer can affect the parameter, there is no cost of moral hazard, since the risks—the probabilities of bad events happening—cannot be changed. Modelled losses provide estimates of damage based on economic models. Indemnity coverage is based on the insurance claims and loss adjustment and are the most expensive to operate and take the most time to pay out (or not)." Center for Global Development Policy Paper 087. July 2016. http://www.cgdev.org/publication/payouts-perils-why-disaster-aid-broken-and-how-catastrophe-insurance-can-help-fix-it.

Darrell Duffie discusses "Financial Regulatory Reform After the Crisis: An Assessment." "In the United States, the most toxic systemic financial firms were investment banks that relied heavily on run-prone wholesale short-term financing of their securities inventories. A large fraction of this funding was obtained from unstable money market mutual funds. A substantial amount of this money-fund liquidity was arranged in the overnight repo market, which was discovered by regulators to rely precariously on two U.S. clearing banks for trillions of dollars of intra-day credit. The core plumbing of American securities financing markets was a model of disrepair. … The FSB [Financial Stability Board] summarized progress within 'four core elements' of financial-stability regulation: 1. Making financial institutions more resilient. 2. Ending 'too-big-to-fail.' 3. Making derivatives markets safer. 4. Transforming shadow banking. At this point, only the first of these cores element of the reform, 'making financial institutions more resilient,' can be scored a clear success, although even here much more work remains to be done." The paper was presented at the 2016 European Central Bank Forum on Central Banking, held June 27–29, 2016. A conference program, with links to papers and video, is at https://www.ecbforum.eu/en/content/programme/overview/programme-overview.html.

The Council of Economic Advisers has published an "issue brief" titled "Benefits of Competition and Indicators of Market Power." "[C]ompetition appears to be declining in at least part of the economy. This section reviews three sets of trends that are broadly suggestive of a decline in competition: increasing industry concentration, increasing rents accruing to a few firms, and lower levels of firm entry and labor market mobility. The U.S. Census Bureau tracks revenue concentration by industry, and one measurement it provides of such concentration is the share of revenue earned by the 50 largest firms in the industry. … [T]he majority of industries have seen increases in the revenue share enjoyed by the 50 largest firms between 1997 and 2012. Several industry-specific studies have found consistent results over longer periods of time." April 2016, https://www.whitehouse.gov/sites/default/files/page/files/20160414_cea_competition_issue_brief.pdf. The chair of the CEA, Jason Furman, provides some additional context in his September 16, 2016, lecture "Beyond Antitrust: The Role of Competition Policy in Promoting Inclusive Growth," available at https://www.whitehouse.gov/sites/default/files/page/files/20160916_searle_conference_competition_furman_cea.pdf.

Steven Bovie, Michael K. Bednar, Ruth V. Aguilera, and Joel L. Andrus ask, "Are Boards Designed to Fail? The Implausibility of Effective Board Monitoring." "In fact, most academic research, popular press accounts, and even U.S. legislation all echo the sentiment and deeply held belief that boards should be able to actively monitor and control management. ... Given the research reviewed in this article, we are pessimistic about the possibility of boards being able to effectively monitor managers on an ongoing basis in many circumstances. ... Given the size and complexity of many modern firms, we believe some firms may effectively be 'too big to monitor', and that successful monitoring by boards may be highly unlikely in many large public firms. It might be time to concede that our conception of boards as all-encompassing monitors is doubtful ... Consequently, we believe that future research and theorizing needs to focus on boards as advice-giving bodies, or bodies that get involved in punctuated events, and look to other corporate governance mechanisms to secure monitoring." *Academy of Management Annals*, 2016, vol. 10, no. 1, pp. 319–407.

Symposia

Richard E. Baldwin has edited *Brexit Beckons: Thinking Ahead by Leading Economists*, with short and readable contributions by 19 economists. From Baldwin's overview essay: "The 23 June 2016 Brexit referendum saw British voters reject membership of the European Union. This VoxEU eBook presents 19 essays written by leading economists on a wide array of topics and from a broad range of perspectives. … [T]he key point is that UK policy in many areas has been made at the EU level for decades. Leaving the EU thus means that the UK will have to replace EU policies, rules, and agreements with British policies, rules, and agreements. As we shall see, this will prove a massively complex task. … Charles Wyplosz suggests that Brexit would be an opportunity for the EU to re-evaluate the degree of centralisation that has been reached so far. He argues for a simultaneous bidirectional change of authority implemented in such a way such that each country gives a little and takes a little in order to arrive at a package that is both politically acceptable and economically efficient. The problem is that this sort of root-and-branch rethinking was tried ten years ago at the European Convention. The result—the Constitutional Treaty—was rejected by several members, some via referendums. … Noone can anticipate where the Brexit vote will take the UK and the EU. The alternative that seems most sensible from an economic perspective is the Norway option. It may well be that the UK government could make this palatable, despite the free movement of people, by bundling it together with a very thorough set of policies to help the UK citizens who have been left behind by globalisation, technological advances, and European integration. Maybe we could call it the 'EEA plus anti-exclusion option' (EEA+AE). If this came to pass, the main economic policy outcome of the Brexit vote would be simple. The UK would end up with more influence over its trade, agricultural, and regional policies, but less influence over the rules and regulation governing its industrial and service sectors." VoxEU, August 2016, http://voxeu.org/content/brexit-beckons-thinking-ahead-leading-economists.

Cityscape, a magazine of the US Department of Housing and Urban Development, has published a nine-paper symposium on "Housing Discrimination Today." Sun Jung Oh and John Yinger ask in the lead article, "What Have We Learned From Paired Testing in Housing Markets?" (pp. 15–59). From the abstract: "Fair housing audits or tests, which compare the way housing agents treat equally qualified homeseekers in different racial or ethnic groups, are an important tool both for enforcing fair housing laws and for studying discriminatory behavior in housing markets. This article explains the features of two types of housing audits: in-person paired audits and correspondence audits, which are usually conducted over the Internet. … The studies reviewed include four national studies in the United States based on in-person audits and many studies based on correspondence audits in the United States and in several European countries. This article also reviews audit-based evidence about the causes of discrimination in housing markets. Despite variation in methods, sample sizes, and locations, audit studies consistently find evidence of statistically significant discrimination against homeseekers who belong to a historically disadvantaged racial or ethnic group. The 2012 national audit study found, for example, that the share of audits in which a White homebuyer was shown more available houses than an equally qualified Black homebuyer was 9 percentage points higher than the share in which the Black homebuyer was shown more houses than his or her White counterpart. In the United States, housing discrimination against Black and Hispanic homeseekers appears to have declined in some types of agent behavior, such as whether the advertised unit is shown to a customer, but to have increased in others, such as steering Black and Hispanic homeseekers toward minority neighborhoods." 2015, vol. 17, no. 3. https://www.huduser.gov/portal/periodicals/cityscpe/vol17num3/index.html.

Negative Interest Rates and Neo-Fisherism

Benoît Cœuré gave a lecture "Assessing the Implications of Negative Interest Rates." "In June 2014, following in the footsteps of the Danish National Bank, the European Central Bank (ECB) became the first major central bank to lower one of its key policy rates to negative territory. The rate of interest on our deposit facility is now –0.4% while the rate on our main refinancing operations is zero. …. It is difficult to know how long these low interest rates will persist, but it seems possible that they will be low for quite some time. That certainly is the view of financial markets, where the return on government bonds is negative for a range of countries, even at long maturities. … Central bankers should however be mindful of a potential 'economic lower bound', at which the detrimental effects of low rates on the banking sector outweigh their benefits, and further rate cuts risk reversing the expansionary monetary policy stance. … The current conditions of financial intermediation suggest, however, that the economic lower bound is safely below the current level of the deposit facility rate and that the impact of negative rates, combined with the APP and forward guidance, has clearly been net positive. … Finally, what about the risks to financial stability? The ongoing economic recovery should help bolster the income and earnings position of euro area households and non-financial corporations, thereby mitigating the risks associated with a continued debt overhang which persists in some countries. …. [T]he best way to counter any potentially emerging risk in any market segment is targeted action by the macroprudential authorities." European Central Bank, July 28, 2016, https://www.ecb.europa.eu/press/key/date/2016/html/sp160728.en.html.

Stephen Williamson provides an overview of "Neo-Fisherism: A Radical Idea, or the Most Obvious Solution to the Low-Inflation Problem?" "A well-established empirical regularity, and a key component of essentially all mainstream macroeconomic theories, is the Fisher effect—a positive relationship between the nominal interest rate and inflation. … Many macroeconomists have interpreted the Fisher relation … as involving causation running from inflation to the nominal interest rate … Market interest rates are determined by the behavior of borrowers and lenders in credit markets, and these borrowers and lenders care about real rates of interest. … But, what if we turn this idea on its head, and we think of the causation running from the nominal interest rate targeted by the central bank to inflation? This, basically, is what Neo-Fisherism is all about. Neo-Fisherism says … that if the central bank wants inflation to go up, it should increase its nominal interest rate target, rather than decrease it, as conventional central banking wisdom would dictate." *Regional Economist*, published by the Federal Reserve Bank of St. Louis, July 2016, pp. 4–9. At https://www.stlouisfed.org/publications/regional-economist/july-2016/neo-fisherism-a-radical-idea-or-the-most-obvious-solution-to-the-low-inflation-problem.

Interviews

Douglas Clement interviews Matthew Gentzkow with a focus on media economics. "I started thinking about this huge, downward trend that we've seen since about the middle of the 20th century in voter turnout and political participation. It's really around the time that TV was introduced that that trend in the time series changes sharply, so I thought TV could have played a role. Now, a priori, you could easily imagine it going either way. There's a lot of evidence before and since that in many contexts, giving people more information has a very robust positive effect on political participation and voting. So, if you think of TV as the new source of information, a new technology for delivering political information, you might expect the effect to be positive. And, indeed, many people at the time predicted that this would be a very good thing for political participation. On the other hand, TV isn't just political information; it's also a lot of entertainment. And in that research, I found that what seemed to be true is that the more important effect of TV is to substitute for—crowd out—a lot of other media like newspapers and radio that on net had more political content. … So, we see that when television is introduced, indeed, voter turnout starts to decline. We can use this variation across different places and see that that sharp drop in voter turnout coincides with the timing of when TV came in. … That drop is especially big in local elections. A lot of new technologies … are pushing people toward paying less attention to local politics, local issues, local communities." *The Region*, Federal Reserve Bank of Minneapolis, May 23, 2016, https://www.minneapolisfed.org/publications/the-region/interview-with-matthew-gentzkow. In the Winter 2015 issue of this journal, Andrei Shleifer provides an overview of Gentzkow's work in "Matthew Gentzkow, Winner of the 2014 Clark Medal."

Aaron Steelman interviews Erik Hurst on an array of topics in labor, household, and urban economics. For example: "Many urban models historically assumed that agglomeration benefits usually came from the firm side. Someone might want to be close to the center city, for instance, because most firms are located in the center city. So the spillover for the household was the commuting time to where the firms were, and the firms chose to locate near each other because of agglomeration benefits. I have always been interested in it from another angle. When we all come together as individuals, we may create agglomeration forces that produce positive or negative consumption amenities. Thinking about it this way, when a lot of high-income people live together, maybe there are better schools because of peer effects or higher taxes. Or maybe there are more restaurants because restaurants are generally a luxury good. Or maybe there's less crime because there is an inverse relationships between neighborhood income and crime, which empirically seems to hold. So, while we value proximity to firms, that's not the only thing we value. How important are these consumption amenities? And more importantly, how do these consumption amenities evolve over time ..." *Econ Focus*, Federal Reserve Bank of Richmond First Quarter 2016, pp. 22–26, https://www.richmondfed.org/publications/research/econ_focus/2016/q1/interview.

Discussion Starters

Juliette Cubanski, Tricia Neuman, Shannon Griffin, and Anthony Damico provide a "Data Note" about "Medicare Spending at the End of Life: A Snapshot of Beneficiaries Who Died in 2014 and the Cost of Their Care." "Of the 2.6 million people who died in the U.S. in 2014, 2.1 million, or eight out of 10, were people on Medicare, making Medicare the largest insurer of medical care provided at the end of life. Spending on Medicare beneficiaries in their last year of life accounts for about 25% of total Medicare spending on beneficiaries age 65 or older. … The share of total traditional Medicare spending on beneficiaries who died at some point during the year has dropped over time, from 18.6% in 2000 to 13.5% in 2014 … This drop is likely due to a combination of factors affecting total traditional Medicare spending over time and spending on decedents, including: growth in the number of Medicare beneficiaries overall, particularly in recent years as the baby boom generation ages on to Medicare, which means more younger, healthier beneficiaries, on average; longer life expectancy, which means people are living longer and dying at older ages … lower average per capita spending on older decedents compared to younger decedents … and slower growth in the rate of annual per capita spending for decedents than survivors …" July 2016, published by the Kaiser Family Foundation, July 14, 2016, http://kff.org/report-section/medicare-spending-at-the-end-of-life-findings.

Lawrence F. Katz and Alan B. Krueger provide evidence concerning "The Rise and Nature of Alternative Work Arrangements in the United States, 1995–2015." "[W]e conducted the RAND-Princeton Contingent Worker Survey (RPCWS), a version of the CWS, as part of the RAND American Life Panel (ALP) in October and November of 2015. … A comparison of our survey results from the 2015 RPCWS to the 2005 BLS [Bureau of Labor Statistics] CWS indicates that the percentage of workers engaged in alternative work arrangements—defined as temporary help agency workers, on-call workers, contract company workers, and independent contractors or freelancers—rose from 10.7 percent in February 2005 to 15.8 percent in late 2015. The increase over the last decade is particularly noteworthy given that the BLS CWS showed hardly any change in the percent of workers engaged in alternative work arrangements from 1995 to 2005. … *A striking implication of these estimates is that 94 percent of the net employment growth in the U.S. economy from 2005 to 2015 appears to have occurred in alternative work arrangements.*" Princeton University Industrial Relations Section, Working Paper 603, September 2016, http://arks.princeton.edu/ark:/88435/dsp01zs25xb933.

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The Journal of

Economic Perspectives

Fall 2016, Volume 30, Number 4

AMERICAN ECONOMIC ASSOCIATION