From Groundnuts to Globalization: A Structural Estimate of Trade and Growth*

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Abstract

Starting with Romer [1987] and Rivera-Batiz-Romer [1991] economists have been able to model how trade enhances growth through the creation and import of new varieties. In this framework, international trade increases economic output through two channels. First, trade raises productivity levels because producers gain access to new imported varieties. Second, increases in the number of varieties drives down the cost of innovation and results in ever more variety creation. Using highly disaggregate trade data, e.g. Gabon's imports of Gambian groundnuts, we structurally estimate the impact that new imports have had in approximately 4000 markets per country. We then move from groundnuts to globalization by building an exact TFP index that aggregates these micro gains to obtain an estimate of trade on productivity growth for each country. We find that in the typical country in the world, new imported varieties account for 10-25 percent of its productivity growth. However, when we structurally estimate the long-run impacts of these productivity growth effects, we find that import variety growth between 1994 and 2003 raised world permanent income by 17 percent.

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I. Introduction

Economists have long postulated that trade may raise growth. However, it was not until the work of Romer [1987] and Rivera-Batiz and Romer [1991] that we had a general equilibrium model that would let us understand how trade might bring this about. While this seminal work has spawned the development of the vast endogenous growth literature, it has fallen short of taking these models to the data.[1] This paper is the first attempt to structurally estimate the impact that trade has on growth as suggested by the endogenous growth literature. To do this, we extend Jones [1995] into a multi-country setting and use detailed data on the import of capital and intermediate goods across countries to estimate the impact that trade has on a country's productivity. Our results suggest that while trade has only temporary effects on a country's growth rate, the effects are persistent enough to imply large gains from trade. Our estimates suggest that about 10-25 percent of the typical country's per capita income growth can be attributed to international trade.

The methodology we employ differs quite sharply with that employed by most of the existing trade and growth literature. Prior work has tended to fall into two categories. Cross-country growth regressions have used a "one regression fits all" approach that is quite vague about the precise mechanisms of how trade globalization affects growth. This has produced a skepticism about the robustness of the results and has led researchers to focus their attention on specific cases of liberalization.[2] These "micro-econometric studies" of particular sectors such as "groundnuts" have the advantage that they can provide rich and compelling econometric evidence of particular trade liberalizations. In the best examples, one can often be precise about the mechanisms through which trade affects growth. Their main disadvantage is that it is hard to extrapolate from groundnuts to globalization.

In this paper we use a hybrid approach to understanding how trade affects growth. By breaking world trade down into 6-digit bilateral import flows and estimating hundreds of

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[1] This was one of Rivera-Batiz and Romer's main objectives. As they state in their opening paragraph, at that time "it would be difficult for any of us to offer a rigorous model that has been (or even could be) calibrated to data".

[2] Hallak and Levinsohn [2004] identify three main classes of "basic methodological shortcomings" in the cross-country evidence. First, trade policy or openness is typically summarized by a one-dimensional index that has little theoretical foundation. Second, there are severe omitted variables biases, which lead to results that are not robust (c.f. Sala-i-Martin [1997], Rodriguez and Rodrik [2001], Noguer and Siscart [2005, and especially 2006]). Finally, there is so much heterogeneity in economic conditions across countries that it is doubtful that there is a unique mapping of trade into growth.

structural parameters per country, we are able to build estimates that preserve the cross-industry richness of each country's economy. The estimation strategy we use enables us to combine all the gains from new and better imported goods in each industry to obtain aggregate implications for each country. We can use these estimates to account for the extent of productivity growth predicted by endogenous growth models and thereby can be precise about the channel through which trade affects growth.

A key aspect of endogenous growth models is that the introduction of new and better products drives productivity growth. Hence, we begin our exploration of the data by documenting that a defining characteristic of the growth of world trade over the last decade has been the import of new goods as well as existing goods from new sources of supply.[3] Analyzing 6-digit bilateral flows over the period 1994-2003, we show that for most countries in the world their trade to GDP ratio rose because they imported new goods not because they imported more of existing goods. In the typical developing country, virtually all of the growth in the ratio of imports to GDP came from the import of new varieties, and new varieties accounted for almost half of the growth. Moreover we show that there are far more trade flows than would be obtained in a world of homogeneous goods. Since countries are importing new goods and these goods are differentiated, this implies gains to productivity and welfare along the lines predicted by endogenous growth models.

In these models, opening to trade causes an immediate jump in per capita income as the access to new and higher quality intermediate inputs increases productivity. We use the empirical methodology of Feenstra and Markusen [1994] to show that we can measure this impact in a way consistent with Jones [1995]. In our calibration, the increase in the number of imported varieties observed over the last 10 years raised GDP per capita in the typical country in the world by 1-1.5 percent. The main intuition is that increasing the number of intermediate goods does not increase productivity much if new varieties are close substitutes to existing varieties or if the share of new

[3] Our data lets us measure intermediate inputs quite precisely. To give an example from our data, we allow for 6 different types of groundnut products: e.g. shelled raw groundnuts, unshelled raw groundnuts, prepared groundnuts, etc. Data limitations force us to treat new imports of some – but not all – groundnut products symmetrically (e.g. shelled and unshelled raw groundnuts), but nonetheless we are able to structurally estimate four different demand parameters and four different supply parameters in the groundnut market per country. These parameters enable us to estimate how new imports of unshelled groundnuts affect each economy without making any restrictions that countries value raw groundnuts similarly or that liberalizing raw groundnuts is similar to liberalizing prepared groundnuts.

varieties is small relative to existing ones. For this reason, a crucial aspect of this calibration is the estimation of elasticities of substitution across different intermediate goods that are allowed to vary in each of the 73 countries studied in around 200 sectors. We apply methods developed in Feenstra [1994] and Broda and Weinstein [2006] to estimate these structural parameters.

These models of endogenous growth also suggest that opening to trade can affect the growth rate of productivity. The wider access to imported intermediate goods means that R&D labor is more productive, which reduces the cost of generating new blueprints for intermediate products. Whether this cost reduction is temporary or permanent is what distinguishes semi-endogenous growth models from fully endogenous growth models. Under some reasonable assumptions we are able to quantify how persistent this reduction is by examining the growth in the set of exported varieties across countries. Using detailed export data to proxy for the new domestic goods in each country, we find that increasing the number of existing varieties only temporarily raises growth rates over their steady state level. We find the half-life of the impact of new goods on growth rates to be around 14 years.

Despite the fact that we find only a temporary increase of growth after an increase in the set of imported intermediate inputs, we show that the impact from the global rise in imported varieties in the last 10 years on future output growth is large. To see how much this would matter for welfare we can compare the present discounted value of per capita income with and without access to the foreign varieties to obtain a measure of how much permanent income rose as a result of the liberalization. Our results indicate that permanent income will ultimately rise by 28 percent in the median country as a result of these new varieties. Of this, only 1.3 percentage points are due to the immediate productivity gain arising from the import of new and better varieties (what we call below the "level effect," following Rivera-Batiz and Romer [1991]). In other words, semi-endogenous growth models suggest that there are very powerful growth effects due to trade liberalization that are ignored by conventional static analyses.

While no previous paper has structurally estimated the impact of trade on growth, our paper is related to a number of strands in the existing literature. First, in a survey of our understanding about growth, Easterly and Levine [2001] argue that "in the search for the secrets of long-run economic growth, a high priority should go to rigorously defining TFP, empirically dissecting it, and identifying the policies and institutions most conducive to its growth". Our paper obeys their injunction by measuring the impact that trade in new and better intermediate inputs has had on productivity growth in different countries around the world. Second, our paper adds to the existing tests of endogenous growth. Kocherlakota and Yi [1996] find evidence in favor of an endogenous growth model relative to exogenous growth models. Jones [1995] finds that fully endogenous growth models have counterfactual predictions as the share of R&D labor has increased in the US over recent decades without the predicted rise in growth rates. As in Jones, we find evidence in favor of the semi-endogenous growth model.

Finally, our paper is related to a growing literature on the importance of new goods for measuring and understanding economic progress. Hummels and Klenow [2005] describe how large economies export more than small economies. They find that 60 percent of the higher exports are due to the export of new goods but fall short of examining their impact on growth or welfare. Broda and Weinstein [2006] examine the welfare impact of new imported goods in the US between 1972 and 2001. They focused only on the static gains from new consumption, ignoring any dynamic effect that new intermediate or capital goods may have had on the rate of output growth of the US. By contrast, this paper's main focus is on how new intermediate inputs affect the level of TFP and especially the growth rate of the economy. This effort to account for the growth effects of trade in new goods is at the centerpiece of the theoretical and empirical work in this paper. Moreover, this paper examines the impact of variety growth on 73 countries in the world, not just the US.

II. The Growth in World Varieties

What is behind international growth in trade to GDP ratios? In order to answer this question, it will be useful to establish some terminology. We define an imported variety as a 6-digit Harmonized System (HS) product category from a particular country. To give an example drawn from our data, "raw, shelled groundnuts" is a product category, and "Gambian, raw, shelled groundnuts" is a variety. Obviously, counting categories and varieties can be problematic because new varieties may be lower or higher quality relative to existing ones. This is an issue that we will deal with in our econometric section, but it is still useful to have some sense of the changes in variety growth in the raw data.

In Table 1, we present summary statistics for the 73 countries that reported 6-digit HS import data using the 1992 classification system in the United Nation's COMTRADE database for at least 5 years between 1994 and 2003.[4] We use the U.S. 1997 Benchmark Input-Output table at the NAICS 6-digit level to divide imports into consumption goods and capital and intermediate input goods (see Appendix 1 for details). Most countries have consecutive import and export data from 1994 to 2003 (see Appendix 3 for years for each country). On average, we have approximately 3 million bilateral trade flows per year. As one can see from Table 1, the median number of imported product categories in our sample is 4,091 in 1994 and 4,164 in 2003.[5] This indicates that the typical country in the world imports just over four fifths of all of the different types of goods (not varieties) traded internationally. In other words, import competition exists in most countries in most markets.

The change in the number of source countries per category is more striking. The median number of varieties imported by a country in our sample rose by 38 percent from 29,973 to 41,302 over the same time period. In order to assess the implications of this change for each importer, we first computed the average number of countries supplying each 6-digit import good and then computed the median across importers of these averages. In 1994, the typical country imported its goods from on average 7 suppliers. This indicates that only very few of the close to 200 potential exporters actually supplied a good into the typical importer's market. Between 1994 and 2003, however, the average number of suppliers of a good in the typical importer rose from 7.0 to 8.1, indicating that most countries experienced a substantial increase in the number of exporters supplying any given market. This 16 percent increase in the number of countries supplying the imports of a good to the typical country in combination with the rise in total number of varieties imported by the typical country, makes a *prima facie* case that the number of varieties entering most countries rose globally.

Figures 1, 2 and 3 portray this information graphically for the 73 countries in our sample. We plot the final number of positive import categories (in logs) against the initial level (in logs) in Figure 1. The dashed line corresponds to the 45-degree line which indicates no growth in imported goods. Almost all countries experienced an increase in the number of goods imported, and those that experienced declines experienced only modest ones. The data indicate that there is

[4] We initially had 79 countries, but we noticed some discrepancies between the COMTRADE data and the World Bank's World Development Indicators database (WDI) that made us not trust the data for a few countries. We dropped 4 countries (Costa Rica, Saint Lucia, Trinidad and Tobago, and Uganda) because the ratio of imports reported by COMTRADE relative to the WDI fluctuated by over 20 percent. We also dropped country years if the ratio of imports in the two databases differed by more than 50 percent. This eliminated Moldova and the Seychelles.
[5] This rise occurred despite the fact that several HS categories were retired over this time period, which caused the total number of HS categories to fall slightly from 5,036 to 4,980.

a general increase in the number of goods imported. As one can see from the figure, countries that imported in a large set of products in 1994 had proportionally less growth in new goods than those in the rest of the sample.

This inverse relationship between growth in new goods and the initial level of goods with positive imports suggests two potential limitations of the data. First, even at the 6-digit level, most countries import most goods (and some countries import virtually all goods), so the scope for identifying variety growth through the new goods dimension is going to be limited. This is especially true for large countries that tend to import in virtually all categories. Second, the total number of existing product categories is bounded above. Statistical offices define goods categories based on the existing set of goods, not future goods. This means that if variety growth manifests itself in new goods, new varieties will initially be placed in the same categories as existing goods, and we will underestimate variety growth.

Figure 2 shows that the growth in the number of source countries per good is also larger in countries that imported from fewer sources per good in 1994. As one can see from Figure 2, virtually all countries in the world shared this common trend of importing from more countries. Figure 3 reports the pattern of growth depending on the initial level of varieties. It shows that variety growth is positive for almost all countries in our sample. The only outliers in these data are countries with some major macroeconomic or political disruption such as Argentina, Central African Republic, Malaysia and Uruguay. Moreover, this figure shows that import variety growth was a common feature of all countries in the sample during this period, despite the fact that some countries could not import in more categories.

A frequently cited stylized fact underlying our sense of increasing globalization is that trade to GDP ratios for most countries have been rising. Given the disaggregate nature of the data we use, we can understand the role played by new varieties of imports in this growth by conducting the following exercise. Let M_{ct} be total imports into country c in time t. Let I_{cs} be the set of positive bilateral import flows into country c in time s. It will also be useful to define $M_{ct}(I_{cs})$ as the value of imports into country c of varieties that were also available in time s. Using these variables, we can decompose imports into a country according to the following equation:

(1) $$M_{ct} \equiv M_{ct}\left(I_{ct-1}\right)+\left[M_{ct}-M_{ct}\left(I_{ct-1}\right)\right],$$

where the first term corresponds to the imports of goods that were available in period $t-1$, and the second term corresponds to total imports in period t of goods that were not imported earlier. If we define Y_{ct} as the GDP of the country, we can rewrite equation (1) as

$$(2) \qquad \frac{M_{ct}}{Y_{ct}} - \frac{M_{ct-1}}{Y_{ct-1}} \equiv \left[\frac{M_{ct}\left(I_{ct-1}\right)}{Y_{ct}} - \frac{M_{ct-1}}{Y_{ct-1}} \right] + \left[\frac{M_{ct} - M_{ct}\left(I_{ct-1}\right)}{Y_{ct}} \right],$$

or

$$(3) \qquad \Delta \frac{M_{ct}}{Y_{ct}} \Bigg/ \frac{M_{ct-1}}{Y_{ct-1}} \equiv \left[\frac{M_{ct}\left(I_{ct-1}\right)}{Y_{ct}} - \frac{M_{ct-1}}{Y_{ct-1}} \right] \Bigg/ \frac{M_{ct-1}}{Y_{ct-1}} + \left[\frac{M_{ct} - M_{ct}\left(I_{ct-1}\right)}{Y_{ct}} \right] \Bigg/ \frac{M_{ct-1}}{Y_{ct-1}}.$$

The left-hand side of equation (3) is the percentage change in the country's import to GDP ratio. The terms on the right correspond to the contribution to this change by intensive import growth and extensive import growth.

Table 2 reports the results from performing this decomposition for our sample of countries. On average, these countries saw their import to GDP ratios rise by 42.1 percent. Of this growth in the import to GDP ratio, 32.4 percentage points was due to new imports. This means that almost 80 percent of the growth in import to GDP ratios was due to new imports in the average country. While the impact was substantially smaller in developed countries, even in this set of countries new imported varieties accounted for more than a third of their import growth. In developing countries, new imported goods accounted for virtually all of the increase in the import to GDP ratio. This pattern is, if anything, even stronger when we look at intermediate goods. In sum, the data clearly makes a strong case for thinking about the import of new varieties when thinking about how trade-to-GDP ratios are rising.[6]

The growth in these new varieties would have little meaning if imports of the same good from different countries are perfect substitutes. One way to confirm whether goods at this level of aggregation are indeed differentiated is by testing a simple prediction by Dorfman, Samuelson and Solow [1958]. They argued that in a world in which goods are perfectly homogeneous and firms are perfectly competitive, one can model trade as a linear programming problem in which one minimizes trade costs subject to the constraint that one must satisfy every country's net offer of each good. With C countries in the world, Dorfman, Samuelson, and Solow show that the

[6] In an appendix to this paper, we define an index of trade dispersion to assess the level of global integration via trade. Results are presented in Table 3.

solution to any such minimization problem will entail no more than $C - 1$ positive bilateral trade flows for any good. The intuition for this result is that if goods are homogeneous and trade costs are positive, countries will not be on both sides of the market, i.e. they will not export and import the same good. Thus, the most flows will obtain when there is one exporter and $C - 1$ importers. If there are more exporters of a good, then trade between them will be zero and the number of flows will tend to fall or at most remain the same.

The "$C - 1$" condition provides a simple test for assessing what share of world trade could plausibly be modeled as the exchange of homogeneous goods. In order to examine this, we analyzed the trade flows for each good in which there exists some trade among the 73 countries that reported trade data in 2003. In each of the 5,036 6-digit categories, we counted the number of positive bilateral trade flows. The frequency distribution is presented in Figure 4. The line in the figure separates those sectors satisfying the necessary condition for being a homogeneous good, i.e. having 72 or fewer flows. Only 4 percent of the goods at the 6-digit level satisfy this condition. This suggests that even at the 6-digit level, it would be a mistake to model more than a small fraction of world trade using a model in which perfectly competitive firms export homogeneous goods. However, if the vast majority of trade is in differentiated products and imported varieties are rising, then this implies that there may be gains from importing new varieties.[7]

To sum up, our examination of the raw data reveals several important features of globalization. First, in most countries, the trade to GDP ratio is rising not because they import more of the same varieties, but rather because they import new goods and, in particular, new varieties of existing goods. This phenomenon is critical for understanding the growth of trade relative to GDP around the world. Second, there appear to be vastly more bilateral flows between countries than one would have predicted using classic comparative advantage models. This implies that countries may have gains from the import of new varieties. How much the increase in new varieties matters for global growth is the issue we address in the next section.

[7] Bilateral trade in homogeneous goods could occur in the Brander and Krugman [1983] model. However, in this model, an expansion of the number of trading partners would also produce a welfare gain because prices would fall.

III. Empirical Strategy

A. Theory

Rivera-Batiz and Romer [1991] analyzed the impact of trade on growth in the context of an endogenous growth model. In this section we generalize that framework along the lines of Jones [1995] so that we can examine how international trade in intermediate goods affects domestic growth. For expositional ease, we first describe the environment in the home country and then introduce a foreign country. We start by assuming that final output is produced in the home country according to the following production function:

$$Y_H = L_Y^{\alpha}\left(\sum_{v=1}^{A} x_v^{\theta}\right)^{\frac{(1-\alpha)}{\theta}} \tag{4}$$

where H denotes the home country, L_Y is the number of workers engaged in production, x_v denotes the capital or intermediate input varieties used in the production process, α is the share of labor in output, and $1/(1-\theta)$ is the elasticity of substitution between varieties of inputs.[8] We assume that the price of final goods output is normalized to 1, and for notational convenience we suppress the country subscript in the discussion that follows.

As in Jones [1995], technological progress is represented by the creation of designs for the new types of intermediate or capital inputs. We first derive the equilibrium prices and quantities of intermediate inputs. Since output of the final good is constant returns to scale, each factor is paid its marginal product. This implies that

$$p_v = (1-\alpha)\frac{Y}{\sum_{v=1}^{A} x_v^{\theta}} x_v^{\theta-1}$$

(5) and

$$w = \alpha\frac{Y}{L_Y}$$

We assume that the producers of capital goods rent designs of these goods for a price of r. Profit maximization by capital goods producers implies that they set

[8] There are two important features of this production function. Prior work in the literature, e.g. Jones [1995], has assumed final goods output is produced according to the following production function: $Y = L_Y^{\alpha}\left(\sum_{v}^{A} x_v^{1-\alpha}\right)$. We generalize this specification as it is hard to take to the data because α governs both the labor share of output and the degree of substitution among varieties. In addition, we follow the literature and do not distinguish capital from intermediate inputs.

(6) $$\max_{x_v} p_v x_v - r x_v$$

The first order condition is given by

(7) $$p_v + x_v \frac{\partial p_v}{\partial x_v} - r = 0.$$

We can use (5) and (7) to obtain the profit maximizing price and quantity, which are given by the following expressions:

(8) $$p_v = p = \frac{r}{\theta}$$

and

(9) $$x_v = x = \frac{(1-\alpha)\theta Y}{rA}$$

Equilibrium profits of capital input producers can be expressed as:

(10) $$\pi_v = \pi = x(p-r) = (1-\theta)xp = (1-\theta)(1-\alpha)\frac{Y}{A}$$

Equation (9) lets us simplify our final goods production function and derive a measure of total factor productivity (TFP). The capital stock in the economy can be defined as

(11) $$K \equiv \sum_A x = Ax$$.

Substituting equations (9) and (11) into equation (4) gives us our final goods production function:

(12) $$Y = A^{\frac{(1-\alpha)(1-\theta)}{\theta}} L_Y^{\alpha} K^{1-\alpha}$$.

We can then write the growth rate of TFP as

(13) $$\widehat{\text{TFP}} \equiv \frac{(1-\alpha)(1-\theta)}{\theta}\hat{A} = \hat{Y} - \alpha \hat{L}_Y - (1-\alpha)\hat{K}$$,

where variables with circumflexes denote log time differences. Expression (13) will facilitate the comparison of the model with the measurements of TFP growth we use in the empirical section.

A central component of endogenous growth models is the innovation function, i.e. the technology with which researchers use technology to produce new products. Jones [1995] postulates that this can be written as

(14) $$\dot{A} = \delta L_A^{\chi} A^{\phi}$$.

where L_A is the number of workers engaged in new intermediate designs and χ is a parameter relating to the effective share of the labor force engaged in R&D. In the formulations used by all fully-endogenous growth models prior to Jones [1995], $\phi = 1$. As a result, these models all had the counterfactual prediction that TFP growth rates should be rising in countries where R&D inputs are rising. The key insight of the Jones model is that if $\phi < 1$, this counterfactual prediction could be eliminated, and the long-run growth rate of TFP would not rise even if R&D exhibited a positive growth rate. We therefore allow, but do not require, that $\phi < 1$.

With these assumptions, we could now derive the return on capital and the prices charged for blueprints, but since these equations and derivations are identical to those in Jones [1995] and play no role in our empirical analysis, we will not present them here.[9]

Instead, to close the model, we assume the consumers maximize an additively separable representative utility function of the form

(15) $$\max_{c_t, L_{At}} \sum_{t=0}^{\infty} e^{-\rho t} u(c_t),\ c_t \equiv \frac{C_t}{L_t},$$

subject to equations (12) and (14),

(16) $$\dot{K} = Y_t - C_t,$$

and

(17) $$L_A + L_Y = L.$$

We are ready to characterize the balanced growth path. Along the balanced growth path, the growth rate of $\hat{A}$ must be zero. This implies that the steady state growth rate of A must be

(18) $$\frac{\chi n}{1-\phi} \equiv \hat{A}*$$

where $n \equiv \dot{L}/L$. Along this path we require that the capital to output ratio be stationary and hence $\hat{K} = \hat{Y}$. If we totally differentiate equation (12) and assume we are on the balanced growth path, we obtain

(19) $$\hat{Y}* = \hat{K}* = n + \frac{(1-\alpha)(1-\theta)}{\theta}\hat{A}*,$$

and hence per capita income, per capita consumption, and the capital to labor ratio grow at the rate given by the second term in equation (19). As is the case with semi-endogenous growth

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[9] See pages 781-3 in Jones [1995].

models, the long run growth rates are pinned down by the population growth rate and the growth rate of TFP.

One of the main results in Jones [1995] is that even permanent increases in the labor share of R&D or in the number of intermediate goods will not have a permanent effect on the growth rate of output. Nevertheless, these changes do affect the growth rate along a transition path to the new steady state. In order to understand these transitional growth dynamics, we log differentiate equation (12) to obtain

$$g_y \equiv \hat{Y} - n = \frac{(1-\alpha)(1-\theta)}{\theta}\hat{A} + (1-\alpha)\left(\hat{K} - n\right) \tag{20}$$

If we denote the investment share of output by i and the rate of depreciation of capital by d, we can rewrite this equation as

$$g_y = \frac{(1-\alpha)(1-\theta)}{\theta}\hat{A} + (1-\alpha)i\frac{Y}{K} - (1-\alpha)(n+d) \tag{21}$$

As in Jones [1995] we assume that both the R&D share of labor and the physical investment rate are constant and are given exogenously. This reduces the dimensionality of the problem and simplifies the analysis.

To analyze the transition dynamics of the model it is useful to define $z = Y/K$. One can show that along the balanced growth path, equation (21) implies that $z^* = (n + d)/i$, that is, the steady state output to capital ratio will equal $(n + d)/i$. In the next section we consider an experiment that perturbs the growth rate of new designs, x, and the capital to output ratio, z, from their steady state values. These variables will be constant in the steady state.

The evolution of the growth rate of per capita output in (21) can be expressed in terms of deviations from the steady state levels of the innovation rate and the capital to output ratio,

$$g_y = g^* + \frac{(1-\alpha)(1-\theta)}{\theta}\left(\hat{A} - \hat{A}^*\right) + (1-\alpha)i\left(z - z^*\right) \tag{22}$$

This equation is critical because it links how a shock that changes innovation rates and the output to capital ratio from their steady state values will translate into growth in income per capita.

In turn, we need to understand the evolution of innovation rates and the output to capital ratio following a shock to the system. We can rewrite equation (20) in order to obtain an equation of motion of the output to capital ratio around the steady state:

$$\frac{dz}{dt} \equiv \dot{z} = \frac{(1-\alpha)(1-\theta)}{\theta}\left(\hat{A} - \hat{A}^*\right)z - \alpha i\left(z - z^*\right)z \tag{23}$$

Equation (14) implies that $\hat{A} = \delta L_A^{\chi} A^{\phi-1}$. Log differentiating this equation around the steady state gives us the equation of motion of the rate of variety creation

(24) $$\frac{d\hat{A}}{dt} \equiv \dot{\hat{A}} = (\phi - 1)\left(\hat{A} - \hat{A}^*\right)\hat{A}$$

In order to understand the impact of new varieties on growth, we need to solve the system of differential equations given by equations (23) and (24). Unfortunately, equations (23) and (24) are nonlinear, but we can linearize them around the steady state. Solving the system of linear equations we can show that the laws of motion of the innovation rates and capital per output are described by the following equations[10]

(25) $$\hat{A} - \hat{A}^* = \left(\hat{A}_0 - \hat{A}^*\right)e^{at}$$

(26) $$z - z^* = -\frac{c}{d-a}\left(\hat{A}_0 - \hat{A}^*\right)e^{at} + \left[\left(z_0 - z^*\right) + \frac{c}{d-a}\left(\hat{A}_0 - \hat{A}^*\right)\right]e^{dt},$$

where $\hat{A}_0$ and z_0 are the initial values of the innovation rate and capital to output ratio, respectively.

If we substitute these back into equation (22), we obtain:

(27) $$g_y = g^* + \alpha\left(\hat{A}_0 - \hat{A}^*\right)e^{at} + (1-\alpha)i\left(z_0 - z^*\right)e^{dt} + (1-\alpha)i\frac{c}{d-a}\left(\hat{A}_0 - \hat{A}^*\right)\left(e^{at} - e^{dt}\right)$$

which gives us the transitional dynamics for output growth. We will return to this equation in the next section.

B. Trade and Growth: A Simple Calibration

We are now ready to understand the impact of new imported varieties on growth. Imagine that there are two symmetric autarkic economies in the steady state with A^* varieties at

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[10] Define $w = \begin{bmatrix} \hat{A} \\ z \end{bmatrix}$ and $\tilde{w} = w - w^*$. We then have $\dot{\tilde{w}} = J(w^*)\tilde{w}$ and $J(w^*) = \begin{bmatrix} a & b \\ c & d \end{bmatrix}$ where $a = -(1-\phi)\hat{A}^*;\quad b = 0;\quad c = \frac{(1-\alpha)(1-\theta)}{\theta}z^*;\quad d = -\alpha i z^*$. The solution to this system is given by $\tilde{w}(t) = c_1\begin{pmatrix} d-a \\ -c \end{pmatrix}e^{at} + c_2\begin{pmatrix} 0 \\ 1 \end{pmatrix}e^{dt}$ where $c_1 = \frac{\left(\hat{A}_0 - \hat{A}^*\right)}{d-a};\quad c_2 = \left(z_0 - z^*\right) + \frac{c}{d-a}\left(\hat{A}_0 - \hat{A}^*\right)$.

time t in each country. Assume further that a share, η, of these varieties are tradable. The GDP, innovation, and growth rate equations (i.e., equations (12), (14), and (27)) provide us with a simple mechanism for tracing the impact of such a change in our model. If the countries open up to trade, the number of varieties in the home market will rise from A^* to $A^*(1+\eta)$ as the home country exports some of its varieties abroad in exchange for the new foreign varieties. This will have two effects. The first, which we call the "level effect," arises from the instantaneous impact that the new varieties will have on the level of GDP through equation (12). The level effect will cause a one-time rise in GDP equal to

$$\text{Level Effect} \equiv \frac{(1-\alpha)(1-\theta)}{\theta}\ln(1+\eta) \tag{28}$$

in percentage terms. However, this liberalization will also affect the growth rate of per capita income through two channels. First, equation (14) tells us that an increase in A will cause the domestic rate of new variety creation to rise by a factor of $(1+\eta)^{\phi}$ because R&D labor now has more varieties of capital goods to work with. In addition, the foreign rate of variety creation will also rise by the same amount since their researchers can use domestic varieties. Of these foreign varieties, a share η will be imported causing the rate of growth of varieties upon liberalization to rise to $[(1+\eta)^{\phi} + \eta\,(1+\eta)^{\phi}]A^*$ or $(1+\eta)^{\phi+1}A^*$. Second, the increase in new varieties will cause the output to capital ratio, z, to jump by the amount of the level effect. These two forces will cause future growth rates of per capita income to rise through equation (27).

Although we will estimate the relevant parameters later in the paper, one can obtain a feel for how the model operates through a simple exercise. Let's assume that only 10 percent of capital goods are tradable. In this case we would have $\eta = 0.1$. As in Jones [1995], we assume that the steady state per capita income growth rate $g^* = 0.02$; the rate of depreciation, d, is 0.05; the population growth rate, n, is 0.02; the labor share of income, α, is 0.67; the income to capital ratio, i, is 0.30; and the real discount rate is 0.95. In addition we need two parameters that we estimate later: θ and ϕ; we set these equal to 0.71 and 0.68 respectively and will justify these choices in the empirical section.[11]

Opening to trade causes an immediate jump in per capita income equal to the level effect. In our calibration, the increase in the number of imported varieties instantaneously raises GDP per capita by 1.3 percent due to the level effect described in equation (28), and this causes the

[11] Our choice of θ corresponds to an elasticity of substitution of 3.4.

GDP to capital ratio, z, to rise from its steady state value of 0.23 to 0.24. In addition, the new varieties mean that R&D labor is more productive and this causes the growth rate of the number of varieties to jump from 0.14 to 0.17. This in turn causes the per capita growth rate to jump from 2.0 percent to 3.7 percent. The evolution of the growth rate is portrayed in Figure 5. As one can see, the high growth rate persists for several decades after the liberalization, and the half-life of the impact of liberalization is 14 years.

An important implication of semi-endogenous growth models, then, is that trade liberalization can have very substantial impacts on economic growth. As we move forward with the analysis, it will be useful to have a numerical metric of the growth effect. One simple method is to compute the impact of the growth effect on permanent income. In order to do this, we assume a discount rate of 0.95 and compute the present discounted value (PDV) of all income over the next 250 years of the economy that experienced an opening to trade, and then subtract the PDV of income if the economy had just had a per capita growth rate of 2 percent over this time period. We can then express this difference in terms of the initial level of income to obtain the impact of the increased growth rate on permanent income.

The results indicate that permanent income rises by 39 percent as a result of trade liberalization. Of this, only 1.3 percentage points are due to the level effect. In other words, semi-endogenous growth models suggest that there are very powerful growth effects due to trade liberalization that are ignored by conventional static analyses. Much of the impact from this exercise comes from the fact that trade liberalization not only gives access to new imported varieties today but also to new future imported varieties. Trade liberalization means that the R&D sector obtains access to the future stream of new foreign varieties which effectively doubles the rate of return on R&D labor after the liberalization both at home and abroad. Since both the home and foreign country benefit from this stream of future varieties, this feedback effect explains why we observe such powerful growth effects in this benchmark case.

We can also see what the impact of trade liberalization on growth would be if we shut down the access the country has to future varieties. Here the thought experiment would be a one-time increase in the number of imported varieties but no future increase in imported varieties. The results from this exercise are portrayed in the plot without feedback effects. The growth rate now only jumps from 2 percent per year to 2.7 percent because the home country only benefits from the stock but not the flow of foreign varieties. While the level effect remains the same, the lower future growth rate means that permanent income only rises by 16 percent due to the trade liberalization. Still, the surprising part of the calculation is the large magnitude of the growth impact. Although the level effect only translates into an impact on growth of a few tenths of a percentage point per year, the persistence of this impact means that it has a substantial impact on permanent income. Since we are not certain about the permanence of trade liberalization, we will assume that countries do not benefit from the future flow of imported varieties when they liberalize. Thus, to the extent that these future flows of imported varieties are important, our results will tend to understate the gains from trade. This suggests that papers that focus on level effects, e.g. Broda and Weinstein [2006], may substantially understate the impact of trade on income because they do not address the growth effect.

C. Implementation

The theory outlined above cannot be applied to the data directly without two modifications: not all varieties are of identical quality and different types of inputs may have different elasticities of substitution. In order to do this we begin by assuming that there are G goods, denoted by x_g, some of which are imported and some produced domestically. This implies that we can rewrite our production function as

(29) $$Y = L_Y^{\alpha}\left(\sum_{g=1}^{G} x_g^{\gamma}\right)^{\frac{(1-\alpha)}{\gamma}},$$

where x_g denotes the output of good g.

We next assume that each imported good is comprised of varieties, and that x_g is a CES composite of differentiated varieties of a particular imported input. Since we will be working with sets of goods that are constantly changing, it will be more convenient to refer to the set of available goods in time t as I_t and the set of varieties available of good g as I_{gt}, with v denoting a variety in that set. We can therefore write each imported input as

(30) $$x_{gt} = \left(\sum_{v \in I_{gt}} d_{gvt} x_{gvt}^{\frac{\sigma_g - 1}{\sigma_g}}\right)^{\frac{\sigma_g}{\sigma_g - 1}} ; \sigma_g > 1 ,$$

where d_{gvt} can be thought of as either the quality parameter for a particular variety or a monotonic transform of the number of sub-varieties within a variety.[12]

Given this structure, we can apply the same methodology as in Feenstra [1994] to measure TFP arising from new inputs, but now we are going to use the dual measure of TFP. We know that we can write output as $Y_t = E_t / c(p_t, I_t)$, where E_t is the total costs of production, and c is the unit cost function given that firms face input prices given by p_t and the set of available inputs I_t.

Given the assumptions underlying equation (29), we can decompose output changes into the contribution of new and existing inputs:

$$\begin{aligned} \ln(Y_1/Y_0) &= \ln\left(E_1/E_0\right) - \ln\left[c\left(p_1, I_1\right)/c\left(p_0, I_0\right)\right] \\ &= \ln\left(E_1/E_0\right) - \ln\left[c\left(p_1, I\right)/c\left(p_0, I\right)\right] - \ln\left[c\left(p_1, I_1\right)/c\left(p_1, I_0\right)\right], \end{aligned} \tag{31}$$

where $I \equiv I_t \cap I_{t-1}$ is the set of the varieties that are common in the two time periods, and the last term of equation (31) traces the change in the minimum unit cost function that is due to an increase in variety from I_0 to I_1. Following Feenstra [1994] and Broda and Weinstein [2006], we can show that given equations (29) and (30), the ratio of unit costs in the first line of equation (31) takes the following simple expression:

$$\frac{c\left(p_1, I_1\right)}{c\left(p_0, I_0\right)} = \frac{c\left(p_1, I\right)}{c\left(p_0, I\right)} \times \prod_g \left(\frac{\lambda_{gt}}{\lambda_{gt-1}}\right)^{\frac{w_{gt}}{\sigma_g - 1}}, \tag{32}$$

$$\text{where } \lambda_{gt} \equiv \frac{\sum_{v \in I_g} p_{gvt} x_{gvt}}{\sum_{v \in I_{gt}} p_{gvt} x_{gvt}}, \; \lambda_{gt-1} \equiv \frac{\sum_{v \in I_g} p_{gvt-1} x_{gvt-1}}{\sum_{v \in I_{gt-1}} p_{gvt-1} x_{gvt-1}}, \text{ and}$$

$$w_{gt} \equiv \frac{\left(1-\alpha\right)\dfrac{s_{gt} - s_{gt-1}}{\ln s_{gt} - \ln s_{gt-1}}}{\sum_g \left(\dfrac{s_{gt} - s_{gt-1}}{\ln s_{gt} - \ln s_{gt-1}}\right)}, \text{ where } s_{gt} \equiv \frac{p_{gt} x_{gt}}{\sum_g p_{gt} x_{gt}},$$

and I_g measures the set of common varieties of a good. The λ ratios each measure the share of common varieties in each period in total expenditures in that period. If new varieties appear, $\lambda_{gt} < 1$, and if varieties disappear, $\lambda_{gt-1} < 1$.

[12] See Feenstra [1994].

Equation (32) states that the exact price index with variety change is equal to the "conventional" price index, $c(p_1,I_0)/c(p_0,I_0)$ (i.e., the exact price index of the common varieties over time), multiplied by an additional term which captures the role of the new and disappearing varieties. The last term in equation (31) tells us the gain in the level of GDP that can be directly traced to increases in imported variety. Equation (32) lets us write the dual definition of TFP as

$$\text{(33)} \qquad \text{TFP} = -\ln\left[c\left(p_1,I_1\right)/c\left(p_1,I_0\right)\right] = \sum_g \frac{w_{gt}}{\sigma_g - 1}\ln\left(\frac{\lambda_{gt-1}}{\lambda_{gt}}\right),$$

where we allow the elasticity of substitution to vary by sector in the data.

Equations (13) and (33) provide us with two ways of measuring TFP growth due to new varieties. If new varieties were the only factor driving TFP, these measures would be equal. We can easily see this in the simple case in which there is only one good. In this case, $\sigma_g = \sigma$. Suppose the number of varieties simply expands from A_0 to A_1. We can then rewrite equation (13) as TFP = $[(1 - \alpha)/(\sigma - 1)]\ln(A_1/A_0)$. If we switch to equation (33), we would need to consider a case in which all varieties enter symmetrically, i.e. $d_{gvt} = 1$, and hence $\lambda_{gt-1} = \lambda_{t-1} = 1$ and $\lambda_{gt} = \lambda_t = A_0/A_1$. Similarly, we would have $w_{gt} = w_t = (1 - \alpha)$. Inspection of equation (33) reveals that this would produce the same measure of TFP.

A second important facet of these two measures of TFP is that they can provide a very useful means of understanding how varieties affect TFP. Equation (13) lets us measure TFP using country-level aggregate variables, while equation (33) lets us understand the contribution of new varieties. By comparing the magnitudes of the two measures, we can ascertain how important new varieties are for aggregate TFP growth.

IV. Econometrics

We rely closely on the methodology derived in Feenstra [1994] as extended by Broda and Weinstein [2006] to estimate elasticities of substitution between varieties of imported goods. As opposed to the previous section, here we index each variable with a country subscript i to emphasize that elasticities are estimated separately for each good and importing country.[13] We estimate the following system of import demand and export supply equations:

[13] After estimating the sigmas, we check for a strong good-specific component by pooling all countries' log sigmas and regressing on the average log sigmas by industry, following Broda, Limão, and Weinstein [2008]. We obtain a coefficient of unity and high levels of significance, with or without country fixed effects. Thus, even though the

(34) $$\Delta^{k_{ig}} \ln s_{igvt} = -\left(\sigma_{ig} - 1\right)\Delta^{k_{ig}} \ln p_{igvt} + \Delta^{k_{ig}} \varepsilon_{igvt}$$

(35) $$\Delta^{k_{ig}} \ln p_{igvt} = \frac{\omega_{ig}}{1+\omega_{ig}}\Delta^{k_{ig}} \ln s_{igvt} + \Delta^{k_{ig}} \delta_{igvt}$$

where $\Delta^{k_{ig}} x_{igvt} = \Delta x_{igvt} - \Delta x_{igk_{ig}t}$ (i.e., differencing across two different varieties of a given *i*-*g* pair), *i* denotes the importer country, *g* a 4-digit good, *v* a particular variety of good *g*, $s_{igvt} = p_{igvt} x_{igvt}$, ε_{igvt} taste or quality shocks to variety *v* of good *g* in country *i*, and δ_{igvt} shocks to the supply of the same variety.

Equation (34) can be thought of as the optimal demand for intermediate varieties of good *g* derived from a CES final good production function, and (35) is the supply of that variety expressed in terms of shares. In particular, the inverse elasticity of supply is given by ω_{ig} which is allowed to be different from zero but restricted to be the same for all varieties within an *i-g* pair. More important for the identification strategy is our assumption that $E\left(\Delta^{k_{ig}} \varepsilon_{igvt} \Delta^{k_{ig}} \delta_{igvt}\right) = 0$. That is, once good-time specific effects are controlled for, demand and supply errors at the variety level are assumed to be uncorrelated.

To derive the key moment conditions that will be used for identification, it is convenient to multiply (34) and (35) together to take advantage of the independence condition of errors:

(36) $$\left(\Delta^{k_{ig}} \ln p_{igvt}\right)^2 = \theta_{i1}\left(\Delta^{k_{ig}} \ln s_{igvt}\right)^2 + \theta_{i2}\left(\Delta^{k_{ig}} \ln p_{igvt} \Delta^{k_{ig}} \ln s_{igvt}\right) + u_{igvt}$$

where

(37) $$\theta_{ig1} = \frac{\omega_{ig}}{\left(1+\omega_{ig}\right)\left(\sigma_{ig}-1\right)}, \quad \theta_{ig2} = \frac{1-\omega_{ig}\left(\sigma_{ig}-2\right)}{\left(1+\omega_{ig}\right)\left(\sigma_{ig}-1\right)} \text{ and } u_{igvt} = \Delta^{k_{ig}} \varepsilon_{igvt} \, \Delta^{k_{ig}} \delta_{igvt}.$$

Unfortunately, $\beta_{ig} = \begin{pmatrix} \theta_{1ig} \\ \theta_{2ig} \end{pmatrix}$ cannot be consistently estimated from (36) as the error term, μ_{igvt} , is correlated with the regressands that depend on prices and expenditure shares. However, it is still possible to obtain consistency by exploiting the panel nature of the dataset combined with the assumption that demand and supply elasticities are constant over varieties of the same good. The intuition is that the independence of the demand and supply shock terms enables us to use

sigmas share a strong common component, in our estimation we allow for them to vary by country to capture the richer aspects of our data.

equation (36) to obtain a hyperbola that links the supply and demand parameters. If the variance of these supply and demand shocks varies across exporters to the country, then each of these parabolas will have a different equation and we can obtain identification by taking a weighted average of the intersection points. Formally, we can define a set of moment conditions for each good g and each importing country i, by using the independence of the unobserved demand and supply disturbances for each variety over time, i.e

$$G_v(\beta_{ig}) = E_t\left(u_{igvt}\left(\beta_{ig}\right)\right) = 0 \quad \forall v, g \text{ and } i. \tag{38}$$

For each good g and importer i, all the moment conditions that enter the GMM objective function can be stacked and combined to obtain Hansen's [1982] estimator:

$$\hat{\beta}_{ig} = \arg\min_{\beta_{ig} \in B} \mathrm{G}^*\left(\beta_{ig}\right)' W \mathrm{G}^*\left(\beta_{ig}\right) \quad \forall g \text{ and } i. \tag{39}$$

where $\mathrm{G}^*\left(\beta_{ig}\right)$ is the sample analog of $G_v\left(\beta_{ig}\right)$ stacked over all varieties v of a good g, W is a positive definite weighting matrix to be defined below, and B is the set of economically feasible parameters β_{ig}, which is common across importers and goods (i.e. $\sigma_{ig} > 1$ and $\omega_{ig} > 0$ $\forall i, g$). We follow Broda and Weinstein [2006] in the way we implement this optimization. We first estimate the "between" version of (36) to obtain estimates of β_{ig} and then use equation (37) to solve for ω_{ig} and σ_{ig} as in Feenstra [1994]. If this produces imaginary estimates or estimates of the wrong sign we use a grid search of β s over the space defined by B. In particular, we evaluate the GMM objective function for values of $\sigma_{ig} > 1$ at intervals that are approximately 5 percent apart.[14]

The estimation of elasticities relies on the independence of errors across relative demand and supply shocks, $E_t\left(\varepsilon_{ivgt}\delta_{ivgt}\right) = 0$. Since most β_{ig} are estimated using an over-identified system we can test the independence of errors assumption. In particular, one concern is that positive productivity shocks δ_{ivgt} may lead to new sub-varieties of 6-digit products that are not

[14] For computational easiness, we performed the grid search over values of σ_{ig} and ρ_{ig} where ρ_{ig} is related to ω_{ig} in the following way: $\omega_{ig} = \rho_{ig} / \left[\sigma_{ig}\left(1-\rho_{ig}\right)-1\right]$. The objective function was evaluated at values for $\sigma_{ig} \in \left[1.05, 131.5\right]$ at intervals that are 5 percent apart, and for $\rho_{ig} \in \left[0.01, 1\right]$ at intervals 0.01 apart. Only combinations of σ_{ig} and ρ_{ig} that imply $\sigma_{ig} > 1$ and $\omega_{ig} > 0$ are used. To ensure we used a sufficiently tight grid, we cross-checked these grid-searched parameters with estimates obtained by non-linear least squares as well as those obtained through Feenstra's original methodology. Using our grid spacing, the difference between the parameters estimated using Feenstra's methodology and ours differed only by a few percent for those σ_{ig} and ω_{ig} for which we could apply Feenstra's "between" approach.

observed in the level of disaggregation of our data. These new sub-varieties would show up in the system as a positive demand shock, ε_{ivgt}. We classify each U.S. 6-digit category by the role that sub-varieties play in its growth, and estimate 4-digit supply elasticities using only the sub-sample of 6-digit varieties in which changes in sub-varieties were negligible. We then compare these estimates, where we expect the identifying assumption to hold, with the estimates obtained using all varieties. These tests are discussed in detail in Appendix II to Broda, Limão, and Weinstein [2006]. The problem of measurement error in unit values motivates our weighting scheme. In particular, there is good reason to believe that unit values calculated based on large volumes are much better measured than those based on small volumes of imports. In the appendix of Broda and Weinstein [2006], they show that this requires us to add one additional term inversely related to the quantity of imports from the country and weight the data so that the variances are more sensitive to price movements based on large shipments than small ones.[15] The use of the between estimate coupled with our need to estimate σ_{ig}, ω_{ig}, and a constant means that we need data from at least three exporting countries for each importer in each good and at least three two-time differences to identify β_{ig}.

V. Results

We begin by characterizing the growth in world varieties in terms of our key parameters. One of the problems that we face is the sheer number of goods and countries in our dataset. With 73 countries and most countries reporting close to 200 3-digit HS sectors, we constructed approximately 13,000 λ ratios and estimated an equal number of elasticities of substitution. It is obviously impossible to report all of these and far too much to hope that there won't be some outliers. One approach to assessing the reasonableness of these estimates is to compare them with existing estimates and our priors.

Given that our dataset incorporates countries with varying degrees of development, it is reasonable to worry about whether our methodology works for the typical country. In order to provide a sense of the distribution of elasticities of substitution, we computed the average and median values of each parameter for each country and then computed the distribution of these parameters across countries. The typical country has a median elasticity of 3.4, significantly

[15] As in Broda and Weinstein [2006], we weight the data by $T^{3/2}[(1/q_{gct}) + (1/q_{gct-1})]^{-1/2}$. The mathematics underlying this weighting scheme is given in the appendix to that paper.

larger than that of the United States. Average σ's tend to be higher than medians because the σ's are bounded below by 1. After sorting countries by their average sigma, we find that the typical country has an average sigma of 6.8, while the US has an average sigma of 4.2, suggesting that on average the US tends to value variety somewhat more than the typical country. Another way of looking at the results is to focus on the results for the sub-samples of developed and developing countries. The bottom of Table 4 reveals that the median elasticity of substitution does not vary by the level of development. This indicates that there is no strong relationship between income per capita and the elasticity of substitution across countries. Not surprisingly, there are some outliers. The United States and Greece have somewhat low sigmas and Sweden and Canada have high sigmas. Overall the median elasticity of substitution shows a fair bit of dispersion, with the minimum median elasticity being 2.3, while the maximum is more than twice as large.

This, of course, raises the question of whether our elasticity estimates themselves are sensible. One approach to assessing their "reasonableness" is by comparing them with our priors. We might suspect that varieties of goods traded on organized exchanges are likely to be more substitutable than those that are not. For example, natural gas exported by different countries is likely to be more similar than telecommunications equipment emanating from different suppliers. Rauch [1999] classifies all 4-digit SITC product categories into 3 groups: those sold in organized exchanges, those that have a reference price in the US and the rest. Broadly speaking, the classification helps distinguish between products that are commodities and those that are differentiated. We obtain concordances between 3-digit HS codes and 4-digit SITC codes to group our estimates of elasticities of substitution into the groups distinguished by Rauch. Table 5 shows median and mean according to these different groups. In all cases, we can strongly reject the hypothesis that the median or mean for the group of commodity products is lower than that for the other two groups. In particular, the average elasticity is 12.1 for commodities while it is around 7.2 for the rest of the products. Thus, our elasticity estimates seem to be plausible by this criterion.

A second way of assessing the reasonability of our estimates is by looking at how stable our estimates are. We would like the estimate of the elasticity of substitution to be stable for a country. This might be violated if the elasticities are not measured precisely or if the elasticity of substitution changes with the number of varieties. If the elasticity of substitution rises with the number of varieties in the market (which in turn would imply that the markups would be falling), this would also imply that our assumption of CES preferences might generate systematic biases. For example, if increasing the number of varieties from 1 to 2 does not yield the same proportional gain in productivity as increasing the number of varieties from 10 to 20, this would be a violation of the CES assumption.

There is a simple way to examine whether we face this problem in the data: examine whether elasticities fall as the number of varieties rises. If we estimate the elasticities separately for the first half of the sample (1994-1998) and the second half of the sample (1999-2003), we can obtain two sets of elasticity estimates for each country that are each based on different data. These elasticities can be thought of as "local" elasticities estimated in the two time periods. We can then use these two sets of estimates to examine the stability of our estimates. First, if one believed that rising numbers of varieties were associated with greater perceived substitutability, one would expect to see a rise in the typical elasticity of substitution over time. Since we observed a 40 percent rise in the number of varieties over this time period, there is scope for a significant impact. We do not observe this: the median elasticity of substitution estimated is 3.6 in both time periods. Similarly, the tenth and ninetieth percentiles of the distribution of elasticities move by less than 5 percent.[16]

The stability of the overall distribution of elasticity estimates could be masking important shifts in elasticities across industries or within countries. It would be disturbing if inputs that were highly substitutable in one time period were differentiated in the second period. Similarly, it could be the case that industries that experienced more rapid variety expansion saw their elasticities rise more rapidly than those of other industries. These two objections would call into question our underlying CES assumption.

If we regress the log of the later period estimates on the log of the earlier estimates and include good fixed effects, we can address these concerns directly.[17] In this specification, we can reject the hypothesis that elasticity estimates in the later period are uncorrelated with those in the early period at all conventional levels of significance (t-statistic = 6.2). Moreover, if we include the log change in the number of varieties in the two periods, the significance of the first term is

[16] Similarly, Broda and Weinstein [2006] find that there is no movement in median elasticities for the US over the 30 years they analyze despite a three-fold increase in the number of varieties imported by the US.

[17] We log the elasticities because the elasticity estimates are bounded below by one, and our estimation procedure produces estimation errors that appear log normal.

unaffected and the significance of the coefficient on the change in the number of varieties is insignificant (t-statistic = -0.3). The R^2 of the "between" regression tells us the extent to which goods in countries where varieties are identified as more substitutable than the average in one period are also identified as more substitutable in the second period. The correlation between a sector's average log elasticity in the first period and that in the second is 0.7, and the R^2 obtained from regressing the later average elasticity estimate on the earlier one is 0.47. This tells us that not only does our methodology find that commodities are more substitutable than other goods, but our methodology also consistently identifies certain goods as more substitutable. We therefore conclude that our elasticity estimates are reasonable by a number of criteria: they conform to our prior that commodities are more substitutable than other goods, they are stable across time, and they seem unaffected by the number of varieties in the market.

We now turn to our measure of variety growth. Our estimates of the gains from new varieties depend on two factors: how differentiated varieties are and the importance of new imported varieties. While the elasticity estimates give us information about the former, the λ ratios provide information about the importance of net variety creation in any given market. If we sort countries by the median λ ratio in each of their import sectors, we find that the median λ ratio in the typical country is 0.92 regardless of whether we use intermediate inputs or consumption goods. This suggests that the typical country experienced a net increase in varieties (creation less destruction) of 9.0 percent over 9 years in the typical sector or about 1.0 percent per year.

There is, of course, substantial variation in median λ ratios across countries, as one can see in Table 4. Some countries have seen the effective number of varieties in their typical import sector almost double. However, there is an unmistakable pattern in the data. All but 3 countries experienced an increase in variety in the typical industry, indicating that the increase in varieties is a global phenomenon. The only countries that experienced a fall in intermediate input variety in the typical industry (median λ ratio higher than 1) were Argentina, Chile, and Uruguay, and the Central African Republic. The experiences of Argentina and Uruguay may reflect major economic crisis that rocked these countries in 2002 and 2003, respectively, while the Central African Republic's experience may be related to its civil war. On the other hand, several countries that liberalized extensively over this period, such as Poland and India, experienced fairly substantial declines in their median λ ratios, indicating that the variety of imports in their representative industries rose substantially. Similarly, some of the EU countries in our sample had lower λ ratios than the median indicating fairly substantial gains in variety. Whether these results reflect the impact of the European trade liberalization, the Polish opening to international trade, and Indian liberalization is difficult to say because we do not know what liberalizations occurred in countries without substantial drops in their λ ratios, but the results are clearly suggestive of such a link.

Using the intermediate input λ ratios and elasticities of substitution for each good in each country we obtain an estimate of the productivity gains from new varieties (see equation (33)). The distribution of the TFP gains calculated on a per-year basis is also reported in Table 4.[18] The growth in new varieties over the period 1994-2003 increased productivity by 1.3 percent in total or 0.14 percentage points per year in the typical country in our sample. There are a few implausibly large outliers in the results that are caused by very substantial increases in imported varieties coupled with very high import to GDP ratios – most notably Hong Kong – but for the most part the estimated productivity gains seem reasonable.

It is difficult to know from Table 4 whether our estimated level effects are plausible or not. Since we are arguing that the level effect should be a component of TFP, we can exploit the the fact that we have developed two TFP measures in order to assess the plausibility of our results. The first point to realize is that the primal measure of TFP (constructed using the formula following the second equal sign in equation (13)) makes no use of the number of varieties and can be thought of as the amount of growth that cannot be explained by factor accumulation. As such, it should capture all sources of productivity growth including imported varieties. By contrast, the dual measure of TFP defined in equation (33) only captures TFP arising from variety growth. Thus, if we regress the primal measure of TFP on the dual, the R^2 should tell us how much of the variance in TFP can be explained by increased imported varieties and the coefficient estimate should, of course, be positive.

In order to measure primal TFP, we rely on the data provided in the Penn World Tables v6.1 to compute TFP following the methodology outlined in Hall and Jones [1999].[19] When we

[18] Instead of using $(1 - \alpha)$ in the computation of the weights in equation (32) we used the share of intermediate input imports to GDP ratio to account for the fact that not all intermediate inputs are tradable. This tends to reduce the magnitude of the level effect.
[19] We assume a labor share of 0.67, compute the capital stock using a perpetual inventory method with a depreciation rate of 0.06, and a labor supply equal to the number of workers in the economy.

regress primal TFP on the level effect from Table 4, the coefficient on the level effect is 2.2 (*t*-stat = 2.98) and the R^2 equals 0.15.[20] Obviously, there are many forces other than new imported varieties that affect TFP growth, but our estimates suggest that the level effects we identify are also systematically related to productivity growth in these countries.

We now turn to the magnitudes. The average and median impacts of the level effects of new varieties on productivity growth are presented in the first two rows of Table 6. On average, new imported varieties raised productivity growth by 0.32 percent per year and the median impact was 0.14 percent per year. These numbers are both significantly different from zero. If we restrict ourselves to the sample of countries for which we can compute TFP from the Penn World Tables v6.1 data, we find that productivity gains from new imported varieties are 23 percent as large as the average country's per capita growth rate or TFP growth rate and 8 percent the size of the median value. This indicates that while there is are other important factors that determine TFP growth, the import of new varieties has a substantial impact.

A simple thought experiment can shed some light on what factors determine the magnitude of the results obtained in this paper. Assume that all varieties are identical and have our median elasticity of substitution of 3.4. This implies that $\theta = 0.706$. If all countries have a labor share equal to the median of 0.67, then the symmetric model presented in equation (13) implies that a one percent increase in the number of varieties will raise productivity by 0.14 percent (= (1 – 0.67)*(1 – 0.706)/0.706 * 0.01)). If we proxy the growth rate of "quality equivalent" varieties by the median λ ratio, then this suggests that variety growth was 8 percent for the typical country, and therefore aggregate productivity should have risen by 1.1 percent between 1994 and 2003. This is not that far from the median impact of 1.48 percent that we obtain using the full set of λ's and σ's, which suggests that the key factor driving the magnitude of the level effect is the fact that we quality adjust the count of new varieties by using λ ratios instead of a simple count of varieties.

We can also use the same formulas employed to construct the level effect to compute the unmeasured gain to consumers from greater consumption good availability. Here we use the λ ratios computed using only consumption good imports and the share of imports of consumer

[20] Because Hong Kong is the only economy with an import to GDP ratio in excess of one and therefore does not fit into our theory, we decided to drop it from our regressions. Including it causes the coefficient to fall to 0.97 (*t*-stat 1.6) R^2= 0.05. If we simply drop the largest outliers, i.e. those countries whose level effects exceed 10 percent, the coefficient jumps to 3.8 (*t*-stat 2.3) R^2= 0.10.

goods to GDP in our weighting variable to compute the impact that new varieties have on consumers. Since this variety effect is not captured in standard price indexes which are computed using common sets of goods, we can think of these as unmeasured gains to consumers from the availability of new imported foreign varieties of goods. The results are presented in the last column of Table 4. The median unmeasured welfare gain of a consumer in our sample of countries was 0.63 percent overall and 0.4 percent in developed countries. These unmeasured gains are much smaller than the level effects largely because most imports are intermediate goods rather than consumption goods.

VI. Why are varieties rising? The Growth Effect

Thus far, we have been concerned with documenting that the import of new varieties is growing, that varieties are differentiated, and that this process has been exerting a non-trivial effect on productivity growth in developing countries. In this section we first test whether this is a feature of the data, and then use our estimated parameters to estimate the growth effect.

Our first challenge is to obtain a measure of the workforce engaged in innovation L_A. Reliable measures of this are hard to find across countries[21]. However, endogenous growth models suggest that in the steady state, L_A should be proportional to the labor force. In Rivera-Batiz and Romer's [1991] paper, the R&D input (F) is proportional to $L^{2/3}K^{1/3}$. Since this has the added feature that wealthier countries, i.e. those with higher capital to labor ratios, are likely to have a higher share of labor in R&D, we adopt this specification here.[22]

Our second challenge is to obtain a good measure of the change in varieties. Ideally, we would have counts of all new varieties produced in a country. Unfortunately, we have no information about the number of non-traded varieties produced in any of our countries. However, if we make some reasonable assumptions, we can identify associations between the new domestic varieties that we cannot observe and the new exported varieties. There are two polar ways to link country observables with new exported varieties. One is to assume that all new products are exportable. In this case, the relevant measure of R&D input is the national value, and we can specify the right-hand side of equation (14) as it is written. A second approach is to

[21] There is, however, a vast literature on the determinants of innovation at the firm level (see Klette and Kortum [2004] for a summary of the relevant stylized facts).

[22] If we assume that $F = L$, we obtain a ϕ equal to 0.9 which produces even greater growth effects than what we report.

assume that the amount of R&D in the tradable goods sector is equal to the fraction of the economy that is devoted to exports. In this "export specification" case, we should multiply F by the share of exports in the economy.

A second problem that we face implementing our test is that some countries in our sample export virtually every 6-digit good. Figure 6 plots the number of sectors with no exports against the level of exports in 1994. Clearly, the largest exporters already export in almost every product category and cannot substantially increase the number of new goods they export. For example, the US and Germany had positive exports in all but a couple of the 5,036 possible sectors. This means that it is almost impossible for us to measure the value of innovation in these economies.

Presumably, the reason why we cannot measure new variety creation in the US is not because the possibility of innovation ended in 1994, but rather because we cannot measure the creation of a new good if it gets classified in a sector in which the US already exports. For example, many new technologies such as LCD monitors or laptop computers did not warrant their own categories at the start of our sample, but constitute new products nonetheless. We can get around this problem if we assume that innovation is equally likely to occur in any of the sectors but we can only measure innovation in a sector when a country is not exporting in that sector to begin with. In this case, for a common rate of innovation, we would expect to count more new exports emanating from a country that is exporting in very few sectors initially than in one that is exporting in many sectors. At the extremes, we would be able to observe every innovation in a country with no initial exports and no innovation in a country that exports in every category. In statistical terms, we can think of the number of sectors with no exports initially as the "exposure" of the country, i.e. how many possible times we can measure new goods.

Theory dictates that we should measure $\dot{A}$ in equation (14) by the count of new exported varieties in a country over the sample period. This implies that we can estimate equation (14) using a negative binomial regression model.[23] The structural interpretation of the offset term in the negative binomial is that it corresponds to the differences in R&D quality in our sample of

[23] A key assumption in standard Poisson regression models is that the variance of the distribution of counts equals the mean. In our sample, we have the common problem of over-dispersion, where the variance is higher than the mean. This implies that the negative binomial distribution is more appropriate for our application.

countries. Formally, we assume that variation in the quality of an R&D dollar spent in different countries can be modeled as a random effect, μ_i, and estimate:

$$\dot{A}_i = Poisson(\kappa_i)$$
$$\text{(40)} \qquad \kappa_i = T_i \exp(\chi \ln F_i + \phi \ln A_i + \mu_i)$$
$$\exp(\mu_i) = \text{Gamma}\left(\frac{1}{a}, a\right)$$

where we make an adjustment for the exposure, T_i, and a is the constant that governs the variance of R&D quality.

Table 7 presents the estimates of equation (40). Our estimates of χ (the coefficient on F) are significantly greater than zero but smaller than one, which is predicted by the endogenous growth models but not the exogenous growth model. Clearly, our data supports the assumption that larger countries have higher rates of innovation. A more interesting result concerns the coefficient on TFP, ϕ. This parameter is significantly greater than zero but less than one: a result that is only predicted by the Jones [1995] model of semi-endogenous growth. Taken together, the results indicate that new variety creation rates are linked to endowment and productivity levels in a manner consistent with the semi-endogenous growth model.

We now turn to estimating the economic significance of the growth effect. In order to do this we repeat our earlier calibration exercise based on equation (27) but now use the estimated parameters and variables from each country to estimate the impact of new imported varieties on growth. We begin by setting the increase in the number of domestically available varieties to $s_c(1/\lambda_c - 1)$, where s_c is the share of intermediate input imports over GDP and λ_c is the median lambda ratio for the country. We set θ for each country equal to value implied by the median elasticity of substitution we estimate. Similarly, we set ϕ equal to the level we estimate in the output specification of Table 7. We assume that the movement in z is the same as the level effect computed in Table 4. Finally, we set all of the remaining parameters equal to the values in our calibration exercise.

The results from this exercise are presented in Table 8. Here we compute the impact that trade has on permanent income and the PDV of the level and growth effects for each country expressed as a percentage of that country's GDP. The median growth effect raises permanent income by 26.5 percent and the median impact overall is 28 percent. This effect differs substantially by income class. The magnitude of the impact for developed countries is much smaller than for developing. Among developed countries the typical growth and level effects were half as large as for developing countries. This reflects the fact that variety growth is much more important in developing countries.

VII. Conclusion

How much does trade matter for growth? This is not a question that can answered simply because trade regimes can vary enormously across countries and their impact may differ depending on a host of variables operative in the country carrying out reform. Rather than trying to answer a general, and perhaps not well-specified question, this paper has focused on quantifying one of the most important channels through which theorists believe trade affects growth. In particular, we estimate the impact that trade in new and better varieties has had on growth around the world. This is a central mechanism through which trade affects growth in many of the endogenous growth models and has never before been estimated. Moreover, rather than comparing aggregate measures of trade across goods or examining particular sectors in specific countries, we use a structure rich enough to allow for important differences across sectors and countries, but flexible enough to allow for simple aggregation over sectors. This enables us to quantify the impact that new imported varieties has had on the global economy.

Our results indicate that while there is a lot of heterogeneity in the impact of new varieties on productivity growth, the typical estimated impact of new imported varieties on TFP is 5 percent as large as productivity growth in the typical country and 14 percent as large as productivity growth in the typical developing country.

Secondly, we provide evidence that the rise in world varieties is consistent with the predictions of the semi-endogenous knowledge driven growth model, and is not consistent with exogenous growth models or the comparative statics of continuum of goods or monopolistic competition trade models. This indicates that not only do new varieties have substantial impacts on world productivity, but R&D is associated with increases in exported varieties in the way assumed by the theory. Although most of the impact of new varieties on growth arises through the level effect, we estimate that for the typical country in the world, the combined effect of new imported varieties between 1994 and 2003 will raise its permanent income by 28 percent. Most of this increase is achieved by small but persistent increases in the growth rate.

However, our estimates imply that these productivity gains are likely to have substantial growth effects on income. These growth effects result from small but persistent impact on the growth of countries that have access to new imported intermediates. The increased set of imported varieties available from 1994-2003 is estimated to increase the permanent income of the world by 17 percent by increasing future growth rates and innovation. These effects are likely not to be captured in standard empirical exercises that look at correlations between contemporaneous growth and openness or even lagged openness.

Nevertheless, we need to mention several limitations of our approach. First, although our modeling of economic structure in any individual market is vastly richer than what finds in the typical macroeconomic analysis, it falls short of the careful empirical studies that can be produced using micro data. For any of the thousands of markets that we consider in this paper, one could easily imagine more careful analyses of exactly how varieties affect welfare than the simple market structure we impose. Our decision not to take more care to model each of these sectors stems from a trade-off of feasibility versus efficiency. No doubt more can be said about the export supply of Gambian raw groundnuts than what we have produced in this paper, but we feel that the time necessary to do the careful analyses of markets and produce an estimate of the impact of trade on growth for more than a handful of countries makes that approach impractical for now.

Second, our close attention to the theory is both a strength and a weakness of this paper. Endogenous growth models themselves employ highly stylized descriptions of consumption, production, and innovation that do not have firm foundations in microeconomic studies of consumer behavior or innovation. Leading macroeconomists have called for taking their models seriously and apply them to data, and we have tried to do so. However, one can have legitimate concerns about the underlying assumptions of the models themselves. In the future one can imagine developing richer models that better describe reality and better empirical methods that can take these models to the data. Nevertheless, we feel that much is learned by taking state of the art models to the data, and seeing how well they describe reality. We hope that is what we have accomplished here.

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Appendix 1

We use the "1997 Benchmark Input-Output Accounts" and the "Concordance between the 1997 Input-Output Commodity Codes and Foreign Trade Harmonized Codes" as our source data.[24] These tables divide the US economy into 511 sectors. Our next task was to use these data to divide imports into those destined for personal consumption and those used as inputs.

To do this, we first need to establish some notation. Let $i \in [1, I]$ denote the index for IO codes. We define the consumption share of imports in sector i, S_i, as "Personal Consumption Expenditures" divided by the sum of all intermediate input use by that sector and all final demand in that sector.

We next used the concordance file to map S_i into the 10-digit harmonized trade data to create S_h. For the 74 sectors in which h did not map uniquely into i we took a weighted average of the S_i's that corresponded to the h sector with the weights given by the concordance file. Our next task was to collapse the data from the HS-10 level to the HS-6 level. We did this by employing the following formula:

$$S_x = \sum_{h \in s} \frac{M_{USh} S_h}{\sum_{h \in s} M_{USh}}, \qquad (41)$$

where M_{USh} denotes the 1997 import value of code h into the US. Then for each 6-digit sector in each country we defined the set of consumption imports as $S_x M_x$, where M_x is total 6-digit imports into the country and intermediate (plus capital) imports as $(1 - S_x M_x)$.

[24] These data are available at http://www.bea.gov/industry/io_benchmark.htm.

Appendix 2

The growth in the number of source countries supplying any good is indicative of a rise in the level of global integration: most countries already import 10-ton trucks, but now they do so from more sources of supply. To get some sense of how far away the world is from the fully integrated equilibrium, we can think of two useful benchmarks. The first is minimal trade dispersion. In this benchmark, conditional on a variety being exported, it is imported by only one country. The second is maximal trade dispersion: conditional on being exported, a variety is imported everywhere. One simple way of measuring how close we are to either extreme is to divide the total number of varieties imported by all countries by the total number of varieties that would be imported if every exported variety were imported everywhere. Since, by definition, every good that is exported must be imported by some country, the ratio of actual varieties imported to potential varieties in an industry can never fall below 1/72 (one divided by the number of possible importers). We therefore normalized the index using the following formula so that 0 corresponds to minimal trade dispersion (each exported variety going to only one destination) and 1 to maximal dispersion (each exported variety imported by every country):

$$\text{Trade Dispersion} = \left(\frac{\sum_{gcc'} i\left(m_{gcc't}\right)}{\sum_{gc'} i\left(\sum_{c} m_{gcc't}\right) * 72} - \frac{1}{72} \right) * \frac{72}{71},$$

where $m_{gcc't}$ equals imports of good g by country c from country c' in time t, and $i(x)$ is an indicator function that equals one if x is greater than zero and equals zero otherwise. The numerator of the first term in the equation above then equals the number of imported varieties we observe. The denominator of this term equals the total number of varieties that *would be* exported if each exported variety were imported by every country.

We present the results from the trade dispersion index in Table 3. Overall, this index grew by almost 20 percent between 1994 and 2003. The number of exported varieties worldwide only grew by 2 percent, which means that most of the growth comes from the increased number of countries importing any given variety.

Despite this rapid increase in varieties imported even relative to the increase in available varieties, our "dispersion index" stood at just under 12 percent in 2003. In other words, conditional on a good being exported, only about one in nine of the world's countries import it. This tells us two important facts about globalization. First, there has been a substantial rise in the number of countries importing any internationally traded good. Second, we are very far away from a world in which an exported good is imported by anything more than a small fraction of potential importing countries.

Appendix 3:
Years for Country Data

Country #	Country Name	Data Range		*Missing Years*
1	Australia	1994	2003	
2	Austria	1994	2003	
4	Canada	1994	2003	
5	Denmark	1994	2003	
6	Finland	1994	2003	
7	France	1994	2003	
8	Germany	1994	2003	
9	Italy	1994	2003	
10	Japan	1994	2003	
11	Rep. of Korea	1994	2003	
12	Mexico	1994	2003	
13	Netherlands	1994	2003	
14	New Zealand	1994	2003	
15	Norway	1994	2003	
16	Portugal	1994	2003	
17	Spain	1994	2003	
18	Sweden	1994	2003	
19	United Kingdom	1994	2003	
20	USA	1994	2003	
25	Algeria	1994	2003	
31	Argentina	1994	2003	
40	Belize	1994	2003	
44	Bolivia	1994	2003	
48	Brazil	1994	2003	
61	Chile	1994	2003	
62	China	1994	2003	
66	Colombia	1994	2003	
71	Croatia	1994	2003	
73	Cyprus	1994	2003	
76	Central African Rep.	1994	2003	
79	Dominica	1994	2003	*1998*
82	Ecuador	1994	2003	
83	Egypt	1994	2003	*2000*
84	El Salvador	1994	2003	
93	Gabon	1994	2003	*1995*
99	Greece	1994	2003	
101	Grenada	1994	2003	
104	Guatemala	1994	2003	
109	Honduras	1994	2003	
110	China, Hong Kong SAR	1994	2003	
111	Hungary	1994	2003	
112	Iceland	1994	2003	
113	India	1994	2003	
114	Indonesia	1994	2003	
117	Ireland	1994	2003	
122	Jordan	1994	2003	*1996*
130	Latvia	1994	2003	
136	Lithuania	1994	2003	*2002*
138	China, Macao SAR	1994	2003	
139	Madagascar	1994	2003	
140	Malawi	1994	2003	*1996-1998, 2000*
141	Malaysia	1994	2003	
147	Mauritius	1994	2003	
155	Morocco	1994	2003	
163	Nicaragua	1994	2003	
169	Oman	1994	2003	
175	Peru	1994	2003	
178	Poland	1994	2003	
181	Romania	1994	2003	
186	Saudi Arabia	1994	2003	*1997*
191	Slovenia	1994	2003	
196	Sri Lanka	1994	2003	*1995-1998, 2000*
198	Saint Kitts and Nevis	1994	2003	*1998*
202	Saint Vincent and the Grenadines	1994	2003	*1996*
207	Switzerland	1994	2003	
211	Thailand	1994	2003	*2002*
212	Togo	1994	2003	
216	Tunisia	1994	2003	
217	Turkey	1994	2003	
223	Uruguay	1994	2003	
229	Venezuela	1994	2003	
238	TFYR of Macedonia	1994	2003	
239	Slovakia	1994	2003	

Figure 1

Growth in the Number of Goods Imported

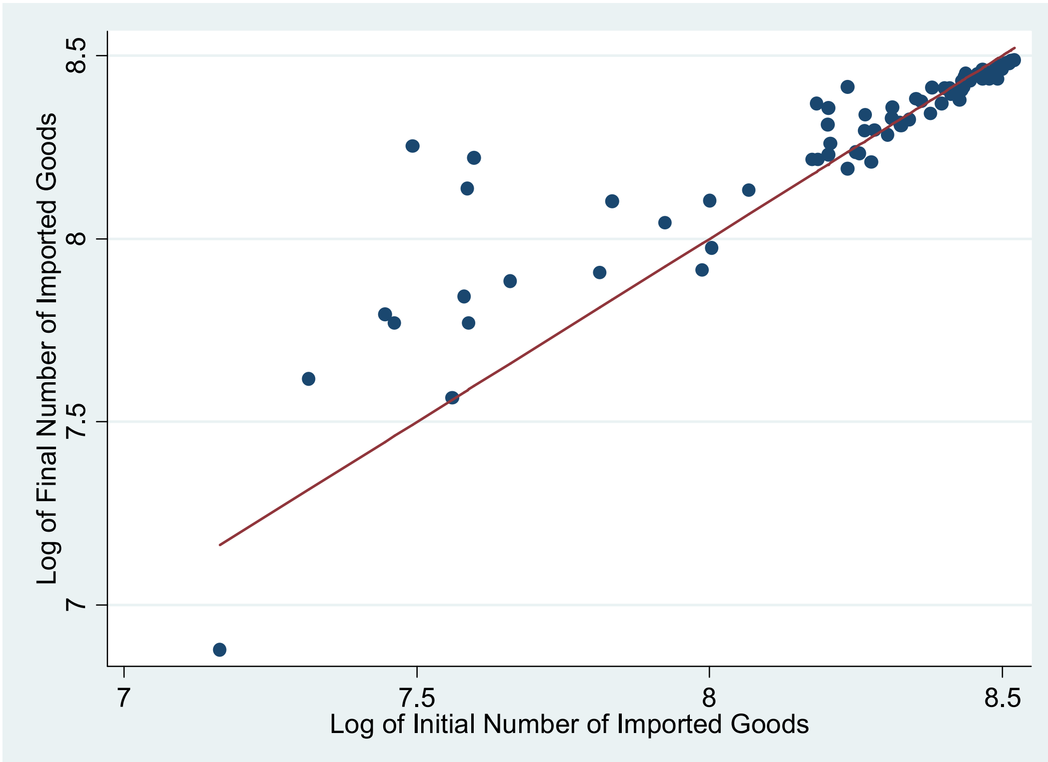


Figure 2

Growth in the Number of Source Countries per Good

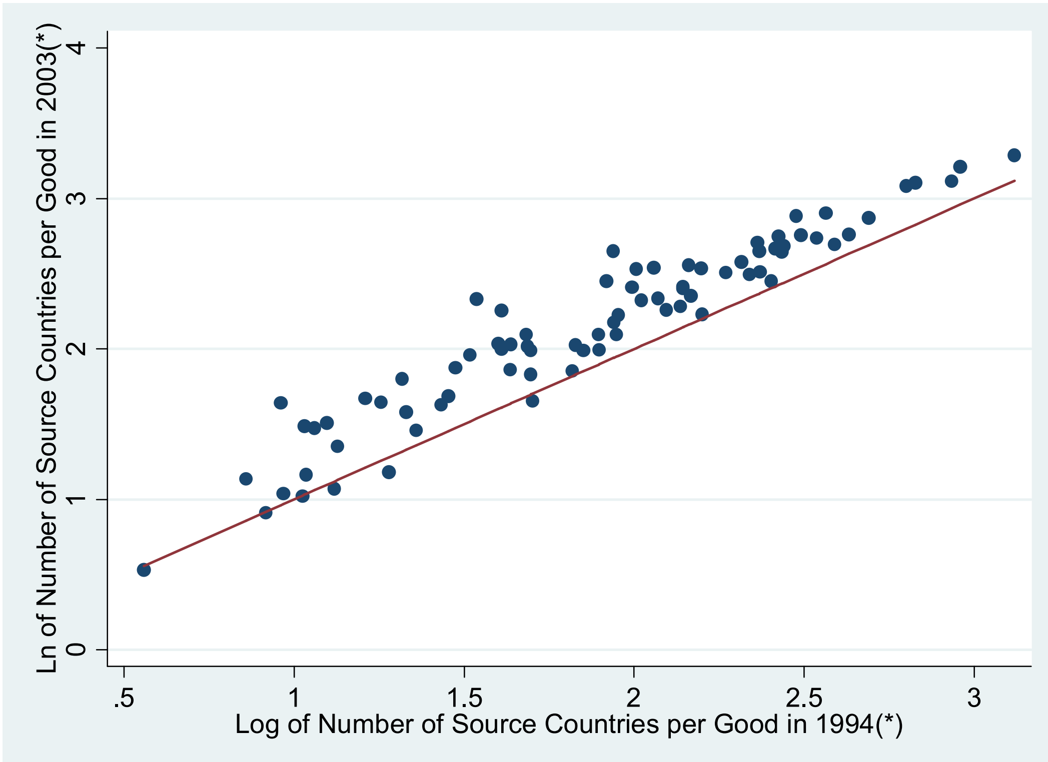


Figure 3

Growth in the Number of Imported Varieties

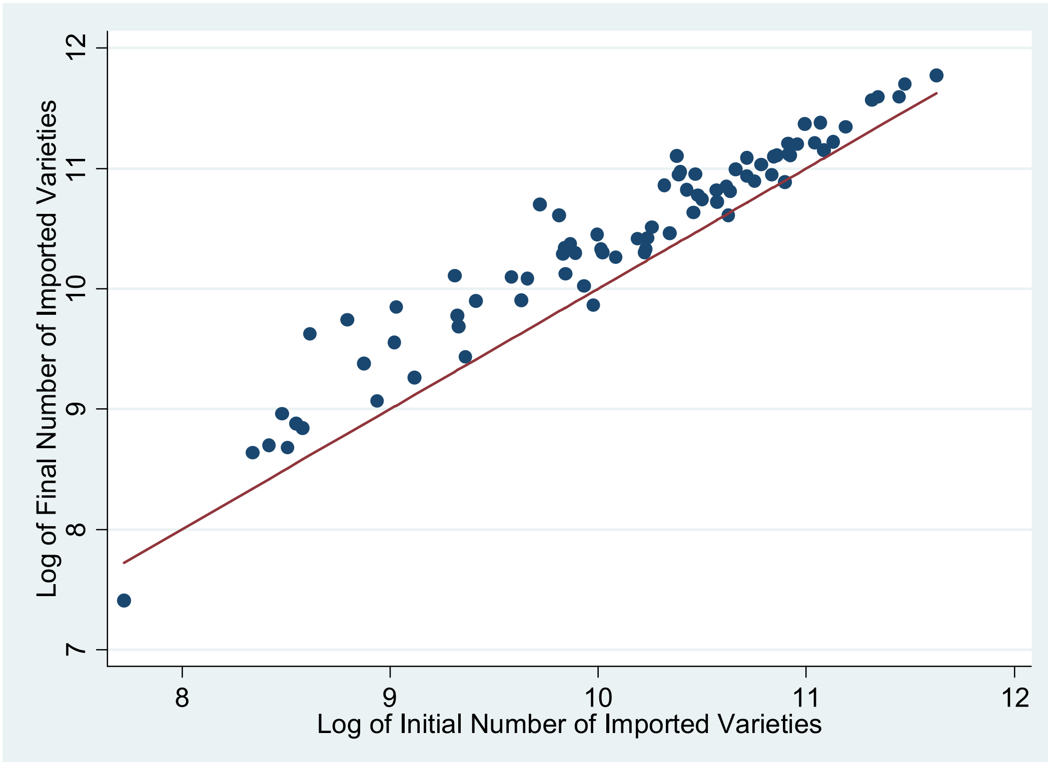


Figure 4

Frequency Distribution of the Number of Bilateral Trade Flows for Each Good

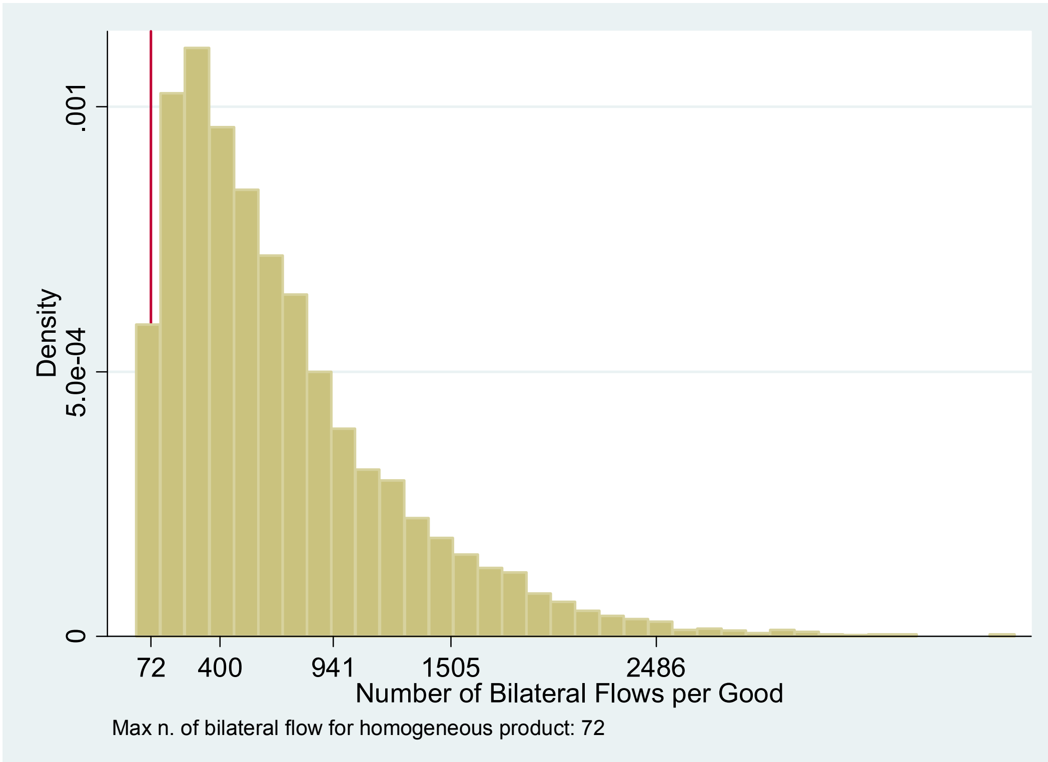
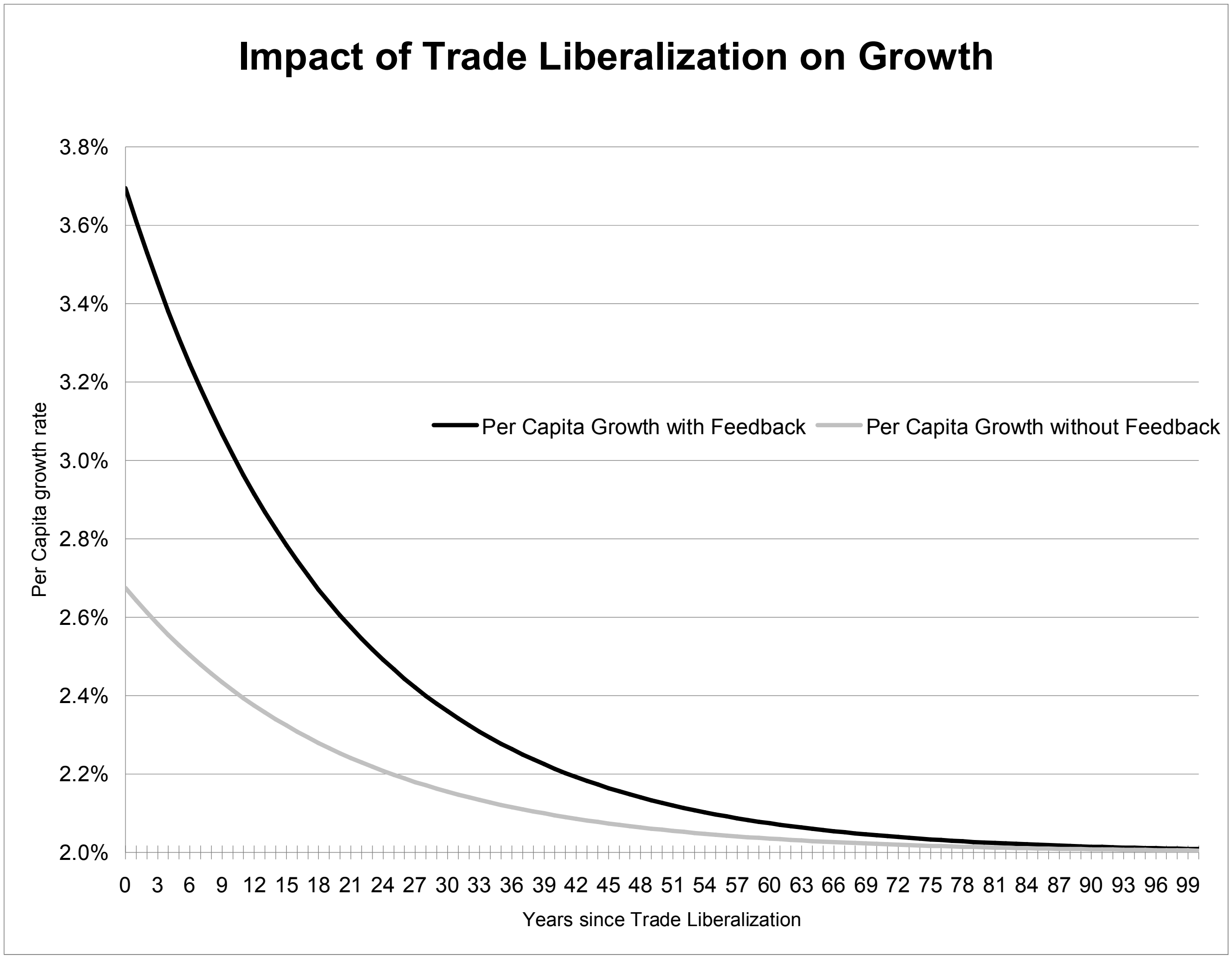


Figure 5



Impact of Trade Liberalization on Growth
3.8%
3.6%
3.4%
3.2%
3.0%
2.8%
2.6%
2.4%
2.2%
2.0%
Per Capita growth rate
Per Capita Growth with Feedback
Per Capita Growth without Feedback
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54 57 60 63 66 69 72 75 78 81 84 87 90 93 96 99
Years since Trade Liberalization

Figure 6

Number of Sectors with No Exports vs Size

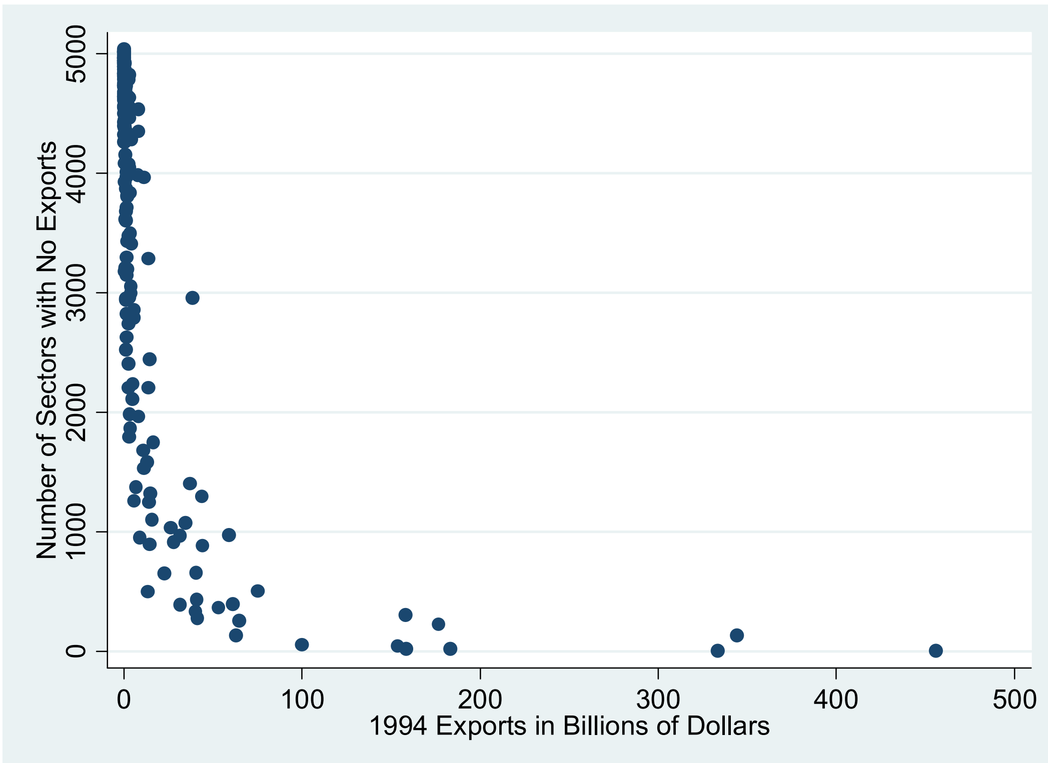


Table 1: Sample Statistics

	All Goods			Consumption Goods			Intermediate Goods		
	Median	Min	Max	Median	Min	Max	Median	Min	Max
First Year	1994	1994	1994	1994	1994	1994	1994	1994	1994
Number of Imported 6-digit Product Categories	4091	1223	4739	3198	1001	3687	4091	1223	4739
Average Number of Source Countries Per 6-digit	6.99	1.17	38.85	7.06	1.23	38.85	6.99	1.17	38.85
Number of Imported Varieties	29973	2111	106994	22885	1745	84729	29973	2111	106994
Share of Intermediate Imports in Total Imports	-	-	-	-	-	-	0.87	0.02	1
Final Year	2003	2003	2003	2003	2003	2003	2003	2003	2003
Number of Imported 6-digit Product Categories	4164	906	4667	3265	749	3637	4164	906	4667
Average Number of Source Countries Per 6-digit	8.13	1.00	53.53	8.23	1.00	53.53	8.13	1.00	53.53
Number of Imported Varieties	41302	1475	120383	30938	1241	94548	41302	1475	120383
	-	-	-	-	-	-	0.87	0.02	1

Note: The 73 sampled countries are listed in the appendix table.
In 1994, out of 4750 6-digit HS categories, 3693 had some share of imports for consumption and all had some share of imports for use as intermediates. In 2003, out of 4743 6-digit HS categories, 3689 had some share of imports for consumption and all had some share of imports for use as intermediates.

Table 2: Decomposing World Trade Growth in 1994-2003

	All Goods			Consumption Goods			Intermediate Goods		
	All Countries	Developed Countries	Developing Countries	All Countries	Developed Countries	Developing Countries	All Countries	Developed Countries	Developing Countries
Average Growth in Imports/GDP	42.1%	35.5%	45.1%	56.1%	47.0%	60.2%	40.3%	34.5%	42.9%
Average Contribution of Existing Varieties	9.7%	22.8%	3.8%	21.8%	33.0%	16.8%	7.6%	21.2%	1.4%
Average Contribution of New Varieties	32.4%	12.7%	41.3%	34.3%	14.0%	43.4%	32.8%	13.3%	41.5%
Number of Countries	71	22	49	71	22	49	71	22	49

Developed Countries are Australia, Austria, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Italy, Japan, Rep. of Korea, Mexico, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, and the USA

Table 3: World Growth in Varieties

	All Goods			Consumption Goods			Intermediate Goods		
	1994	2003	Growth Rate	1994	2003	Growth Rate	1994	2003	Growth Rate
Total Imported Varieties	2,264,396	2,739,784	21%	1,816,480	2,196,032	21%	2,264,396	2,739,784	21%
Total Available Varieties	20,738,448	21,078,288	2%	16,511,256	16,788,600	2%	20,738,448	21,078,288	2%
Index of Trade Dispersion	0.097	0.118	22%	0.097	0.119	22%	0.097	0.118	22%

Table 4: Impact on Exact Import Price Index for 73 Countries 1994-2003

Rank in GDP per capita		Country Name	Median Sigma	St Error (Median Sigma)	Consumer Welfare and Level Effect (in percent)	Share of Intermediate Imports in Total Imports	Intermediate Goods: Median Lambda Ratio	Intermediate Goods: Total Percent Productivity Gain (Level Effect)	Consumption Goods: Median Lambda Ratio	Consumption Goods: Consumer Welfare Effect (in percent)
1	207	Switzerland	3.9	0.15	0.692	0.590	0.963	0.404	0.967	0.288
2	10	Japan	2.9	0.18	0.334	0.654	0.968	0.239	0.973	0.095
3	5	Denmark	3.6	0.17	-1.107	0.657	0.947	0.580	0.945	-1.686
4	15	Norway	3.0	0.13	0.819	0.651	0.954	0.506	0.960	0.312
5	8	Germany	3.9	0.22	0.503	0.635	0.943	0.378	0.946	0.125
6	2	Austria	4.1	0.19	0.545	0.639	0.984	0.236	0.984	0.310
7	20	USA	2.3	0.13	1.910	0.583	0.948	1.292	0.956	0.618
8	18	Sweden	5.0	0.37	0.385	0.654	0.937	0.121	0.931	0.264
9	7	France	3.7	0.21	1.029	0.638	0.898	0.551	0.894	0.478
10	13	Netherlands	3.3	0.19	4.175	0.613	0.887	2.669	0.904	1.507
11	112	Iceland	3.0	0.14	6.247	0.622	0.928	4.580	0.935	1.667
12	6	Finland	3.1	0.15	1.548	0.684	0.970	0.659	0.964	0.890
13	110	Hong Kong	4.4	0.24	29.601	0.569	0.926	25.305	0.932	4.297
14	1	Australia	2.5	0.10	6.059	0.599	0.961	4.810	0.968	1.249
15	4	Canada	5.1	0.42	6.076	0.628	0.914	5.202	0.947	0.874
16	19	United Kingdom	2.4	0.09	1.672	0.576	0.943	0.908	0.938	0.764
17	9	Italy	3.7	0.21	1.013	0.643	0.902	0.737	0.920	0.276
18	117	Ireland	4.0	0.16	2.487	0.609	0.951	2.404	0.948	0.083
19	138	Macau	4.4	0.44	0.493	0.561	0.979	0.418	0.988	0.074
20	14	New Zealand	3.2	0.21	1.854	0.598	0.907	1.222	0.927	0.632
21	17	Spain	2.8	0.14	2.002	0.668	0.943	1.792	0.950	0.210
22	73	Cyprus	2.9	0.06	10.195	0.563	0.847	6.579	0.791	3.616
23	99	Greece	2.6	0.11	0.910	0.664	0.918	0.219	0.920	0.691
24	11	Rep. of Korea	3.0	0.13	0.885	0.707	0.957	0.824	0.970	0.061
25	16	Portugal	3.4	0.15	0.799	0.661	0.958	0.658	0.955	0.141
26	191	Slovenia	3.7	0.21	1.751	0.685	0.923	0.045	0.918	1.706
27	186	Saudi Arabia	2.9	0.11	0.836	0.645	0.947	0.644	0.941	0.193
28	31	Argentina	3.4	0.16	0.196	0.734	1.031	0.179	1.047	0.017
29	223	Uruguay	3.4	0.19	1.946	0.736	1.012	1.714	1.024	0.232
30	169	Oman	3.9	0.18	9.286	0.642	0.514	7.565	0.510	1.721
31	198	Saint Kitts and Nevis	3.3	0.19	11.350	0.574	0.865	10.605	0.924	0.745
32	93	Gabon	3.3	0.18	3.446	0.679	0.902	2.201	0.916	1.246
33	48	Brazil	2.9	0.16	0.390	0.784	0.938	0.266	0.932	0.124
34	111	Hungary	4.7	0.28	1.350	0.740	0.904	0.813	0.894	0.537
35	61	Chile	3.5	0.11	-0.762	0.558	1.518	-0.546	1.281	-0.216
36	141	Malaysia	2.5	0.14	18.788	0.775	0.865	14.585	0.832	4.203
37	71	Croatia	5.0	0.37	4.324	0.670	0.870	2.770	0.865	1.553
38	229	Venezuela	3.3	0.17	0.604	0.708	0.906	0.500	0.917	0.104
39	239	Slovakia	4.1	0.23	5.842	0.766	0.866	5.029	0.879	0.813
40	12	Mexico	3.1	0.22	0.673	0.726	0.983	0.442	0.981	0.231
41	147	Mauritius	2.8	0.13	8.217	0.664	0.718	6.470	0.749	1.747
42	40	Belize	4.2	0.23	3.234	0.512	0.863	2.151	0.883	1.083
43	178	Poland	4.5	0.24	5.314	0.729	0.841	2.902	0.810	2.412
44	79	Dominica	3.1	0.12	6.650	0.547	0.846	5.853	0.894	0.797
45	101	Grenada	3.0	0.16	5.171	0.580	0.843	4.262	0.858	0.910
46	211	Thailand	2.9	0.20	2.434	0.805	0.936	2.027	0.934	0.407
47	217	Turkey	3.4	0.19	1.669	0.748	0.901	0.971	0.911	0.698
48	202	Saint Vincent	3.4	0.24	12.595	0.557	0.895	8.262	0.914	4.333
49	66	Colombia	2.9	0.18	-0.787	0.706	0.950	-0.469	0.928	-0.318
50	238	TFYR of Macedonia	3.4	0.21	3.643	0.672	0.771	2.990	0.768	0.653
51	175	Peru	3.1	0.16	1.745	0.712	0.940	1.282	0.956	0.463
52	216	Tunisia	3.2	0.16	2.728	0.722	0.942	1.952	0.938	0.776
53	136	Lithuania	3.9	0.23	16.053	0.726	0.563	12.621	0.575	3.432
54	130	Latvia	3.5	0.20	5.864	0.635	0.725	4.344	0.685	1.519
55	82	Ecuador	3.5	0.21	1.913	0.659	0.837	1.333	0.800	0.580
56	84	El Salvador	3.4	0.17	5.495	0.624	0.856	4.058	0.853	1.437
57	122	Jordan	3.2	0.14	3.134	0.718	0.940	2.647	0.922	0.487
58	25	Algeria	3.6	0.14	2.166	0.723	0.814	1.945	0.856	0.221
59	181	Romania	5.8	0.56	0.262	0.731	0.764	-0.606	0.718	0.868
60	104	Guatemala	3.4	0.19	2.510	0.614	0.888	1.041	0.884	1.469
61	155	Morocco	3.4	0.14	3.308	0.747	0.886	2.153	0.886	1.156
62	83	Egypt	3.7	0.22	-0.061	0.790	0.968	-0.053	1.001	-0.008
63	114	Indonesia	2.9	0.12	0.509	0.743	0.938	0.355	0.927	0.154
64	44	Bolivia	2.9	0.16	1.383	0.687	0.920	0.661	0.931	0.722
65	196	Sri Lanka	4.6	0.42	0.785	0.725	0.943	0.480	0.985	0.305
66	109	Honduras	5.0	0.35	2.370	0.609	0.873	1.797	0.887	0.572
67	62	China	3.4	0.15	0.725	0.762	0.961	0.610	0.965	0.115
68	163	Nicaragua	4.1	0.37	17.400	0.634	0.887	12.398	0.850	5.002
69	113	India	3.7	0.21	0.052	0.694	0.837	-0.021	0.811	0.073
70	76	Central African Rep.	3.8	0.49	0.689	0.555	1.056	0.425	1.078	0.264
71	212	Togo	3.2	0.20	2.406	0.564	0.887	0.783	0.824	1.623
72	139	Madagascar	3.6	0.27	6.659	0.654	0.680	5.162	0.704	1.496
73	140	Malawi	3.7	0.23	28.558	0.695	0.319	21.451	0.287	7.107
		Median Country	3.4	0.2	1.48	0.66	0.92	1.28	0.92	0.63
		Median Developed	3.4	0.2	1.20	0.63	0.94	0.82	0.95	0.40
		Median Developing	3.4	0.2	1.85	0.69	0.89	1.71	0.91	0.70

Note: Developed Countries are defined in the notes to table 2.

TABLE 5

Table 5: Estimated Sigmas and Rauch Classification

	Rauch's classification of goods: Commodity	Reference Priced	Differentiated
	World 1994-2003 (3-digit goods, 6 digit varieties)		
Mean across countries	12.1	7.3	7.2
Number of Observations		4139	7998
Test if different than Commodity (p-value)		0.000	0.000
Median across countries	3.8	3.0	3.3
Number of Observations		4139	7998
Test if different than Commodity (p-value)		0.000	0.000

Table 6: World TFP Accounting (Level Effects Only)

	Intermediate Goods					
	Per-year Productivity Gains due to Expanded Imported Varieties (1)	Per Capita GDP Growth Rates (2)	(1) as a share of (2) (3)	Per-year Productivity Gains due to Expanded Imported Varieties (4)	TFP Growth Rates (5)	(4) as a share of (5) (6)
	All Countries in Sample (N = 73)			All Countries in Sample (N = 53)		
Average	0.32	1.7	19	0.29	1.3	23
Median	0.14	1.7	8	0.10	1.2	8
	Developed Countries (N = 22)			Developed Countries (N = 19)		
Average	0.30	2.1	14	0.30	2.0	15
Median	0.09	1.9	5	0.10	2.0	5
	Developing Countries (N = 51)			Developing Countries (N = 34)		
Average	0.34	1.5	22	0.29	0.9	32
Median	0.19	1.4	13	0.10	0.7	14

Notes: All values are expressed in percentages. Developed Countries are defined in the notes to table 2.

Table 7: Determinants of Innovation in New Varieties

Dependent Variable: Count of New Exported Goods		
	Intermediate Goods	
Measure of Size:	Exports	Output
F	0.238	0.267
	[0.031]	[0.027]
A	0.334	0.677
	[0.12]	[0.098]
N. Obs.	58	58
Pseudo R^2	0.063	0.0824

Standard errors in brackets

Table 8: Level and Growth

GDP per capita	Country Name	PDV of Gain Relative to GDP Growth	Level	Total	Percent Change in Permanent Income Effect Growth	Level	Total
	World	5.75	0.97	6.72	17.25	1.11	18.36
	Median Country World	8.8	1.1	9.8	26.5	1.3	28.4
	Median Developed	5.6	0.7	6.5	16.8	0.8	18.6
	Median Developing	11.5	1.5	12.5	34.5	1.7	35.6
1	Switzerland	3.9	0.4	4.2	11.6	0.4	12.0
2	Japan	2.9	0.2	3.2	8.8	0.2	9.1
3	Denmark	5.4	0.5	5.9	16.2	0.6	16.8
4	Norway	4.3	0.4	4.8	13.0	0.5	13.5
5	Germany	5.9	0.3	6.2	17.7	0.4	18.0
6	Austria	1.7	0.2	1.9	5.0	0.2	5.2
7	USA	4.7	1.1	5.9	14.2	1.3	15.5
8	Sweden	6.7	0.1	6.8	20.2	0.1	20.3
9	France	10.5	0.5	11.0	31.6	0.6	32.2
10	Netherlands	12.3	2.3	14.7	37.0	2.7	39.6
11	Iceland	8.8	4.0	12.8	26.5	4.6	31.0
12	Finland	3.0	0.6	3.6	8.9	0.7	9.6
13	Hong Kong	22.3	22.2	44.6	67.0	25.3	92.3
14	Australia	5.3	4.2	9.5	15.8	4.8	20.6
15	Canada	11.9	4.6	16.5	35.7	5.2	40.9
16	United Kingdom	5.0	0.8	5.8	15.1	0.9	16.0
19	Italy	2.2	0.4	2.6	6.7	0.4	7.2
18	Ireland	5.9	2.1	8.0	17.8	2.4	20.2
19	Macao	2.2	0.4	2.6	6.7	0.4	7.2
20	New Zealand	9.5	1.1	10.5	28.4	1.2	29.6
21	Spain	5.8	1.6	7.4	17.5	1.8	19.2
22	Cyprus	18.2	5.8	23.9	54.5	6.6	61.0
23	Greece	7.3	0.2	7.5	21.9	0.2	22.1
24	Korea	4.3	0.7	5.0	12.8	0.8	13.6
25	Portugal	4.3	0.6	4.9	12.9	0.7	13.6
26	Slovenia	7.7	0.0	7.7	23.0	0.0	23.0
29	Saudi Arabia	-0.6	1.5	0.9	-1.7	1.7	0.0
28	Argentina	-2.8	0.2	-2.6	-8.4	0.2	-8.2
29	Uruguay	-0.6	1.5	0.9	-1.7	1.7	0.0
30	Oman	67.9	6.6	74.5	203.6	7.6	211.2
31	Saint Kitts and Nevis	19.6	9.3	28.9	58.7	10.6	69.3
32	Gabon	10.6	1.9	12.5	31.7	2.2	33.9
33	Brazil	5.8	0.2	6.0	17.4	0.3	17.7
34	Hungary	10.6	0.7	11.3	31.9	0.8	32.7
35	Chile	-39.6	-0.5	-40.1	-118.7	-0.5	-119.3
36	Malaysia	20.1	12.8	32.9	60.4	14.6	75.0
39	Croatia	17.0	4.4	21.4	50.9	5.0	55.9
38	Venezuela	9.3	0.4	9.8	27.9	0.5	28.4
39	Slovakia	17.0	4.4	21.4	50.9	5.0	55.9
40	Mexico	1.8	0.4	2.1	5.3	0.4	5.7
41	Mauritius	32.7	5.7	38.4	98.1	6.5	104.5
42	Belize	15.7	1.9	17.5	47.0	2.2	49.1
43	Poland	19.0	2.5	21.5	56.9	2.9	59.8
44	Dominica	18.4	5.1	23.6	55.3	5.9	61.1
45	Grenada	17.4	3.7	21.1	52.2	4.3	56.5
46	Thailand	6.7	1.8	8.4	20.0	2.0	22.0
49	Turkey	4.4	-0.4	3.9	13.1	-0.5	12.6
48	Saint Vincent and the Grenadines	14.7	7.3	21.9	44.1	8.3	52.3
49	Colombia	4.4	-0.4	3.9	13.1	-0.5	12.6
50	Macedonia	25.6	2.6	28.3	76.9	3.0	79.9
51	Peru	6.1	1.1	7.3	18.4	1.3	19.7
52	Tunisia	6.3	1.7	8.0	19.0	2.0	20.9
53	Lithuania	66.2	11.1	77.3	198.5	12.6	211.2
54	Latvia	32.6	3.8	36.4	97.9	4.3	102.3
55	Ecuador	17.3	1.2	18.4	51.8	1.3	53.1
56	El Salvador	16.6	3.6	20.2	49.9	4.1	54.0
59	Jordan	27.6	-0.5	27.1	82.8	-0.6	82.2
58	Algeria	20.4	1.7	22.1	61.1	1.9	63.1
59	Romania	27.6	-0.5	27.1	82.8	-0.6	82.2
60	Guatemala	11.5	0.9	12.4	34.5	1.0	35.6
61	Morocco	12.3	1.9	14.2	37.0	2.2	39.2
62	Egypt	3.1	0.0	3.1	9.4	-0.1	9.3
63	Indonesia	5.8	0.3	6.1	17.4	0.4	17.8
64	Bolivia	7.6	0.6	8.2	22.9	0.7	23.5
65	Sri Lanka	6.1	0.4	6.5	18.4	0.5	18.8
66	Honduras	14.8	1.6	16.4	44.5	1.8	46.3
67	China	4.0	0.5	4.5	11.9	0.6	12.6
68	Nicaragua	18.8	10.9	29.7	56.4	12.4	68.8
69	India	16.9	0.0	16.9	50.7	0.0	50.6
70	Central African Republic	-5.2	0.4	-4.8	-15.5	0.4	-15.0
71	Togo	11.3	0.7	12.0	33.8	0.8	34.6
72	Madagascar	39.4	4.5	44.0	118.3	5.2	123.4
73	Malawi	126.5	18.8	145.3	379.5	21.5	400.9