From Torino to Tychy: The limits of offshoring in the car industry*

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Abstract

This paper estimates the role of country/variety comparative advantage in the decision to offshore assembly of nearly 2000 models of 184 car brands headquartered in 25 countries. While offshoring in the car industry has risen from 2000 to 2013, the top five offshoring brands account for the majority of car assembly relocated to low wage countries. We show that the decision to offshore a particular car model depends on two types of cost (dis)advantage of the home country relative to foreign locations. The first type, the component of assembly costs common to all models, is estimated via a structural triadic gravity equation. The second effect, model-level comparative advantage, is an interaction between proxies for the model's skill and capital intensity and the factor abundance of the headquarters country.

1 Introduction

Car makers have a long history of assembly in foreign countries: Ford of Canada began manufacturing operations in 1904. For the most part, the car industry, like other industries, has moved production abroad to obtain better access to foreign customers.[1] Recently, there has been a rise in use of foreign assembly to serve markets other than just the host country. In 2010, with unions pointing out that Renault had moved three quarters of its car production

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[1]Irarrazabal et al. (2013) report that 62% of the goods made by US affiliates are sold in the domestic market.

outside of France, then president Sarkozy summoned Renault's CEO, Carlos Ghosn, to the Elysée Palace "to explain the carmaker's strategy." He was reportedly told to retain production of the Clio for the French market in France, rather than move it to the Renault plant in Turkey.[2] Around the same time, Fiat's CEO, Sergio Marchionne, boasted that its plant in Tychy, Poland was assembling almost as many cars as the company's five largest Italian plants combined. In March 2014 Porsche announced that it would move production of the Cayenne SUV from Germany to Slovakia. This would mark the first time that Porsches would be assembled outside of Germany.

Stories such as these suggest a major change in the pattern of auto assembly is under way. Will auto production go the way of clothing and consumer electronics and migrate to less developed countries? This paper quantitatively investigates the state of offshoring in the passenger car industry.[3] We propose two ways to measure the amount of offshoring of assembly and show that it is not growing as much as the anecdotes above suggest. Furthermore offshoring for the home market is highly heterogeneous: the top five offshoring brands account for about two thirds of the cars made abroad and sold in the brands' home market.

To explain the large observed variation in offshoring, we examine the country- and model-level determinants of the decision to assemble a particular model in a lower wage country. Our aim is to understand why offshoring takes place and in particular which firms find it attractive. The results we obtain support a comparative advantage model of offshoring. Firms based in countries that have relatively high assembly costs are more likely to offshore in general and the most likely models to be offshored are the less expensive cars of brands based in high income countries. We interpret price as a proxy for the skill and capital intensity of the model and per capita income as a proxy for abundance in the corresponding factors of production.

Why is offshoring in the car industry of particular interest? First of all, the car industry is large and considered important by government policy makers. Passenger cars are the largest expenditure category among goods.[4] Industry associations in the European Union (EU) and United States (US) report very large employment shares for the broadly defined automotive sector. Including parts and other related activities, it accounts for 5.8% of the total employed population of the EU and nearly 5% of US employment. Car makers were deemed sufficiently important to receive $US 81 bn under both the Bush and Obama administrations. General Motors was largely nationalized in 2009.

[2]Three years later, our data show that two thirds of the new generation Clios are produced in Turkey with the remainder in France.

[3]We view it as complementary to the detailed, but mainly descriptive, account in the monograph, *Made in Torino?* by Barba Navaretti and Ottaviano (2015).

[4]They account for 4% of personal consumption expenditures in the United States.

A second compelling reason to study offshoring in the car industry is the existence of extraordinarily rich data. IHS Automotive (formerly Polk), an automotive consultancy, provides a nearly exhaustive account where cars are made and then sold. Comparable data do not appear to be available on a worldwide basis for any other sector of the economy. Most government-provided data sets are restricted to parent firms or affiliates based in a single reporting country. IHS tracks the factory where nearly 2000 models are assembled by nearly all manufacturers and brands. The data, running from 2000 to 2013, shows annual flows at the level of individual models identifying location of assembly and country of sale (the data are based in part on new car registrations). Because we can map the origins of each brand back to a headquarters country (which we designate as the brand's "home"), we capture the three essential locations that form part of our criteria for offshoring: where each brand makes the cars it sells in its brand home and other markets.

Some important dimensions of the data include the following:

- 2162 local nameplates for 1775 "global nameplates" (models) identified by the makers.
- For each model we also know the start and end year of each "program" (version of the model).
- The data also distinguishes the size and function of the model.[5]
- For about 1000 models we have destination-specific sales price information.
- 184 brands from 25 different brand homes.
- 73 different markets (countries that record brand/origin)
- 49 different assembly countries (almost all world production)

Using the auto data set, we conduct three main empirical exercises. The first step quantifies the magnitude and direction of offshoring to this date. By offshoring we mean the relocation of production intended for a given market to new assembly sites. Our narrow definition of offshoring focuses on the home market of the brand. The narrow definition of offshoring thus removes all relocation of production to get closer to foreign customers.[6] Our broad definition considers all assembly outside the brand's home country to be offshoring. In both cases, we define the home country to be the place where the headquarters of the brand is located. In cases such as Volvo where headquarters functions are mixed between countries

[5] We also know body types such as sedans, hatchbacks or convertibles, but we do not use this information.

[6] This motive for production abroad is also referred to as "tariff-jumping" though tariffs are often not the main trade cost.

(Sweden and China), the home country is defined based on where the brand was founded (Sweden). By direction, we distinguish "downward" offshoring to lower income countries from "flat" and "upward" offshoring to other countiries at similar or higher income levels. Our threshold for flat is for the producing country per-capita income to be no more that 20% above or below the per capita income of the brand home.

After establishing that offshoring to serve the home market remains small and is mainly carried out by a small number of brands, we investigate the determinants of the decision to offshore all or part of the production of a car model. We hypothesize that a key input in that decision would be a general cost advantage of the home country in car assembly. To obtain the country-specific "assembly advantage" term, we first estimate a specification of multinational production flows derived from Arkolakis et al. (2013). This specification has origin-year and brand-destination-year fixed effects as well as indicators for bilateral frictions. In the model, the origin-year fixed effects are proportional to the ratio of worker productivity to their wages.

Our final exercise is estimate a fractional logit on the percent of production that is offshored at the model level. One previous study has also sought to identify the characteristics of products that vehicles that makes them more susceptible to offshoring: McCalman and Spearot (2013) examined the Post-NAFTA expansion of capacity to produce light trucks in Mexico. They found that US firms "offshored varieties that were older and less complex to produce." We will compare our worldwide car results to their North American trucking results. The remainder of the paper consists in 5 sections. Section 2 documents the changes that occurred in worldwide production of cars over the 2000-2013 period. Section 3 then specifies our definitions of offshoring, and quantifies its extent and patterns over time and space. Our modeling of the offshoring decision and estimating equation are described in section 4. The measurement of the different covariates involved in the offshoring regression is contained in section 5, and section 6 provides our estimates of the decision to produce their models in a country where costs are lower than at home.

2 Emerging economies in the auto assembly sector

In this section we chart the changes in the location of passenger car production that have occurred from 2000 to 2013. First, we define offshoring and measure it for the assembly of passenger cars. Second, we look at three specific cases of "emerging market" economies that assemble growing shares of the world's cars.

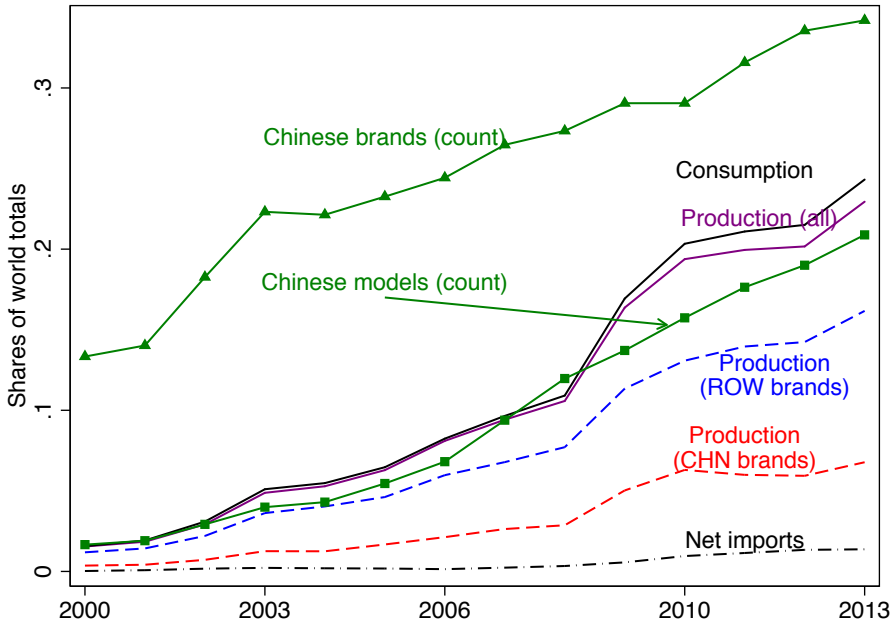
We begin by noting that total car production in the OECD in 2013 is 38 million units, the same (rounded) amount as in 2000. It increased somewhat in the lead-up to the 2008

crisis, then fell sharply, before stabilizing at the old level. On the other hand, non-OECD production has risen every year since 2000, cumulating a five-fold increase from 2000 to 2013.

We distinguish between relocation of assembly to the peripheral countries located near the traditional production centers (e.g. Slovenia and Mexico) versus the much lower wage countries that have been the focus of public fears about offshoring: China and India. We find that the other OECD countries (which includes the periphery countries mentioned above) account for over 95% of narrow offshoring. Production rises outside the OECD appear to have been almost entirely oriented towards serving their growing markets.

Figures 1 and 2 zoom in on the changing nature of production in three economic areas that have experienced impressive growth in their shares of world production: China, Eastern Europe (Poland, the Czech Republic, Slovakia, Hungary, Slovenia, Romania, and Bulgaria), and Mexico.

Figure 1: The Growth of China



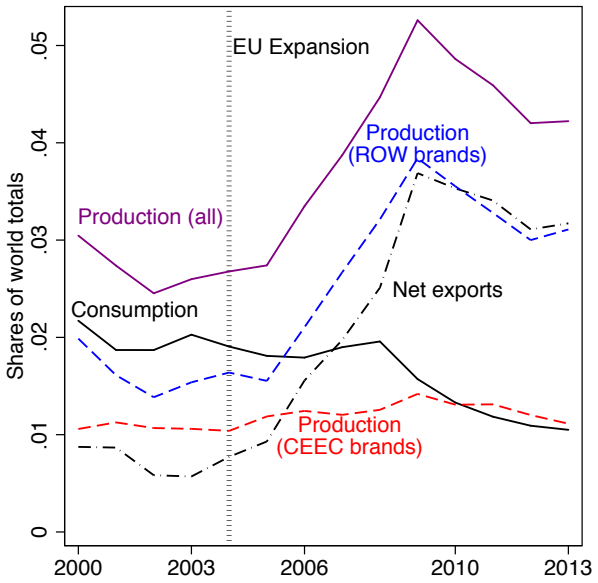
The case of China, shown in Figure 1 is the most straightforward to describe. There, production growth has matched demand growth almost exactly one for one until purchases outstripped production in 2010 and China became a small net importer. Foreign brands have gradually moved ahead of Chinese brands. Initially China had a very large number of very small brands. In 2000 its share or world brands was 8.7 times higher than its share of world production. Over the following 13 years the Chinese brands expanded production on the intensive margin. By 2013 the brand to production share ratio fell to 1.5. Chinese

brands remain on the small side and based on the experience of the traditional producers, we may expect a "shake-out" to occur in the future.

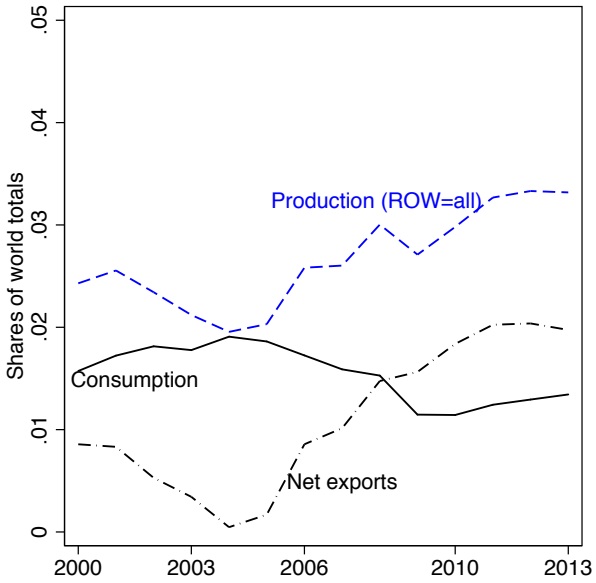
China may one day replicate in car assembly its success in areas like electronics assembly where it is already the "workshop of the world." However there is no sign of this in the data yet. One limitation China faces is that it has few free trade agreements with major markets. Our regression analysis in section 5.1 finds that trade agreements have large effects.

Figure 2: The Growth of the Periphery

(a) "New Europe"



(b) Mexico



Contrasting with the Chinese case, Figure 2 shows that Eastern Europe and Mexico have experienced sluggish growth in domestic demand, while hosting a share of world production that grows steadily over time starting in 2004. In both cases, net exports grow substantially over the period as a result. This pattern is particularly pronounced for Eastern Europe, where the pattern suggests an important role for entry into the EU of those countries, that manifests itself into a boom of re-exported production of foreign brands.

Two cases provide a good illustration of the migration of assembly to Eastern and Central Europe. Starting in the 1970s, an assembly factory in Tychy assembled a Polish version of the Fiat 126. Fiat purchased the plant in 1992 when it was privatized. Recently, Fiat allocated to the Tychy factory the new and highly successful 500 model. Tychy assembled almost as many cars as Fiat's five biggest plants in Italy with one third the workers each earning one

third the pay.[7] Tychy operates 24 hour per day, six days per week, whereas Fiat's Italian plants operated at 40% capacity utilization in 2012.

Renault's Revoz plant in Novo Mesto, Slovenia provides a somewhat similar story. It began as a joint venture in the 1980s.. The plan was to focus on selling cheap Renaults in the Yugoslav market. That plan had to be altered when Yugoslavia fell apart and Slovenia emerged instead as an offshoring and exporting platform.

Mexico (which has no local brand), also benefits from a regional trade agreement. NAFTA was signed in 1993, but its tariff reductions were phased in over the next decade. We unfortunately lack data before 2000 so we miss most of the period where the NAFTA tariff cuts were being phased in. The reasons behind the 2004 turnaround and subsequent boom in Mexico's net exports shown in Figure 2(b) are unclear.

The picture that emerges from figure 2 is one of two major historical production bases (North America and Western Europe) offshoring part of their car assembly to their respective low-cost "peripheries" (Mexico for the US brands and Eastern Europe for the European brands). We now try to quantify the offshoring movement in a more global and systematic way.

3 Measuring offshoring

The data set we have allows us to track the production of individual products. We can distinguish horizontal (market-seeking) activities from offshoring because we know the location of assembly and also where the cars are sold for each model. Another great advantage of our data is to be able to follow a specific variety over time, and therefore keep track of changes in the location of production with potential transfer to low cost countries.

To measure offshoring we must first define it. Feenstra (2004) defines offshoring as the "transfer of production overseas, whether it is done within or outside the firm." In departure from other analyses, we focus on single "task" or "activity": the assembly of passenger cars. Our data has no information on the sources of components so this will not be a paper about "slicing the value chain" except in the sense of separating final assembly from design and distribution. The question begged by Feenstra's definition is when should we consider overseas production to be *transferred*? It seems like the essential condition should be that *but for* this increase in offshore production, there would have been no corresponding reduction in home-country production.

We work with two definitions of offshoring. Our first definition is that *a car is considered offshored if it is consumed in the home country but assembled in a different country.* This

[7] Facts taken from Rattner article in *Financial Times*, October 4, 2012.

approach excludes offshore production that is aimed at serving the host country's market, with the general presumption that much or all of those sales would not be served by the brand if it did not produce locally. Such production therefore has small or no impact on domestic workers. This version of offshoring takes the conservative stand that only one market is with 100% probability possible to serve from plants at home—the domestic one—and focuses attention on that destination only. We call it "narrow" offshoring.[8] This seems to correspond to what political leaders have in mind when talking about offshoring. We reproduce a quote by French president's Chief of Staff, made public at a time when the French government was negotiating with Renault's CEO Carlos Ghosn about the potential re-location of a new model's (Clio 4) assembly in Turkey:

> "Ghosn said very clearly that the Clio 4s corresponding to the French market will be made in France ...You can't ask Renault to make cars for Turkey in France, which would mean not selling any more cars in Turkey." (Claude Guéant, Sarkozy Chief of Staff, January, 18, 2010)

The narrow definition of offshoring is the appropriate one if most overseas production for foreign markets would have to be produced in those markets. Thus it would not substitute for domestic employment.

An alternative definition, takes a quite opposite view, emphasizing substitution between domestic and foreign employment, regardless of the final market. From a worker perspective, Fiat 500s made in Tychy are Fiats not made in Torino—no matter who ultimately buys them. Consequently, our "broad" definition of offshoring is production outside the brand home divided by the brands production in all locations. This includes vertical, horizontal and export platform MP.[9] The right definition depends on the cross-substitution possibilities, which are difficult to assess ex ante. Therefore, our approach is to "bracket" the actual extent of offshoring with these two admittedly extreme definitions.

Narrow offshoring selects a home where the brand was historically produced and divides imports by total consumption. Broad offshoring looks at the total production outside of the brand home base. This "brand home" country is therefore an essential concept in our definitions of offshoring. We choose to define "home" as the country where the brand is headquartered or where it was founded.

To illustrate the different forms of multinational production and how they map into offshoring with a single model, consider the case of the Renault Twingo. For almost all

[8] Ramondo and Rodríguez-Clare (2013) refer to this as "pure vertical MP" but the "vertical" terminology would be confusing in this context since we only consider one stage of production (assembly). Also offshoring has become the standard term in policy discussions.

[9] We thank Peter Neary for suggesting us that we should consider export platform production in our definitions of offshoring.

markets, this model was sourced entirely from the Flins factory near Paris until 2007. The exceptions were assembly in Colombia and Uruguay for local sales ("horizontal MP" in the taxonomy of Ramondo and Rodríguez-Clare (2013)). In 2007, with the launch of a new version (II), Twingo production in France was terminated and all (new) Twingo production was concentrated in Slovenia to be exported to most destinations (including France).[10] The exception was a small amount of production for the version I in Colombia, mainly for the local market, but with a few cars shipped to neighboring Ecuador and Venezuela ("export platform MP"). All Twingo cars sold in France starting in 2007 were produced in Novo Mesto, Slovenia ("offshoring"). Under the narrow definition, this car switch from 0 to 100% offshored in 2007. Under the broad definition, the pivotal year involved a change from a small positive number (the local sales in Latin America) to 100%. Table 1 displays sales of that model in the HQ country and in the only 4 markets that are served by one of the Latin American plants.

Table 1: The Twingo example

Market:	FRA		COL		URY	VEN	ECU
Plant:	Flins	Novo Mesto	Medellin	Novo Mesto	Montevideo	Medellin	Medellin
Version:	I	II	I	II	I	I	I
2000	76622		1749		578		
2001	78891		1927		476		
2002	67588		3508				
2003	53146		4503				
2004	47699		5168				
2005	45594		7456				
2006	38133		9937			2666	53
2007	8525	43618	10069			3377	34
2008		65333	6660			960	
2009		107456	7756			137	25
2010		92183	5565				
2011		68236	6780			23	
2012		39697	3273				
2013		39032		285			

Note: The figures reported are total sales. Over the whole period, this model is sold by Renault in 42 different markets and produced in 4 different plants: Flins in France, Novo Mesto in Slovenia, Medellin in Colombia, and Montevideo in Uruguay (which stopped production in 2002). All other countries where that car is continuously sold (Germany, Italy, etc.) exhibit the same sourcing pattern as for cars sold in France.

[10] The Flins factory continued to produce the Clio but production at the factory in 2013 was only a quarter of its 2000 level.

Figure 3: Offshoring by income level of source country, narrow (solid) and broad (dashed) definitions

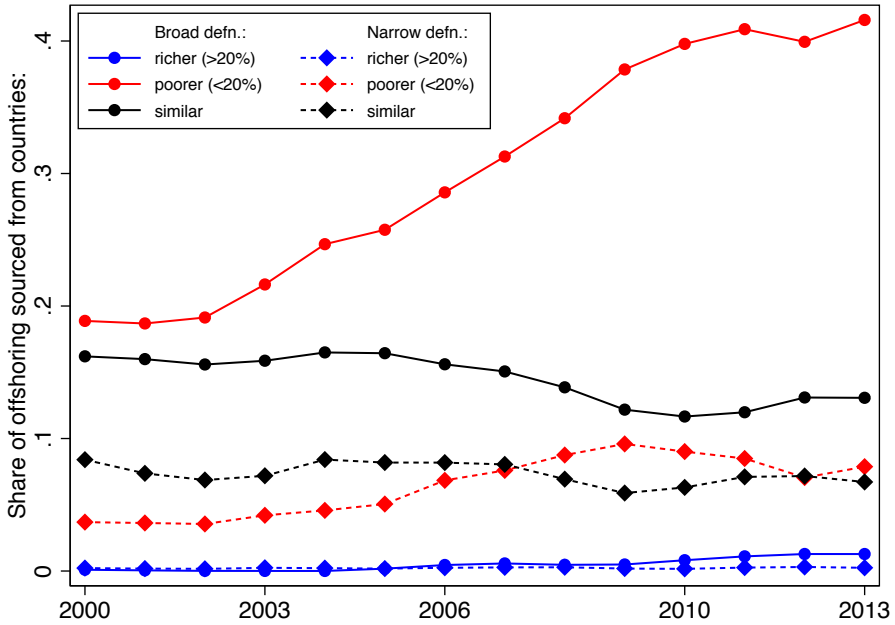


Figure 3 depicts trends in offshoring based on the two different definitions of offshoring and three different offshoring destinations. The solid lines are based on the broad definition and the dashed lines are for the narrow definition. The direction of offshoring will be considered "up" for imports from countries that have per capita incomes that are 20% higher than the home country. Offshoring "down" corresponds to imports from countries 20% poorer than the home. "Flat" offshoring refers to similar average income levels. We use market exchange rates in each case since we are aiming at comparing wages, rather than standards of living.[11] We average incomes from 2000 to 2013 so as to prevent offshoring in a given country from shifting from being down to flat if, say the income of the country grew substantially during the period.[12] The relative nature of this definition implies that even a well-to-do country like Finland can be considered offshoring down if, as in the case of the Think (it is a brand), the brand home is super-rich Norway.

The picture from figure 3 is that narrow offshoring (dashed lines) remains globally a limited phenomenon, since the part of it that concerns low cost locations never reaches

[11] We considered using data on manufacturing wages in the transport equipment sector but the loss of countries due to missing data did not seem like a good trade-off given that we are dividing countries into coarse categories.

[12] This prevents sudden jumps in offshoring that are not related to actual changes in production but only to country classification.

10% of the home demand. This offshoring "down" is however clearly trending upwards, contrasting sharply with the flatness of both offshoring "up" and of offshoring "flat." The broad offshoring shares (solid line) are uniformly higher than the corresponding narrow shares, as was to be expected from the inclusion of all kinds of MP (vertical, horizontal and export patform) under that approach.

Figure 4 shows that the patterns we see at the global level for offshoring are not replicated evenly across the main brand homes. The figure applies the same vertical range (0–50%) to each country's level of narrow offshoring so as to facilitate comparisons. The top row shows the two large countries whose increase in offshoring from lower income countries was most pronounced, France and Italy. The United States and Germany exhibit quite different patterns. While the low cost locations are also attracting production of US and German brands, the rate of progress is much more modest. The extraordinary level of "flat" offshoring of US brands is distinctive and almost entirely attributable to the long history of market integration with Canada. The UK and Japan, are at the other extreme from France and Italy, with extremely little (narrow) offshoring of any kind. While this is perhaps not so surprising for the UK brands, consisting mostly of luxury and sports car at the start of our sample, it is quite striking for Japanese mass-oriented car producers.

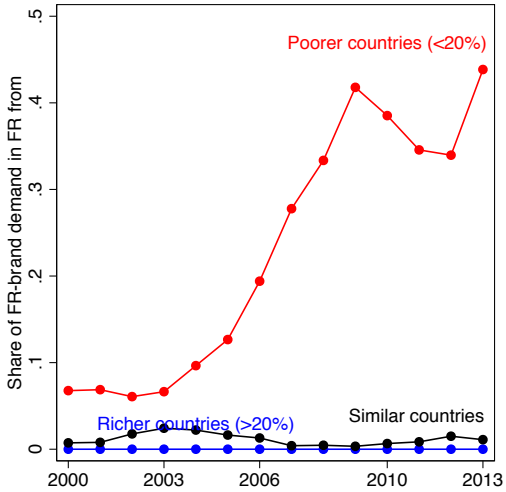
The broad definition of offshoring does not change the picture dramatically for France and Italy (figure 5). Both countries have seen a very impressive rise in the share of production in poorer countries for cars aimed at serving both the domestic and foreign consumers. The picture for the USA is more radically changed suggesting that when serving third markets, US brands tend to use more low-cost production facilities (often local) than when serving the domestic market. Offshoring of US cars in Canada seems to be mainly intended to serve the US market. While UK remains an exception with very low levels of broad offshoring, Japan sees a regular increase in the share of cars produced in poorer countries, intended for foreign consumers.

Turning back to the narrow definition, figure 6 shows that even within a brand home like France, the country that shows the most marked trend towards offshoring, there is huge heterogeneity. While Peugeot and Citroen have both increased sourcing from poorer countries, it is Renault that has moved towards offshoring in a major way, now sourcing about two thirds of the cars it sells in France from lower wage locations, most notably the Novo Mesto, Slovenia and Bursa, Turkey plants.

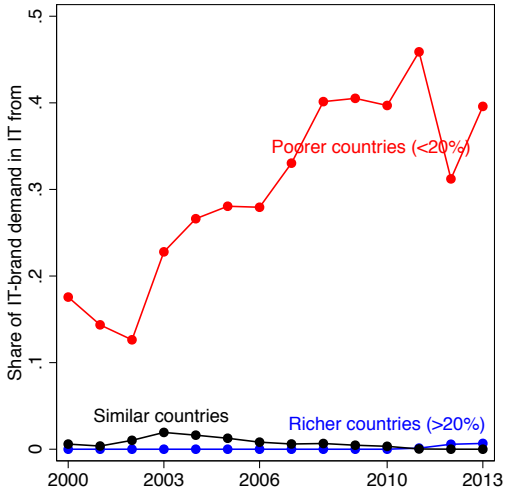
Figure 7 shows that the brand heterogeneity exhibited in France is part of a broader phenomena in which just five top brands account for 62% of the world's offshoring (narrow definition in 2013). This figure was even more impressive in the early 2000s, where the top 5 offshoring brands represented 86% of world (narrow) offshoring. These figures suggest that

Figure 4: Offshoring (narrow) in six major brand homes

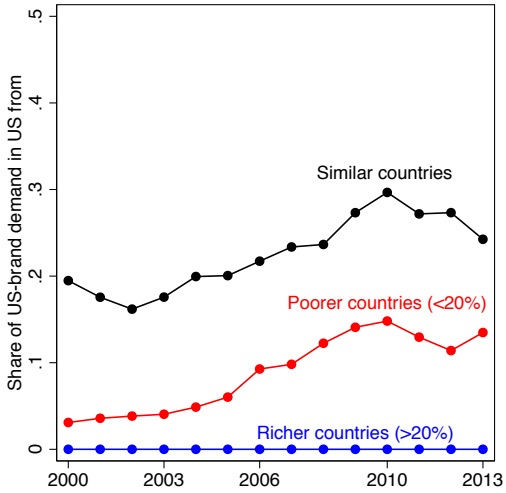
(a) France



(b) Italy



(c) USA



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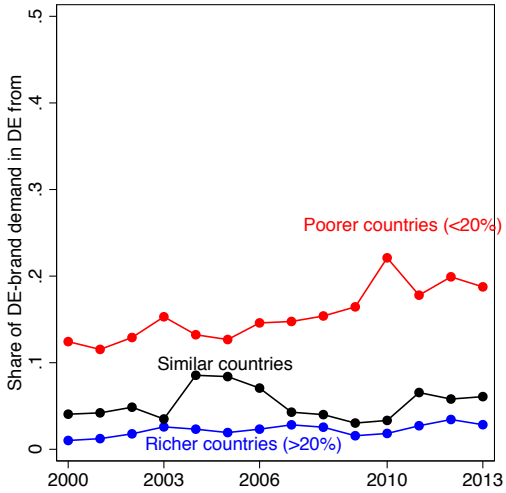

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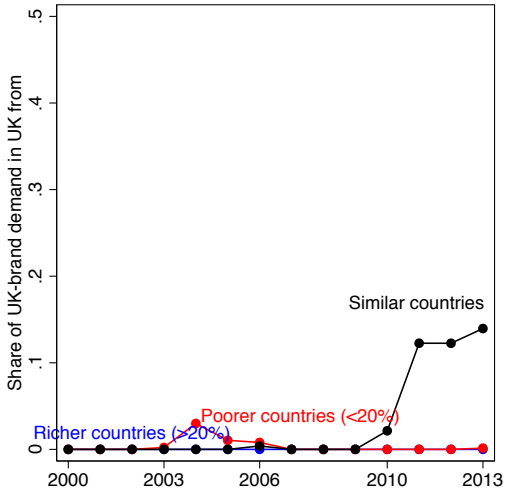

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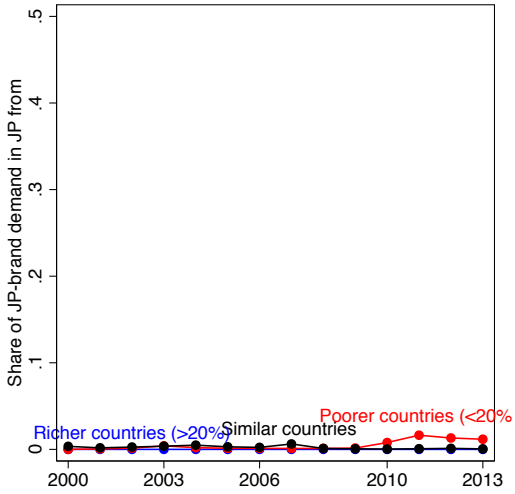
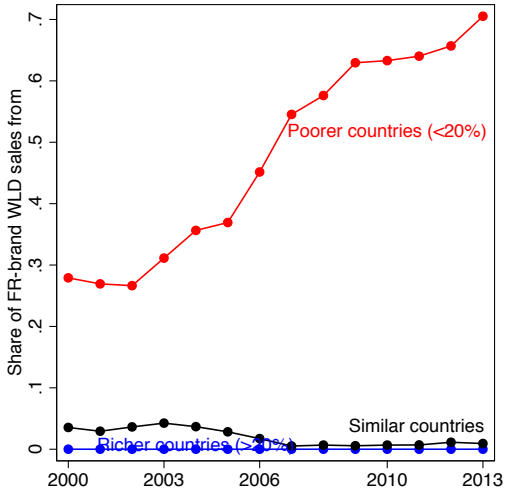
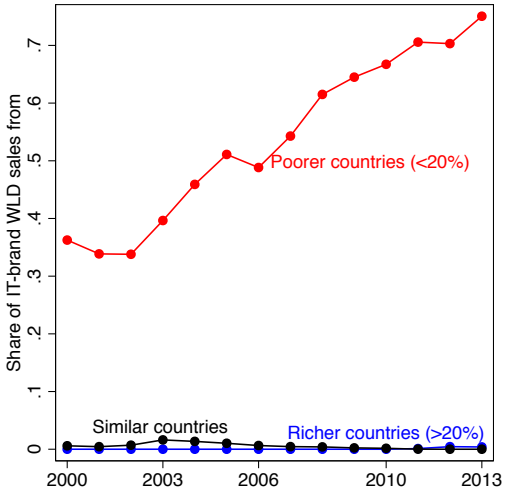


Figure 5: Offshoring (broad) in six major brand homes

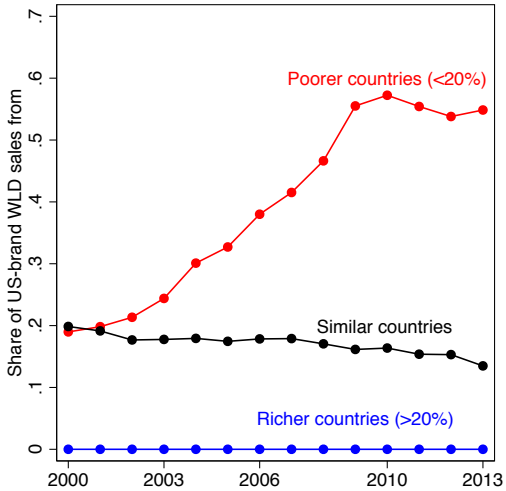
(a) France



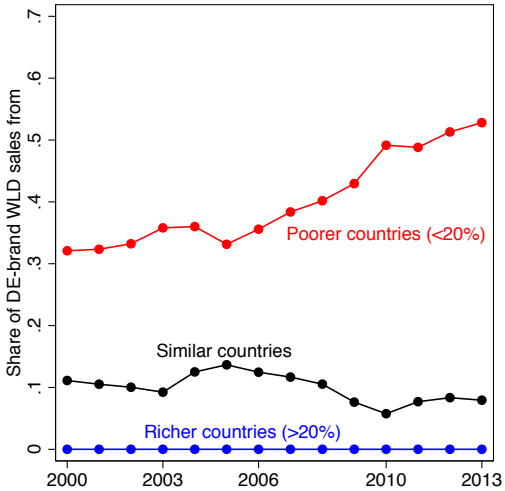
(b) Italy



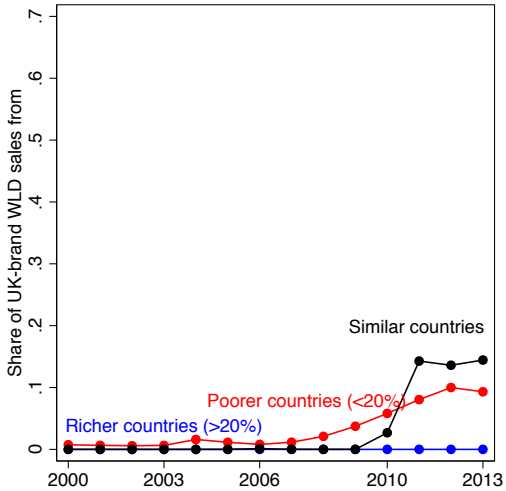
(c) USA



(c) Germany



(c) UK



(c) Japan

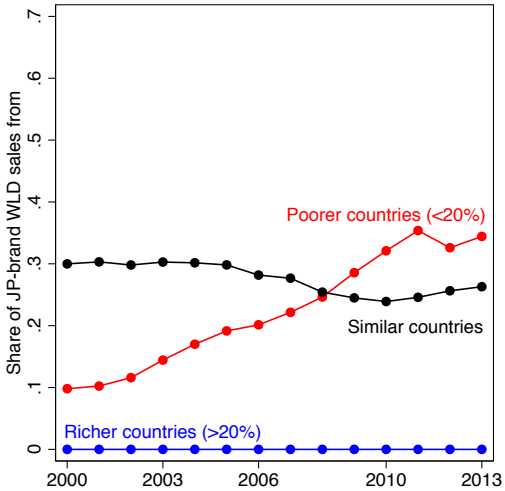
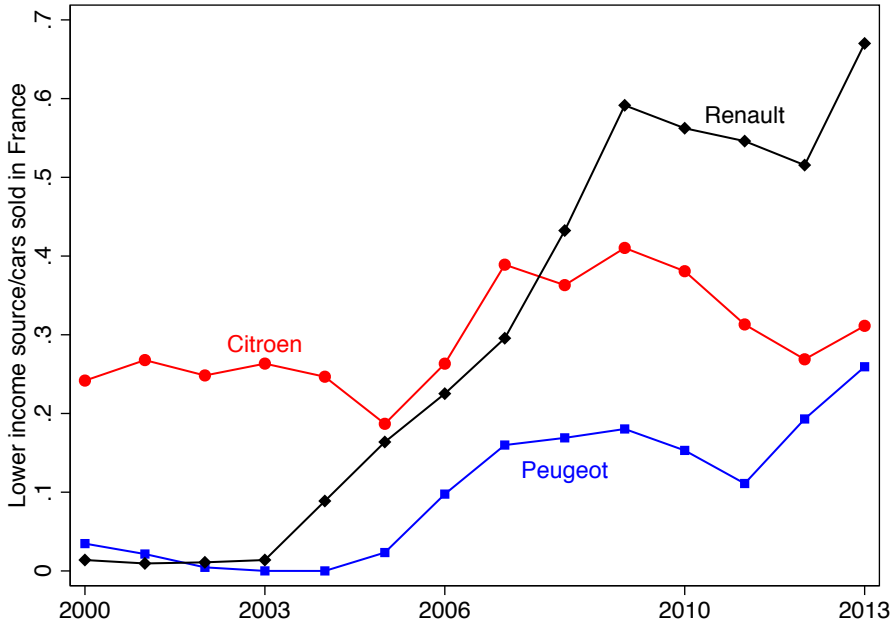


Figure 6: Brand-level differences in offshoring within France



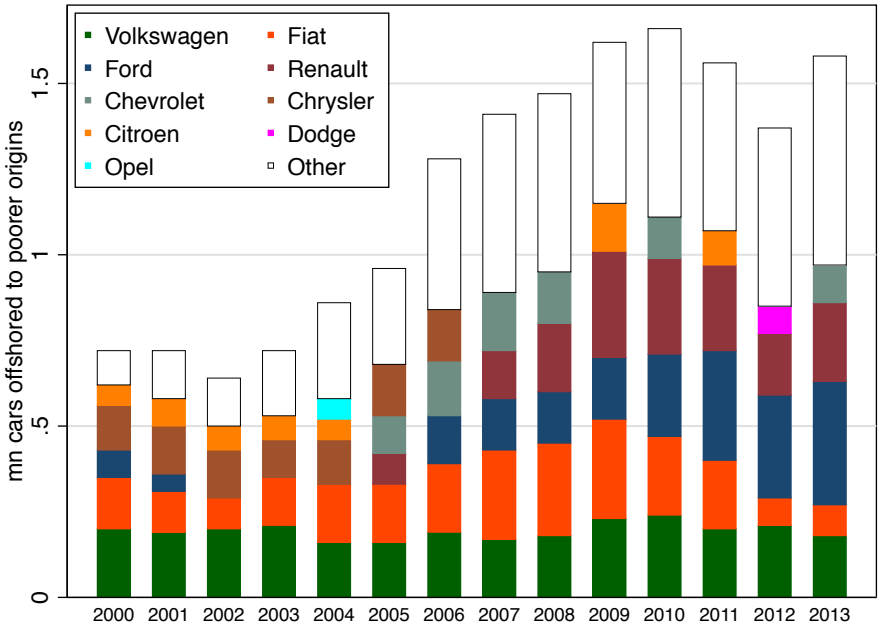
brand heterogeneity must be examined if one is to understand the rise in offshoring. One might question our insistence on brands at this point. Isn't it really just *firm* heterogeneity? The case of Fiat is our best reply since both Ferrari and Maserati are owned by Fiat but neither brand offshores production. Similarly, within our data range, of the Volkswagen-owned brands (Audi, Bugatti, Porsche, Seat, Skoda, etc.), only VW itself engages in significant offshoring.

We summarize offshoring trends as follows: Offshored cars from poorer—yet OECD—countries have small market share at home, but have doubled from four to eight percent. Downward offshoring exceeds offshoring from similar-income sources. Broad definition offshoring is much larger but it includes horizontal (market-seeking) MP that probably does not substitute much for home production. The China story in cars is completely different from iPhones. There is massive heterogeneity in offshoring: Similar countries and firms offshore in vastly different amounts. The "few" (top 5 brands) account for the majority of offshoring.

4 Comparative advantage and the offshoring decision

What factors drive offshoring? Why are some models offshored and others not? McCalman and Spearot (2013) study US truck makers offshoring to Mexico. Their results point to low complexity, older vintages, and small scale as variables associated with higher shares of

Figure 7: A few firms account for most offshoring from low-wage countries



trucks sourced from Mexican factories. With only one outsourcing country in their data set, they obviously could not investigate the role of country attributes. On the other hand, since our data contains 25 HQ countries and 49 assembly countries, we are able to examine the roles of country and country-model interactions in determining comparative advantage.

We use time-varying assembly-country fixed effects from a theory-based gravity equation as our measure of the "assembly advantage" for each country. Being estimated for all passenger cars, it cannot explain why some models are offshored but others are not. For this we need a theory and measurement of *model-level comparative advantage*. For this exercise we shall move away from the multi-country model of the gravity equation and employ instead a simple two-country model of a home country that potentially offshores assembly of a car model to a lower income foreign country. When necessary to avoid confusion between the two uses of the term model, we will refer to car models as varieties.

Our estimating equation for the offshoring decision takes its inspiration from the seminal papers of Dornbusch et al. (1980), Feenstra and Hanson (1997), and Schott (2004). We hypothesize that model m-level comparative advantage of country i is determined by the *interaction* of i development level and m skill-intensity. We use log per capita income, $\ln y_{it}$, as the development proxy and the model-specific component of log prices $\ln p_m$ is the skill-intensity proxy. The coefficient of chief interest in these regressions is $\ln y_{it} \times \ln p_m$. This interaction term should have a negative effect on offshoring because, in accordance with the

work of Schott (2004), high income countries have comparative advantage in high-end cars.

$$\text{offs}_{m(i)t} = \Lambda(\beta_1 \widehat{\text{FEP}}_{it} + \beta_2 \ln p_m + \beta_3 \ln y_{it} + \beta_4 (\ln p_m \times \ln y_{it}) + \cdots) \tag{1}$$

Since the FEP and interaction terms are both increasing in the home's advantages, the effects of offshoring probabilities are negative, i.e. we expect $\beta_1 < 0$ and $\beta_4 < 0$. We now provide a simple theoretical framework to motivate this interaction.

Let costs of domestic production for a model m be given by a nested Cobb-Douglas that takes the following form

$$c(m) = \alpha \left(w_H^{z(m)} w_L^{1-z(m)} \right)^{\beta} p_I^{1-\beta} \exp(\epsilon(m)), \tag{2}$$

where $z(m)$ is the cost share parameter for high-skilled workers, paid w_H, while the low skilled ones are paid w_L. Importantly, those cost shares can vary by model. Costs comprise labor with share β and a basket of intermediate inputs priced p_I and used with a constant share $1 - \beta$. There is also a random term $\epsilon(m)$ that captures the (mis-)match between the precise model m and the domestic country in terms of overall productive efficiency. In log terms,

$$\ln c(m) = \ln \alpha + z(m)\beta \ln w_H + (1 - z(m))\beta \ln w_L + (1 - \beta) \ln p_I + \epsilon(m). \tag{3}$$

Car manufacturers can also resort to a different production location than the domestic market, i.e. offshore to a country where all variables are superscripted with an asterisk, and ship back to home the assembled cars, with cost τ. There is also an additional cost for operating a factory abroad by the manufacturer denoted γ. Both τ and γ take the iceberg form. Costs in the case of offshoring are given by

$$\ln c^*(m) = \ln \alpha^* + z(m)\beta \ln w_H^* + (1 - z(m))\beta \ln w_L^* + (1 - \beta) \ln p_I^* + \ln(\tau\gamma) + \epsilon^*(m). \tag{4}$$

It is convenient to introduce notation ω and κ, such that

$$\begin{aligned} \omega &\equiv \ln \left(\tfrac{w_H}{w_L} \right) \quad \text{and} \quad \kappa \equiv \ln \alpha + \beta \ln w_L + (1 - \beta) \ln p_I, \\ \omega^* &\equiv \ln \left(\tfrac{w_H^*}{w_L^*} \right) \quad \text{and} \quad \kappa^* \equiv \ln \alpha^* + \beta \ln w_L^* + (1 - \beta) \ln p_I^* + \ln(\tau\gamma). \end{aligned}$$

The choice to offshore will be driven by cost minimization, such that

$$\begin{aligned}\text{Prob(offshoring)} &= \text{Prob}\left[\ln c^*(m) < \ln c(m)\right] \\ &= \text{Prob}\left[\kappa^* + z(m)\beta\omega^* + \epsilon^*(m) < \kappa + z(m)\beta\omega + \epsilon(m)\right] \\ &= \text{Prob}\left[\epsilon^*(m) - \epsilon(m) < \kappa - \kappa^* + z(m)\beta(\omega - \omega^*)\right]. \end{aligned} \tag{5}$$

Assuming that $\epsilon^*(m) - \epsilon(m)$ is distributed logistically (which will be the case if each of those terms is distributed Gumbel) gives immediately a closed form formula for this probability of offshoring:

$$\text{Prob(offshoring)} = \Lambda\left[\kappa - \kappa^* + \beta z(m)(\omega - \omega^*)\right], \qquad \text{with} \qquad \Lambda(x) = (1 + e^{-x})^{-1}. \tag{6}$$

This equation would be estimable with a simple binary logit, were it not for a small subset of the data where models are incompletely offshored. To handle such cases we estimate instead using fractional logit.

There are three variables in equation 6 that affect the propensity to offshore. The first $\kappa - \kappa^*$ is the additional cost needed to assemble cars (to be delivered to the domestic consumer) in the home country of the brand compared to alternative assembly locations. Our regresssions will use the fixed effect of country i as a production site from our gravity equation (described in next section) as a proxy for $\kappa - \kappa^*$. The second variable in (6) is the relative costs of skilled and unskilled labor compared to the rest of world, $\omega - \omega^*$. This determinant (that we capture empirically with the level of development of the country) will make offshoring of model m more likely all the more that this model uses intensively skilled labor. Intuitively, a rich country where the *relative* price of skilled labor is low will tend to offshore models with low z. On the contrary, rich countries will keep at home the models for which they have a comparative advantage, i.e. the ones that require a lot of skilled labor. Empirically, we expect skill intensity of the model to be well proxied by the price of this model. As we describe in the next section, we must purge the prices of each model of market-level determinants (such as sales taxes).

5 The proxies for assembly costs and skill intensity

The next two subsections explain how we estimate our proxies for $\kappa - \kappa^*$, the cost disadvantage of the home country in assembly, and $z(m)(\omega - \omega^*)$, the product-level comparative advantage term.

5.1 Triadic gravity estimates of assembly costs

First, we need to estimate cost advantage in assembly of each car-producing nation. To do so, we take an equation from the multinational production model by Arkolakis et al. (2013), hereafter ARRY, to the data. Their own empirical work lacked the data variation needed to estimate the two sets of frictions present in this equation. We therefore believe this is the first empirical estimate of what we will call the "triadic gravity" equation. The triad in question is

1. The HQ country (which we think of as the design location), denoted i
2. The final assembly location, denoted ℓ
3. The country in which the car is consumed, denoted n, also referred to as the destination or market.

$X_{i\ell n}/X_n$ is the market share obtained by ℓ-made cars of i-based brands in n. ARRY's equation (7) delivers this share as the product of two factors:

$$\frac{X_{i\ell n}}{X_n} = \psi_{i\ell n}\lambda_{in}^E,$$

where $\psi_{i\ell n}$ is the probability that country ℓ is the minimum-cost location for a firm from i serving market n, and λ_{in}^E is the share of n's expenditures spent on firms from i. We can leave λ_{in}^E unspecified here because it forms part of a fixed effect in the empirical implementation of the triadic gravity.

The costs associated with delivering a car designed in i and produced in ℓ to consumers in n depend on wages denoted w_ℓ, costs $\tau_{\ell n}$ for shipping products from ℓ to n, costs $\gamma_{i\ell}$ for i-based transferring HQ inputs to factories in ℓ, T_ℓ^P, the common factor for "production technology" in ℓ, and unobserved productivity shocks, distributed multivariate Pareto with parameters θ and ρ. The probability i-based firms serving n choose ℓ as supplier is

$$\psi_{i\ell n} = \frac{\left[T_\ell^P (w_\ell \tau_{\ell n}\gamma_{i\ell})^{-\theta}\right]^{\frac{1}{1-\rho}}}{\sum_k \left[T_k^P (w_k \tau_{kn}\gamma_{ik})^{-\theta}\right]^{\frac{1}{1-\rho}}}. \tag{7}$$

We can therefore express market shares as a function of two frictions and two sets of fixed effects:

$$\frac{X_{i\ell n}}{X_n} = \exp\left[\mathrm{FEP}_\ell + \mathrm{FES}_{in} - \frac{\theta}{1-\rho}(\ln \tau_{\ell n} + \ln \gamma_{i\ell})\right]$$

The production (P) and sales (S) fixed effects (FE) have structural interpretations with,

$$\text{FEP}_\ell = (1-\rho)^{-1}(\ln T_\ell^P - \theta \ln w_\ell)$$

$$\text{FES}_{in} = \ln \lambda_{in}^E - (1-\rho)^{-1} \ln \left[\sum_k T_k^P (w_k \tau_{kn} \gamma_{ik})^{-\theta} \right]$$

Since FEP_ℓ summarizes productivity relative to wages, which reflect opportunity costs of producing in other sectors, we think of it as the *cost advantage* in this industry. The next step is to parameterize the two frictions, $\tau_{\ell n}$ between factory and buyer, $\gamma_{i\ell}$ between HQ and factory. Let $\mathbf{D}$ represent the vector of five common friction determinants

- Home ($\times\text{OECD}_\ell/\text{LDC}_\ell$): the reverse of a border effect.
- Distance & Contiguity, standard measures of spatial separation
- $\text{RTA}_{\ell n}$, regional trade agreements such as NAFTA, EU, etc.

Denoting the corresponding vector of marginal costs for trade and production as $\mathbf{g}^T$ and $\mathbf{g}^P$, trade and multinational production frictions are given by

$$\tau_{\ell n} = \exp(\mathbf{D}'_{\ell n}\mathbf{g}^T), \qquad \gamma_{i\ell} = \exp(\mathbf{D}'_{i\ell}\mathbf{g}^P)$$

The triadic gravity estimating equation is therefore obtained by substituting the frictions terms for τ and γ, yielding

$$\frac{X_{i\ell n}}{X_n} = \exp\left[\text{FEP}_\ell + \text{FES}_{in} - \frac{\theta}{1-\rho}\mathbf{D}'_{\ell n}\mathbf{g}^T - \frac{\theta}{1-\rho}\mathbf{D}'_{i\ell}\mathbf{g}^P\right]$$

We use quantity shares $Q_{i\ell n}/Q_n$, with $Q_n \equiv \sum_i \sum_\ell Q_{i\ell n}$ in place of unobserved *value* market shares $X_{i\ell n}/X_n$. Acknowledging unobserved/imperfectly measured frictions determinants, the moment condition we want to estimate is

$$\mathbb{E}\left[\frac{Q_{i\ell n}}{Q_n}\right] = \exp\left[\text{FEP}_\ell + \text{FES}_{in} + \mathbf{D}'_{\ell n}\widetilde{\mathbf{g}}^T + \mathbf{D}'_{i\ell}\widetilde{\mathbf{g}}^P\right] \tag{8}$$

where the $\widetilde{\mathbf{g}}$ coefficients multiply $\mathbf{g}$ by $-\theta/(1-\rho)$.

Comparing this to ARRY equation (22), we see that their specification features $i\ell$ fixed effects which absorb $\gamma_{i\ell}$. Because T_ℓ^P, w_ℓ and $\gamma_{i\ell}$ enter multiplicatively in the numerator of (7), a structural $i\ell$ fixed effect is separable into ℓ terms and $\gamma_{i\ell}$ if one is willing to parameterize $\gamma_{i\ell}$. However, ARRY only have data on exports for affiliates from one origin, the USA,

courtesy of the BEA. This data limitation implies that $\gamma_{i\ell}$ is not identified in the presence of ℓ fixed effects.

A further advantage of our dataset concerns destination markets n. BEA data used by ARRY have just five specified destinations: USA, CAN, JPN, GBR, and a 14-country European Union composite. Our estimation includes 20 HQ countries, 49 producing, and 73 consuming countries. Thus we have the requisite HQ-assembly variation to identify $\gamma_{i\ell}$ and much more variation for estimating the effects of the five determinants of $\tau_{\ell n}$. It should be noted, however that a large fraction (72%) of the final estimating sample has $Q_{i\ell n} = 0$.

Taking triadic gravity to the data requires an error term. If we assumed a multiplicative error term distributed as a homoskedastic log-normal then we could take logs and estimate the MLE via OLS. Santos Silva and Tenreyro (2006) argue that we should prefer estimators that are consistent under weaker assumptions on the error term, such as the Poisson pseudo-MLE (PPML).This estimator has the additional advantage of keeping the zeros in the regression. We estimate this condition using PPML with market shares as the dependent variable. Our estimator is equivalent to the multinomial pseudo-MLE proposed by Eaton et al. (2012).[13] We have 14 years of data so we estimate the model with ℓt and *int* fixed effects. To deal with the large number of FEs, we use the **poi2hdfe** estimator provided by Paulo Guimaraes (with Pedro Portugal).

Table 2: Triadic gravity trade and MP frictions estimates. Dependent variable: {HQ i, made-in-ℓ} market shares in n

	trade $\tau_{\ell n}$	MP $\gamma_{i\ell}$
home (OECD)	1.965^a	3.453^a
	(.312)	(1.294)
home (LDC)	5.555^a	5.236^a
	(.603)	(.909)
ln distance	$-.639^a$	.217
	(.131)	(.345)
contiguity	$.372^b$	.221
	(.181)	(.457)
RTA	1.312^a	.892
	(.206)	(.606)

164,196 observations (20 HQ, 49 assemblers, 73 markets, 14 years). Poisson with ℓt and *int* fixed effects. Significance levels: c: $p < 0.1$, b: $p < 0.05$, a: $p < 0.01$.

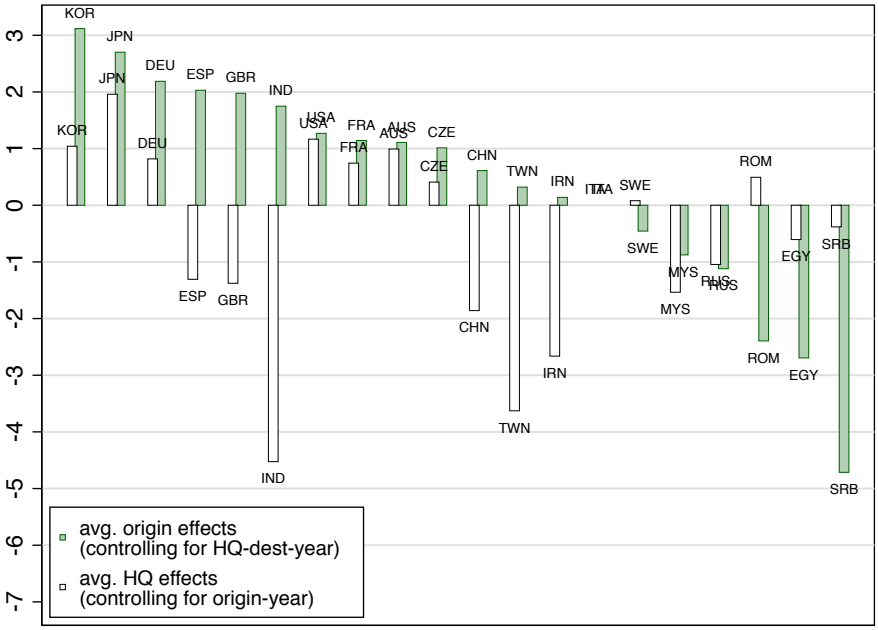
[13]Notes by Sebastian Sotelo establish that the MNPML can be estimated with using *poisson* with the market share as the dependent variable and including a full set of origin and destination fixed effects. Head and Mayer (2014) show that the estimator performs well under a fairly wide range of error term structures.

Table 2 provides results of our triadic gravity regression. The display is organized such that the first column shows results related to $\tau_{\ell n}$, while the second show the ones for $\gamma_{i\ell}$, all variables being included in the same regression that also includes the full set of production(-time) and HQ-destination(-time) fixed effects. The most impressive coefficients relate to the home dummies, which point to very large advantage of producing at home. This is true both in terms of producing where the markets are (first column), and for operating an assembly plant in the same country where the brand is headquartered. For both variables, the revealed effects on market share are very large: Sales in a OECD market are 7 times larger if the car is assembled locally, and 32 times larger when the production country is also the HQ country. The LDC home coefficients imply essentially that production has to be home-based for market shares to be lifted out of the negligible area. The other $\tau_{\ell n}$ frictions have the usual sign and imply overall that even outside national borders, proximity is important for market shares in the car industry. Small distance and membership of a regional agreement are both important aspects of sales performance, with RTA multiplying market shares by nearly a factor of four on average. This last determinant is also positive and large for $\gamma_{i\ell}$, but less significant. Distance and contiguity seem, on the other hand, to have no significant effects on coordination costs, once one departs from national borders.

We want to estimate a cost advantage in assembly effect, $\text{FEP}_{\ell t}$, for each headquarter country. There is an analogy with worker and firm fixed effects often used in employer-employee data sets (Abowd et al. (1999)-style regressions), as with the "places vs people" issue in economic geography. Identification is impossible without a certain degree of *overlap*. In the case of workers, that means one needs either simultaneous dual-job holders or job-switchers. In labour markets only the latter source of variation is common. Fortunately, both sources of overlap are amply available in the car data. The United States as a production country makes American, German, and Japanese brands along with smaller levels of production of other brands. Meanwhile, Japanese brands are assembled in 31 different countries.

There is one outright failure to identify a country effect. Norway only made a home-based brand (TH!NK). Identification is possible but still somewhat problematic in a case like Bulgaria, which produces only Chinese brands. Figure 8 reports our results where for each country we average the FEP_ℓ and FES_{in} obtained from the estimation of equation 8. This results in two bars for each country, one giving the advantage of the country as an assembly site, the other one summarizing the strength of its brands through its position as a headquarter (Italy serving as the reference country in both cases which is why it is set to zero). Each effect is identified by overlap: the origin (production) country effect is identified on the performance of "non-local" brands (Ford or Honda exporting from the UK

Figure 8: The best assembly and HQ countries for cars



for instance). Bars are ranked in decreasing order of the production effect.

Results show that Korea, Germany, Japan and the United States for instance, rank high both as production sites and as headquarters of high performance brands (relative to Italy). The UK is revealed to be a better production place than the US, but headquarters weaker brands. This may seem surprising if one thinks of brands such as Jaguar, Aston Martin, etc. and compares to Chevrolet, Plymouth, etc. However, the regression identifies a high quality brand based on performance by a given brand produced in multiple countries. The UK brands only perform well when produced in the UK. The luxury brands from the UK are further penalized by the fact the dependent variable is measured in quantity, rather than value, shares.

Emerging economies such as Malaysia or Russia perform negatively on both metrics. Romania is an interesting case since the regression reveals it to be a quite bad location for assembling cars, other than for the local brand, Dacia. In 2013, There was only one assembly plant other than the one producing Dacias (and re-badging some of those as Renaults, the owner of Dacia). This plant was shipping one model of Ford for a set of essentially European countries. Therefore our regression is identifying the production FE for Romania as the relative bad performance of Fords and (re-badged) Renaults assembled in Romania compared to other production locations for those brands.

5.2 Model-level measure of skill intensity

To obtain a model-specific component of prices, denoted $\ln p_m$, we need to purge the raw retail price data of the destination-specific factor. This is necessary because there are *large destination n-level price effects*. For examples, a given model is generally much more expensive in Denmark than other countries. We have 81,727 observations of $\ln p_{mnt}$ for a set of 1777 models and 28 destinations markets. Therefore we run a two-dimension fixed effects regression:

$$\ln p_{mnt} = \text{FEM}_m + \text{FEN}_{nt} + \epsilon_{mnt} \tag{9}$$

With 14 years and 28 countries, there would in principle be 392 destination-years with a full data set. However, the price data is much more sparse. The maximum is 268 with a mean of 46, and a median of nine. The minimum is two.

We define $\ln p_m \equiv \widehat{\text{FEM}}_m - \text{mean}(\widehat{\text{FEM}}_m)$ as the deviation of the model fixed effect from the mean across all models. This normalization is useful because it allows us to interpret the base effects in regression specifications with interactions.

The fixed effects used to estimate $\ln p_m$ are available for 1112 brand-model combinations. For the 999 remaining distinct brand-models that do not have fixed effects, we use the average within the brand for the segment (14 function-size-price segments identified using Polk). For brands that are not represented in a given segment we use the average for all the models in that segment.

6 Estimates of offshoring probability equation

The dependent variable in the narrow-definition offshoring regression specification is the *fraction* of i-brand, model m *sales in* i assembled in a country with *20% lower per capita income* than i. Broad offshoring down is the fraction of i-brand, model m world-wide sales assembled in countries with 20% lower per capita income.[14]

Equation (5) suggests the use of fixed effects for the headquarter country to capture $\kappa - \kappa^*$ embodying the production cost difference between the home country of the brand and also cost of delivering the product to domestic consumers, and of managing a foreign affiliate ($\tau\gamma$). In this case, it is possible to estimate the effects of z, the skill intensity of the model, captured empirically by its price, and the interaction of z with our measure of difference in comparative advantage in cars, captured by income per capita. The problem with this specification is that many of those fixed effects are perfect predictors of whether or not to offshore. Since the coefficients in linear regressions on binary dependent variables

[14]Note that both the numerator and the denominator of broad offshoring are defined more expansively.

are normally quite proximate to the average marginal effects obtained by logit or probit regressions, we run a first set of LPM regressions.[15]

The first two columns of Table 3 keep offshoring decisions independently of where the model is headquartered, whereas the last two columns limit the sample to OECD countries. In each of those samples, we further distinguish between narrow and broad offshoring. A first result is that high-priced models are less likely to be offshored, specially when the broad definition is applied, in which case a doubling of the price results in a drop of the probability of producing in a low wage country by nearly 30 percentage points. Our main variable of interest is the interaction between the price of the model and income per capita. A ten percent increase in income results in an 1.5% larger effect (in absolute value) of the price. This supports our hypothesis that rich countries have a comparative advantage in skill-intensive models, which results in a lower propensity to source those from abroad as income rises.

The linear offshoring specification does not take into account that offshoring fractions cannot exceed one or fall below zero. Table 4 shows that in the vast majority of cases the offshoring fraction is zero or one, i.e. at the boundaries of the permissable range, which suggests to also run a logit estimation. The logit also allows the marginal effects to depend on the probability of offshoring. Since Table 4 shows that 1% (narrow definition) and 15% (broad definition) of offshoring fractions lie between 0 and 1, we use *fractional logit* as our estimation method rather than standard logit, which expects a truly binary dependent variable.

Under this specification, offshoring of model m in year t is a function of two variables obtained from the triadic gravity equation , which replaces the headquarter-year fixed effects: $\widehat{\text{FEP}}_{it}$ and $\ln(\tau_{it}\gamma_{it})$, with τ_{it} and γ_{it} being calculated as the average of the predicted bilateral frictions when taking coefficients from Table 2. As in the linear specification, $\ln p_m$, and its interaction with $\ln y_{it}$ are estimated, and the omission of headquarter-time effects also allows identification of $\ln y_{it}$. Additional explanatory variables are included to capture scale effects (worldwide sales of model and brand) and vintage effects (age of model and years left in program). We also include 13 function-size-price segment dummies and 13 year dummies.

Table 5 provides our estimates of the fractional logit regressions. Columns (1) to (3) consider all models, whereas the last two columns eliminate models associated with non-OECD brands. The first specification is a linear model, which we use as a starting point. We then move to our preferred fractional logit results in column (2) . In both specification the assembly cost advantage of the headquarter country strongly reduces the likelihood of offshoring. The interaction between price and income is negative as expected in both the

[15] McCalman and Spearot (2013) estimate a linear specification along these lines.

Table 3: Offshoring regressions—Linear regressions

sample:	all HQ countries		only OECD HQ	
market:	home	all	home	all
ln model price ($\ln p_m$)	-0.086^a	-0.281^a	-0.044	-0.296^a
	(0.025)	(0.032)	(0.039)	(0.046)
ln brand sales	0.013^a	0.019^b	0.018^a	0.024^b
	(0.005)	(0.008)	(0.006)	(0.009)
age of model	-0.001	-0.000	-0.002	0.000
	(0.002)	(0.003)	(0.003)	(0.004)
years left to model	0.005^b	0.012^a	0.007^b	0.016^a
	(0.002)	(0.003)	(0.003)	(0.004)
ln model sales	-0.001	-0.010^b	-0.001	-0.010^c
	(0.002)	(0.005)	(0.002)	(0.005)
$\ln p_m \times \ln y_{it}$	-0.048^a	-0.114^a	-0.130^a	-0.156^b
	(0.011)	(0.016)	(0.040)	(0.065)
Observations	9779	14722	7436	12095
R^2	0.230	0.305	0.222	0.274
count of models	1494	2109	1043	1597

Note: Brand-clustered standard errors in parentheses. Significance levels: c: $p < 0.1$, b: $p < 0.05$, a: $p < 0.01$. Additional controls not reported here: headquarter-year and segment fixed effects.

Table 4: Offshoring fractions: narrow vs broad

Fraction of	Home sales		World sales	
model-years offshored	Count	Percent	Count	Percent
all	1,296	8.79	4,663	31.64
majority	46	0.31	613	4.16
minority	133	0.90	1,448	9.83
none	8,318	56.45	8,012	54.37
n/a*	4,943	33.54		

* n/a occurs under the narrow definition of offshoring because of model-years not sold in the home market of the model's brand.

linear and logit regressions. The statistical significance of the effect is much greater in the logit. The interpretation of interaction terms is complicated by the non-linearity of the logit model.[16] The best way to understand these effects is through graphical display. The marginal effects of model price and income are displayed in Figure 9. In panel (a) we see that for low income countries the marginal effect of higher price is approximately zero. This is telling us that poor countries are unlikely to offshore *any* models, regardless of their price. This fact is illustrated in Figure 10 where we see the model predicts and the data depicts the absence of offshoring by poor countries.

The marginal effect of a higher price remains near zero until relatively high levels of GDP per capita are achieved. For countries with incomes over that of Czech Republic in 2013, the marginal effect becomes increasingly negative. For the highest income HQ country (Australia in 2013), increasing the price by 10% decreases the likelihood of offshoring by two percentage points. This should be seen as a large effect given that the average probability of offshoring is just six percent. The histogram of per capita incomes shown below the marginal effects in Panel (a) reveals that a large fraction of the models in our sample are produced in countries whose incomes are high enough to yield negative marginal effects.

Panel (b) of Figure 9 displays the marginal effects of higher income conditional on price. There are large positive effects for inexpensive cars and negative effects for very expensive cars. The switchover point from positive to negative effect occurs at a price level that most of us would consider luxurious. As the histogram below panel (b) indicates, such high priced models are relatively uncommon. For the vast majority of models, higher income countries are *more* likely to engage in offshoring.

Our regressions incorporate dummies for the market "segment" of each model. We classified all models into 14 segments based on three categorical variables provided by IHS:

[16] See Ai and Norton (2003) for a fulsome discussion.

Table 5: Offshoring regressions

	(1)	(2)	(3)	(4)	(5))
method:	OLS		Fractional logit		
sample:	all HQ countries			only OECD HQ	
market:	home (*narrow*)		all	home	all
HQ comp. adv. ($\widehat{\text{FEP}}_{it}$)	-0.024^c	-0.545^b	-0.204	-0.542^b	-0.371^b
	(0.012)	(0.226)	(0.136)	(0.243)	(0.155)
Frictions ($\ln \tau_{it}\gamma_{it}$)	-0.029	-1.461^b	-0.013	-1.574^b	-0.188
	(0.029)	(0.724)	(0.278)	(0.781)	(0.411)
ln model price ($\ln p_m$)	-0.026	-0.174	-1.690^a	-0.623	-2.162^a
	(0.023)	(0.589)	(0.253)	(0.945)	(0.304)
ln brand sales	0.008	0.197	0.224^b	0.161	0.215^b
	(0.006)	(0.159)	(0.091)	(0.156)	(0.088)
age of model	0.000	-0.012	0.011	-0.023	0.001
	(0.002)	(0.046)	(0.027)	(0.053)	(0.028)
years left to model	0.005^b	0.078^b	0.085^a	0.073^c	0.088^a
	(0.003)	(0.037)	(0.024)	(0.041)	(0.025)
ln model sales	0.003	0.031	-0.051^c	0.033	-0.050
	(0.003)	(0.049)	(0.030)	(0.052)	(0.033)
ln GDP/cap ($\ln y_{it}$)	0.063^a	3.564^a	1.122^a	2.592^a	0.237
	(0.016)	(0.898)	(0.242)	(0.990)	(0.339)
$\ln p_m \times \ln y_{it}$	-0.028^b	-1.974^a	-0.937^a	-1.445	-0.560
	(0.013)	(0.749)	(0.227)	(1.245)	(0.488)
Observations	9271	9271	14189	7426	12084
R^2	0.092	0.206	0.285	0.195	0.273
model count	1461	1461	2074	1042	1596

Note: Brand-clustered standard errors in parentheses. Significance levels: c: $p < 0.1$, b: $p < 0.05$, a: $p < 0.01$. Additional controls not reported here: year, segment, scale, vintage

Figure 9: Marginal effects of interacting comp. adv. factors

(a) Model price (b) GDP per capita

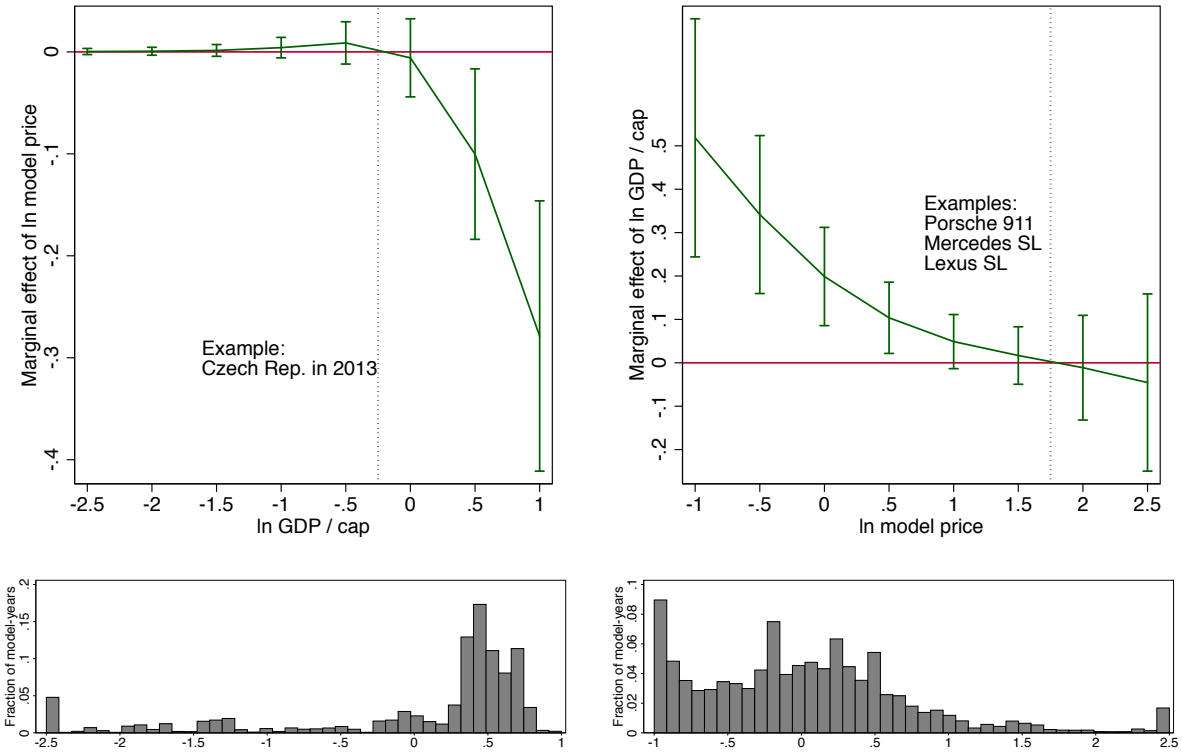
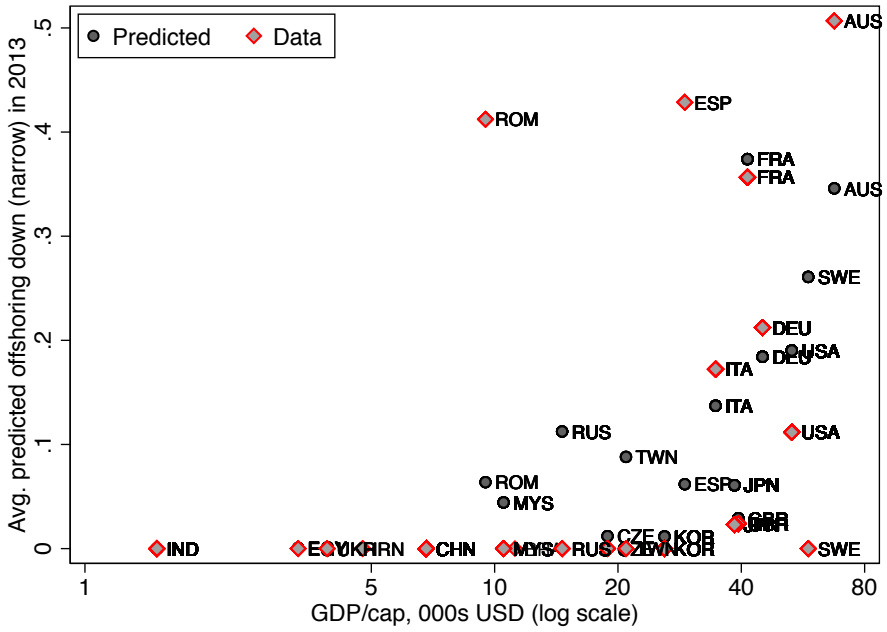


Figure 10: Offshoring is for the rich



- Function/usage (SUV, MPV, sport car, etc.) referred to in the data set as "Global Sales Sub-segment"
- Size categories (A–F), measured in length, but relative to the corresponding functional category. In the data this is called the "Global Sales Segment."
- Price class: entry/mid-level (1), premium (2), luxury (3). The first two are defined relative to size and function categories; luxury is a stand-alone segment. This variable is called the "Global Sales Price Class."

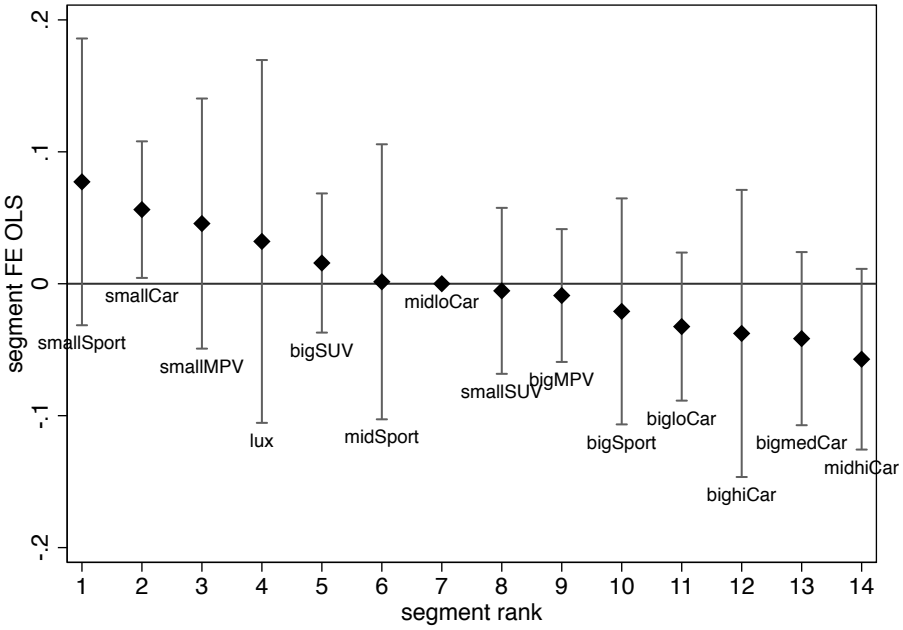
Table 6: Size of 14 categories (2000–13 totals)

Category	*Value ($bn)*	*Volume (mn)*	*Price($th)*	*Brands(#)*
midloCar	5906.20	251.16	23.52	88
bigSUV	4273.56	67.87	62.97	82
smallCar	2891.35	181.62	15.92	88
smallSUV	1844.00	54.81	33.64	80
midhiCar	1659.16	48.24	34.39	37
bigMPV	1287.40	33.85	38.03	46
smallMPV	1229.24	53.46	22.99	50
bigmedCar	1107.06	21.36	51.83	24
bighiCar	324.98	2.83	115.03	10
bigloCar	305.17	9.61	31.77	31
midSport	215.03	6.01	35.77	23
bigSport	199.87	2.28	87.56	25
smallSport	69.92	2.68	26.09	24
lux	55.11	0.24	228.98	16

We provide some basic information on the 14 segments in Table 6. The table sorts the segments by an estimate of worldwide sales values in that segment. The quantities come from our main data set but the average prices for each segment are estimated based on much more limited data. We see that segments are very different in size. Thus a firm can achieve high market share in the "lux" (luxury) category with much lower volume of sales than in the "midloCar" segment. The dominant feature of this figure is that smaller cars are more offshoreable. This effect is above and beyond the fact that smaller cars are cheaper since we have controlled separately for price at the model level. This could be due to lower shipping costs for smaller cars and lower import tariffs (which are generally positively associated with larger engine sizes). More speculatively, smaller cars may be less skill-intensive.

The segment-level fixed effects are displayed in Figure 11, where mid-sized, low price cars

Figure 11: Segment-level effects of offshoring rates



(midlocar) are taken as the benchmark.[17]

It is interesting to compare our results to those of McCalman and Spearot (2013). They find variety-level scale effects. In particular trucks produced at above-median scale are *less* likely to be offshored, the opposite of their prediction. We cannot think of any microeconomic underpinnings for dichotomizing scale and therefore measure it as log world-wide sales (in units) of the model. It has small and statistically insignificant effects. On the other hand brand-level scale is a positive predictor of board offshoring, a result that is consistent with the mechanism of Helpman et al. (2004).

A second variable for which we can compare results is the "vintage" of a model. McCalman and Spearot (2013) find that varieties less likely to be offshored in their first year of production. The story attached to this result is that older varieties have more routinized production methods which facilitate offshoring. However, recent work by Hanson finds a negative relationship between offshoring and routinization. We find that model age has effect that is small and not statistically different from zero.

Our price results are quite different from McCalman and Spearot (2013). They find that only price residuals matter and they enter negatively. Our data lacks the features of models that might be used to estimate price residuals. However, we find that prices themselves have negative impacts on offshoring, provided the per-capita income of the home country is high

[17] As can be seen in Table 6, midlocar is the by far largest segment by volume.

enough.

The chief finding of McCalman and Spearot (2013) is that complexity reduces offshoring. They measure complexity using variation in a large vector of features. Our data contains no direct analogue. However, we conjecture that if we did have variation in features, it would be higher for higher priced cars.

McCalman and Spearot (2013) have data on US and Mexico only so they cannot estimate the role country-specific "assembly advantage" as we do here. Also they cannot estimate the interaction between country development and model prices. Furthermore, as their data set has sales in Canada and US only, they cannot calculate our "broad" measure of offshoring.

7 Conclusion

Offshoring assembly to lower wage countries is growing but it remains limited in several ways. First, the magnitude of offshoring to lower wage countries is small, accounting for just eight percent of the home country's market. Furthermore, the lower wage countries in question generally do not include the countries best known as offshoring sites for other industries. Car makers produced in China mainly for the Chinese market. For making cars for the home or third-country markets, the preferred assembly locations appear to be Mexico (for serving the North American market) and the Eastern European countries that entered the European Union in 2004. The other sense that offshoring is limited is that it is highly concentrated among a few firms. The top 5 brands in any given year account for about two thirds of narrow offshoring.

Broad offshoring down is much bigger (40% of global production) but often motivated by market access. There appears to be a *double penalty of offshoring*: γ frictions give a cost disadvantage to factories outside the home country and τ frictions add further costs on the cars when they are imported back into the home market. The only force militating in favour of offshoring by the narrow definition is comparative disadvantage at home. We therefore hypothesized that comparative advantage should play a major role in determining why some models are offshored and others not. We found that estimates of HQ country *comparative disadvantage* in car assembly are strong negative predictors of narrow offshoring but have weaker effect on broad offshoring. This makes sense given that broad offshoring undoubtedly includes much production abroad that is oriented towards market access in the host country.

Looking within countries we find that *low-price* models from a *high-income* country are the most likely to be offshored. A traditional Heckscher-Ohlin interpretation of this result is that price is acting as proxy for skill intensity and per capita income is a proxy for relative skill abundance. Alternatively, it could be that high price is measure of quality, which high

income countries have a comparative advantage in supplying (see Schott (2004) and others). Prices also capture markups of course there is an intuition that low markups and competition "force" them to be offshored. However, a cost minimizing firm should still want to produce its high-markup models in the low-cost location.

References

Abowd, J., Kramarz, F., Margolis, D., 1999. High wage workers and high wage firms. Econometrica 67 (2), 251–333.

Ai, C., Norton, E. C., 2003. Interaction terms in logit and probit models. Economics letters 80 (1), 123–129.

Arkolakis, C., Ramondo, N., Rodríguez-Clare, A., Yeaple, S., 2013. Innovation and production in the global economy. Tech. rep., National Bureau of Economic Research.

Barba Navaretti, G., Ottaviano, G., 2015. Made in Torino? Fiat, Chrysler and the future of industry. Il Mulino.

Dornbusch, R., Fischer, S., Samuelson, P. A., 1980. Heckscher-Ohlin trade theory with a continuum of goods. The Quarterly Journal of Economics, 203–224.

Eaton, J., Kortum, S., Sotelo, S., 2012. International trade: Linking micro and macro. Tech. rep., NBER.

Feenstra, R. C., 2004. Advanced international trade: Theory and evidence. Princeton University Press, Princeton, New Jersey.

Feenstra, R. C., Hanson, G. H., 1997. Foreign direct investment and relative wages: Evidence from Mexico's maquiladoras. Journal of international economics 42 (3), 371–393.

Head, K., Mayer, T., 2014. Gravity equations: Workhorse, toolkit, and cookbook. In: Helpman, E., Gopinath, G., Rogoff, K. (Eds.), Handbook of International Economics. Vol. 4. Elsevier, pp. 131–195.

Helpman, E., Melitz, M. J., Yeaple, S. R., 2004. Export versus FDI with heterogeneous firms. American Economic Review, 300–316.

Irarrazabal, A., Moxnes, A., Opromolla, L. D., 2013. The margins of multinational production and the role of intrafirm trade. Journal of Political Economy 121 (1), 74–126.

McCalman, P., Spearot, A., 2013. Why trucks jump: Offshoring and product characteristics. Journal of International Economics 91 (1), 82–95.

Ramondo, N., Rodríguez-Clare, A., 2013. Trade, multinational production, and the gains from openness. Journal of Political Economy 121 (2), 273–322.

Santos Silva, J., Tenreyro, S., 2006. The log of gravity. The Review of Economics and Statistics 88 (4), 641–658.

Schott, P. K., 2004. Across-product versus within-product specialization in international trade. The Quarterly Journal of Economics, 647–678.