Romer or Ricardo?

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Abstract

How much trade and growth comes from distinct varieties (Romer) versus quality differences (Ricardo)? How important is new variety creation versus creative destruction for productivity differences and growth across countries? How much growth comes from innovation at home vs. abroad? We write down a model of trade and growth featuring these forces and draw out testable implications for the behavior of export and import growth rates across product categories. We infer that Ricardian and Romerian forces are about equally important for trade and growth overall. But the U.S. innovates mostly by creating new varieties and improving its own products, whereas developing countries such as China grow mostly by creatively destroying the products of rich countries. For small countries the vast majority of growth comes from innovation abroad.

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1 Introduction

Many theories of growth revolve around the creation of new varieties in the vein of Romer (1990). Other theories feature quality improvements upon existing varieties, often involving creative destruction, such as in Aghion and Howitt (1992) and Grossman and Helpman (1991a). These same branches coexist in the trade literature. Krugman (1980), Rivera-Batiz and Romer (1991), and Melitz (2003) model trade in horizontal varieties. Grossman and Helpman (1991a,b) and Eaton and Kortum (2002), and Bernard et al. (2003) emphasize trade due to vertical differentiation in quality and productivity across countries.

The Melitz and Eaton-Kortum branches continue to thrive alongside each other. This begs the question: how important are differentiated varieties versus Ricardian productivity differences in accounting for trade flows? How much do varieties versus quality levels contribute to aggregate productivity differences across countries? How much of a given country's growth comes from innovations abroad versus at home?

We write down a model of trade and growth featuring both Melitz variety and Eaton-Kortum quality ladder components. New varieties and quality improvements arrive exogenously in the model; we use the model to identify the telltale signs each force should leave in the data. More specifically, we look at export and import growth rates by country and product category. New varieties will tend to show up as new export categories or rapid export growth in a category in the country that develops them. Creative destruction of another country's products, in contrast, will fuel simultaneously positive export growth and negative import growth in a country-category. More subtly, quality improvements on existing products within a country lead to modest export growth without a concomitant shrinkage of imports.

We conduct indirect inference by simulating a model of 20 trading economies, and comparing its quantitative predictions to data on trade flows at the 4-digit SITC level in 20 countries from 1991 from Feenstra et al. (2005). These 20 countries (one of which is actually the EU) account for about 95% of world trade. We use the moments from the Feenstra et al. (2005) dataset to infer the rate of new variety creation and creative destruction on imported products for each country.

We arrive at five key findings. First, a modest majority of trade is Ricardian (59%) rather than the Romerian (41%). Second, products typically migrate from advanced countries to developing countries via creative destruction over their life cycle. For example, 96% of U.S. exports are Romerian, whereas 76% of Chinese exports are Ricardian. Third, income differences stem from differences in the the number of varieties produced rather than differences in average product quality. Fourth, growth comes almost equally from new products (56%) and quality improvements on existing products (44%). Fifth and finally, around one-half (45%) of growth comes from innovations abroad, though less for the U.S. (20%) and more for small countries (80% to 90%).

Our effort relates to a number of prior studies. Feenstra and Rose (2000) identify the pattern of products being first produced by advanced nations before diffusing or switching to developing countries. Autor, Dorn and Hanson (2013, 2016) document the impact of competition from Chinese imports on U.S. production. Martin and Mejean (2014) demonstrate the impact of low-wage competition on the quality of products exported by France.

Hsieh, Klenow and Nath (2020) use a two-country model with only creative destruction to study the impact of cross-country idea flows on the gains from trade. We generalize their model to many countries, allow new variety creation, and try to answer a different set of questions. Like us, Buera and Oberfield (2020) study the role of international trade in technology diffusion and overall growth in a multi-country setting. Their focus is on conditions that yield a Fréchet distribution and hence fall into the Eaton-Kortum class of Ricardian trade. Perla, Tonetti and Waugh (2021) incorporate both variety creation and quality growth, but do not incorporate international technology diffusion. Importantly, none of these studies looks at the dynamics of import and export growth across categories within countries to shed light on the sources of trade and growth.

The rest of the paper is organized as follows. Section 2 lays out our multi-country model of trade with variety creation and quality growth. In Section 3 we describe how we infer the sources of innovation in each country from the distribution of export and import growth. Section 4 lays out the trade and TFP data we use. In Section 5 we present our parameter estimates, and in Section 6 we draw out their implications for the sources of trade, TFP levels, and TFP growth across countries. We offer Conclusion in Section 7.

2 Model

This section presents a model of trade and growth. The static trade model is a composite of a model of trade in differentiated products and trade from comparative advantage. In the dynamic model countries innovate by climbing up quality ladders and by introducing new products. The share of trade in differentiated products vs. the share of trade from comparative advantage is an endogenous outcome of the creation of new products by the country and the rate at which it steals products from other countries.

2.1 Static equilibrium

Aggregate consumption in country k is given by a CES combination of products

$$C_k = \left(\sum_{j \in W} \sum_{i \in J_{jk}} \left(q_{ij}\, C_{ijk} \right)^{1-\frac{1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

where C_{ijk} is consumption of product i from country j sold in country k, q_{ij} is quality (or equivalently process efficiency), J_{jk} is the set of country j's products sold in country k, and W is the set of countries in the world.

We assume a product is made with one unit of labor and that firms pay a fixed cost f in units of domestic labor to sell that product in the domestic market. The overhead cost allows the highest quality producer to charge the monopoly markup $\frac{\sigma}{\sigma-1}$, as the next lowest quality competitor will be deterred by zero ex post profits under Bertrand competition. The overhead cost also determines the cutoff quality – varieties below the threshold have negative present discounted value, and therefore exit endogenously. The cutoff rises endogenously with wage growth, which ensures that the distribution of quality across varieties is stationary.

The corresponding fixed cost of selling a product in the foreign market is f in units of labor of the destination country. The product will only be sold in country k when gross profits exceeds the fixed cost of selling in country k. After we impose profit maximization, the cutoff quality q_j^k in the foreign market is

$$q_j^k \equiv \frac{\sigma}{\sigma-1}\frac{w_j\,\tau_k^{\frac{\sigma}{\sigma-1}}}{P_k}\left[\frac{f(\sigma-1)\left(1-\frac{\tau_k-1}{\tau_k}x_k\right)}{L_k}\right]^{\frac{1}{\sigma-1}} \quad \text{for } k \neq j \tag{1}$$

where w_j denotes the nominal wage in country j, P_k is the CES price index in country k, $\tau_k \geq 1$ is the gross trade cost faced by all countries (except for producers in country k) selling to country k, x_k is the trade share in country k's output, and L_k is total labor supply in country k. The cutoff quality for domestic producers q_j^j is also given by equation 1 after τ_k outside the square brackets is set to 1. The cutoff quality q_j^k is increasing in the source country's wage w_j and decreasing in the destination country's size L_k. A rising wage in the producer's country thus also increases the quality cutoff for products imported from that country and induces the endogenous exit of low quality imports.

We now distinguish between "Romerian" and "Ricardian" products. Country j's Romerian products are products where only country j has the blueprint. As in Melitz (2003), a Romerian product is sold in every market where the profit covers the fixed cost. The set of countries where this is the case is defined by

$$K_{ij}^{Rm} \equiv \{k \in W \,|\, q_{ij} > q_j^k\} \tag{2}$$

where the cutoff q_j^k is given by equation 1. Product i from country j is sold in more countries when q_{ij} is larger, the wage of the exporting country w_j is lower, and the destination country is larger.

A Ricardian product is one where more than one country has the blueprint. A Ricardian product from j is sold in country k if two conditions are met. First, as is the case with a Romerian product, profits have to exceed the fixed cost. Second, as in any model of trade from comparative advantage, country j also has to be the lowest cost seller among all the countries with the blueprint for the same product. The set of countries in which country j sells a Ricardian product i is thus defined as:

$$K_{ij}^{Rd} \equiv \left\{ k \in W \,\middle|\, j = \arg\min_{\ell \in \tilde{K}_{ik}} \left\{ \frac{\tau_k \, w_\ell}{q_{i\ell}} \right\} \right\} \tag{3}$$

where $\tau_k = 1$ for $j = k$ and $\tilde{K}_{ik}$ denotes the set of countries with blueprints for product i and where $q_{i\ell}$ exceeds the threshold for selling in country k.[1]

The set of products country j sells to country k is then given by

$$J_{jk} \equiv \{i \in P_j^{Rm} \,|\, k \in K_{ij}^{Rm}\} \;\cup\; \{i \in P_j^{Rd} \,|\, k \in K_{ij}^{Rd}\} \tag{4}$$

where P_j^{Rm} and P_j^{Rd} denote the set of country j's Romerian and Ricardian products and the sets K_{ij}^{Rm} and K_{ij}^{Rd} are defined by equations 2 and 3. The first term in equation 4 denotes country j's Romerian products sold in country k; the second term are j's Ricardian products where country j is the lowest cost supplier in country k.

The distribution of wages in the world is pinned down by each country's set of products P_j^{Rm} and P_j^{Rd}, the quality cutoffs of each bilateral pair given

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[1] Formally $\tilde{K}_{ik} \equiv \{\ell \in W \,|\, q_{i\ell} > q_j^k\}$.

by equation 1, the pattern of trade defined by equations 2, 3, and 4, and the condition that aggregate labor demand is equal to labor supply and total exports is equal to total imports of each country. Given a distribution of wages around the world, the real consumption wage is then given by

$$\frac{w_k}{P_k} = \frac{\sigma-1}{\sigma} M_k^{\frac{1}{\sigma-1}}\, \tilde{q}_k$$

where M_k is the number of products sold in country k and

$$\tilde{q}_k \equiv \left[\frac{1}{M_k} \sum_{j \in W} \sum_{i \in J_{jk}} \left(\frac{w_k}{w_j\, \tau_k}\, q_{ij} \right)^{\sigma-1} \right]^{\frac{1}{\sigma-1}}$$

is the quality of the representative product consumed in country k weighted by the relative wage and the trade cost. For a given distribution of trade cost and relative wages, the real wage is increasing in the number of products consumed and the power mean of the quality of these products.

2.2 Innovation

We now introduce dynamics. Aggregate growth comes from moving up the quality ladder of existing products, as in Grossman and Helpman (1991a), Aghion and Howitt (1992), and Klette and Kortum (2004), and from the creation of new products, as in Romer (1990). Both types of innovation can come from domestic as well as foreign innovators.

Table 1 summarizes the arrival rates of innovation from innovators in country j. Domestic innovators improve upon domestic products with probability λ_j *for each produced variety*. Domestic innovators also innovate upon imported products with probability δ_j *for each imported variety*. The quality drawn by both types of innovation follows a Pareto distribution with shape parameter θ and a scale parameter equal to the existing quality level. Thus, the proportional step size of innovation on a given variety follows a Pareto distribution

Table 1: Channels of Innovation in Country j

	Probability
Innovation on domestic products	λ_j
Innovation on imported products	δ_j
Creation of new products	κ_j

Note: The average step size for quality improvements on domestic and imported products is $\left(\frac{\theta}{\theta-(\sigma-1)}\right)^{1/(\sigma-1)} \geq 1$. The quality of a new variety is drawn from the quality distribution of existing products produced by country j.

with shape parameter θ and scale parameter 1. The average proportional improvement in quality on an existing variety, conditional on innovation, is thus $\left(\frac{\theta}{\theta-(\sigma-1)}\right)^{1/(\sigma-1)} > 1$. Domestic innovators also create brand new varieties at rate κ_j. This arrival rate is for each of the country's produced varieties, and the quality of a new variety is drawn randomly from the quality distribution of these products.

Table 2 shows the arrival rate of quality improvements on existing products and of new products in country j implied by the innovation rates in Table 1. Quality improvements and new products can come from innovation by domestic firms (shown in column 1) and foreign firms (shown in column 2). The first row shows the probability that a product exported by country j moves up its quality ladder. The odds this occurs from domestic innovation is λ_j, and a domestic innovator will always replace the domestic incumbent with probability 1. The quality of an exported product can also increase from foreign innovation, and the probability a foreign innovator innovates upon this product is δ_k when the foreign country imports this product. But the foreign innovator will not necessarily replace the domestic incumbent, as this also depends on the relative wage and the trade cost. Since the quality step size follows a Pareto distribution, the probability that the quality improvement from the innovator in foreign country k is large enough to replace the incumbent in j is $\left(\frac{w_j}{\tau_j w_k}\right)_m^\theta \equiv \min\left[\left(\frac{w_j}{\tau_j w_k}\right)^\theta, 1\right]$. The conditional probability is higher when the foreign innovator is in a low-wage country, when the incumbent producer is in a high wage country, and when the trade cost is low.

If, on the other hand, the foreign country does not import the product and only produces it for domestic consumption, the foreign innovator will innovate upon its own blueprint for the product with probability λ_k. In this case, the innovator will replace the incumbent in country j with probability $\left(\frac{w_j\, q_{ik}}{\tau_j\, w_k\, q_{ij}}\right)_m^\theta$. The probability that a product exported by j is improved upon by *any* foreign innovator is a weighted sum of $\delta_k \left(\frac{w_j}{\tau_k w_k}\right)_m^\theta$ for the foreign countries that import the product from j and the sum of $\lambda_k \left(\frac{w_j\, q_{ik}}{\tau_j\, w_k\, q_{ij}}\right)_m^\theta$ for the countries that do not import the product. This sum is shown in row 1, column 2 in Table 2.

The second and third rows show the probabilities of quality improvement of non-traded and imported varieties in country j. The probability that a domestic innovator innovates upon a non-traded variety and replaces the incumbent is again given by λ_k. The probability that a domestic innovator in country j innovates upon a variety imported from country k and replaces the foreign incumbent is $\delta_j \left(\frac{\tau_j\, w_k}{w_j}\right)_m^\theta$. This probability is decreasing in the wage of country j relative to that of country k. Conditional on innovation, a high wage country is not likely to replace its imports from the low wage country. For example, US innovators may innovate upon products imported from China, but producing these products is not likely to be viable with US wages. On the other hand, a low wage country is much more likely to replace its imports from a high wage country conditional on innovation (though a low wage country may innovate less often).

Finally, the probability of quality improvements on non-traded and imported varieties due to a foreign innovation is a weighted sum of λ_k and δ_k, as it was the case with foreign innovations on exports. Again, note that a foreign innovator is more likely to replace the incumbent the lower the innovating country's wage is relative to the incumbent country's wage.

The last two rows in Table 2 show the arrival rate of new products. In particular, the second to last row gives the rate at which products enter country j due to creation of new products. Innovators in the home country j create new products at rate κ_j. Innovators in foreign countries also create new products. The arrival rate of foreign products from any foreign country is the sum of κ for all the other countries in the world, weighted by the probability that profits from the new product is sufficient to cover the fixed cost in country j.

The last row shows the arrival rate of products that are new to country j but that are not new to the world. This occurs when there are some newly created products that are not immediately sold in country j because their quality does not exceed the quality threshold. After such products are improved upon by another country, the profits from selling this product may increase by enough to meet the fixed cost of selling in country j. This event is likely to be larger in a small country where many products are not sold because the profits from selling to the small market does not justify the fixed cost. This event is also more likely when a low wage country innovates upon its imports from a high wage country.

The expected growth rate of the real consumption wage in j is a function of Table 2 arrival rates as follows:

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\begin{aligned}
\mathbb{E}\left[(1+g_j)^{\sigma-1}\right] = 1 + & \underbrace{\left(x_j^x + x_j^n\right)\ \lambda_j\, S_{\lambda_j} + x_j^x \delta_j^*\, S_{\delta_j^*} + x_j^n \lambda_j^*\, S_{\lambda_j^*}}_{\text{quality improvement on domestic products}} \\
+ \quad & \underbrace{x_j^m \left[\tilde{\delta}_j\, S_{\tilde{\delta}_j} + \tilde{\lambda}_j^*\, S_{\tilde{\lambda}_j^*}\right]}_{\text{quality improvement on imports}} \quad + \quad \underbrace{\left(x_j^x + x_j^n\right)\ \left[\kappa_j\, S_{\kappa_j} + \kappa_j^*\, S_{\kappa_j^*}\right] + x_j^o\, \tilde{\delta}_j^*\, S_{\tilde{\delta}_j^*}}_{\text{new varieties}} \qquad (5) \\
- & \chi_j\, S_{\chi_j} - \chi_j^*\, S_{\chi_j^*}
\end{aligned}
$$

where x_j^x, x_j^n, x_j^m, and x_j^o denotes the number of exported, non-traded, imported, and non-consumed products in country j; S_{λ_j}, $S_{\delta_j^*}$, $S_{\lambda_j^*}$, $S_{\tilde{\lambda}_j^*}$, $S_{\kappa_j^*}$, S_{κ_j}, and $S_{\tilde{\delta}_j^*}$ denote the change in the inverse of the quality-adjusted price of the innovated

Table 2: Arrival rate of quality improvement and new products in country j

	Domestic Innovation j	Foreign Innovation $k \in W \neq j$
Existing Products in j		
Exported by j	λ_j	$\delta_j^* \equiv \sum_{k \in W \neq j} \left(\begin{array}{c} \tilde{\alpha}_{jk}\, \lambda_k \left(\frac{w_j\, q_{ik}}{\tau_j\, w_k\, q_{ij}} \right)_m^\theta \\ +\ \alpha_{jk}\, \delta_k \left(\frac{w_j}{\tau_j\, w_k} \right)_m^\theta \end{array} \right)$
Non-traded	λ_j	$\lambda_j^* \equiv \sum_{k \in W \neq j} \left(\begin{array}{c} \beta_{jk}\, \lambda_k \left(\frac{w_j\, q_{ik}}{\tau_j\, w_k\, q_{ij}} \right)_m^\theta \\ + \sum_{\ell \in W \neq j,k} \beta_{jk\ell}\, \delta_\ell \left(\frac{w_j q_{ik}}{\tau_j w_\ell q_{ij}} \right)_m^\theta \end{array} \right)$
Imported by j	$\tilde{\delta}_j \equiv \delta_j \sum_k \gamma_{jk} \left(\frac{\tau_j\, w_k}{w_j} \right)_m^\theta$	$\tilde{\lambda}_j^* \equiv \sum_{k \in W \neq j} \left(\begin{array}{c} \sum_{\ell \in W \neq j} \tilde{\gamma}_{jkl} \lambda_\ell \left(\frac{w_k q_{i\ell}}{w_\ell q_{ik}} \right)_m^\theta \\ + \sum_{\ell \in W \neq j,k} \gamma_{jk\ell}\, \delta_\ell \left(\frac{w_k}{w_\ell} \right)_m^\theta \end{array} \right)$
New Products in j		
New to world	κ_j	$\kappa_j^* \equiv \sum_{k \in W \neq j} \kappa_k\, P\left(j \in K_{ik}^{Rm} \right)$
New to j only	–	$\tilde{\delta}_j^* \equiv \sum_{k \in W \neq j} \left(\begin{array}{c} \eta_{jk}\, \lambda_k \left(\frac{q_{ik}}{q_k^j} \right)_m^\theta \\ + \sum_{\ell \in W \neq j,k} \eta_{jk\ell}\, \delta_l \left(\frac{q_{ik}}{q_\ell^j} \right)_m^\theta \end{array} \right)$

Note: $(x)_m^\theta \equiv \min\left[(x)^\theta, 1\right]$. $\tilde{\alpha}_{jk}$ is the number of country j's exported products also produced in country k as a share of the total number of j's exported products. α_{jk} is the number of country j's exported products supplied to country k as a share of the total number of j's exported products. β_{jk} is the number of country j's non-traded products also produced in country k as a share of the total number of country j's non-traded products. β_{jkl} is the number of country j's non-traded products also produced in country k and exported from country k to country ℓ as a share of the total number of country j's non-traded products. $\tilde{\gamma}_{jk\ell}$ is the number of country j's imported products supplied by country k and also produced in country ℓ (as a non-traded product if $\ell \neq k$) as a share of country j's imported products. $\gamma_{jk\ell}$ is the number of country j's imported products supplied by country k and also imported by country ℓ as a share of country j's imported products. η_{jk} is the number of products not consumed in country j but produced in country k as a share of the total number of country j's non-consumed products. $\gamma_{jk\ell}$ is the number of products not consumed in country j but exported from country k to country ℓ as a share of country j's non-consumed products. $P\left(j \in K_{ik}^{Rm}\right)$ is the probability that the quality of new Romerian product i of country k exceeds the quality threshold in country j.

(or new) product relative to the quality-adjusted price of the average consumed product (raised to $\sigma - 1$);[2] χ_j and χ_j^* denote the number of exiting domestic and foreign products; and finally, S_{χ_j} and $S_{\chi_j^*}$ denote the average quality-adjusted price of the exiting products.

Equation 5 says that aggregate growth in the consumption wage in country j is the sum of the contribution of quality upgrading on domestic products (first term), quality upgrading on imported products (second term) and, the introduction of new products (third term), net of the effect of exit from obsolescence (last two terms). Quality upgrading on domestic products is increasing in the rate at which domestic innovators improve upon their own products, λ_j, the probability that foreign innovators improve upon country j's products, δ_j^* and λ_j^*, and the quality-adjusted price of the innovated products, S_{λ_j}, $S_{\delta_j^*}$, and $S_{\lambda_j^*}$. Likewise, the contribution of quality upgrading on imported products is increasing in the rate at which domestic and foreign innovators improve upon these products, $\tilde{\delta}_j$ and $\tilde{\lambda}_j^*$, and their quality-adjusted price post-innovation. The third term in equation 5 is the contribution of new products, which is increasing in the rate at which domestic and foreign innovators create new products, κ_j, κ_j^*, and $\tilde{\delta}_j^*$, and the quality-adjusted price of the new products. Finally, the last two terms in equation 5 is the loss from exit of domestic and foreign products due to the rising real wage, which are the product of the exit rate and the average quality-adjusted price of the exiting products.

The change in a product's quality-adjusted price depends on the step-size of innovation and the change in the labor cost when the product is reallocated across countries. The latter can be large when a low wage country takes over an imported product from a high wage country. Specifically, when country j successfully innovates upon an imported by country k, the expected proportional

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[2] For example, $S_{\lambda_j} \equiv \left[\frac{\theta}{\theta-(\sigma-1)} - 1\right] \left(\frac{\tilde{q}_j^d}{\tilde{q}_j}\right)^{\sigma-1}$ is the change in the product of the average improvement in quality from λ and the ratio of the quality of the representative domestic product to the quality of the representative consumed product (raised to $\sigma - 1$).

change in the quality-adjusted price of the innovated product in country j is

$$\frac{\theta}{\theta-(\sigma-1)}\max\left\{1,\left(\frac{\tau_j w_k}{w_j}\right)^{\sigma-1}\right\}.$$

When $w_j < \tau_j w_k$, the expected step-size is $\frac{\theta}{\theta-(\sigma-1)}$. However, when $w_j < \tau_j w_k$, the expected step-size increases proportionally with $\left(\frac{w_k}{w_j}\right)^{\sigma-1}$. Intuitively, the change in the quality-adjusted price of an innovated product can be large when a low wage country improves upon and replaces a product from a high wage country because the marginal cost falls sharply when this happens.

We can rearrange equation 5 to express growth from domestic vs. foreign innovation:

$$\begin{aligned}\mathbb{E}\left[(1+g_j)^{\sigma-1}\right] = 1 &+ \underbrace{\left(x_j^x + x_j^n\right)\lambda_j\, S_{\lambda_j}^{\sigma-1} + x_j^m\,\tilde{\delta}_j\, S_{\tilde{\delta}_j}^{\sigma-1} + \left(x_j^x + x_j^n\right)\kappa_j\, S_{\kappa_j}^{\sigma-1}}_{\text{domestic innovation}} \\ &+ \underbrace{x_j^x\,\delta_j^*\, S_{\delta_j^*}^{\sigma-1} + x_j^n\,\lambda_j^*\, S_{\lambda_j^*}^{\sigma-1} + x_j^m\,\tilde{\lambda}_j^*\, S_{\tilde{\lambda}_j^*}^{\sigma-1} + \left(x_j^x + x_j^n\right)\kappa_j^*\, S_{\kappa_j^*}^{\sigma-1} + \tilde{\delta}_j^*\, S_{\tilde{\delta}_j^*}^{\sigma-1}}_{\text{foreign innovation}} \\ &- \chi_j\, S_{\chi_j}^{\sigma-1} - \chi_j^*\, S_{\chi_j^*}^{\sigma-1}.\end{aligned} \tag{6}$$

Domestic innovators contribute to growth by improving upon domestic products, imported products, and by creating new varieties. Foreign innovators contribute to country j's growth by improving upon country j's products, their exports to country j, by creating new varieties that they sell in country j, and by creatively destroying a high-wage country's products that were previously not sold in country j.

In a steady state, all countries grow at the same rate and differences across countries in the arrival rates of innovation show up as differences in the real wage. In the empirical section of the paper we will show the contribution of the three sources of innovation to cross-country TFP gaps. We will also use equation 5 to decompose the contribution of foreign vs. domestic innovation to each country's growth, and equation 6 to decompose the role of quality upgrading vs. new products to growth.

The arrival rates of innovation also determine the share of Romerian vs. Ricardian trade and the product life-cycle. First, the share of Romerian vs. Ricardian trade of each country is determined by the rate at which new varieties are created in the country vs. the rate at which the country improves upon its imports. It is easiest to see this in simplified model with two countries and with no trade costs. In this case, the net arrival rate of a Romerian export in country j is:

$$\kappa_j \; - \; \text{Romer Share}_j \, \delta_k \left(\frac{w_k}{w_j} \right)_m^{\theta}$$

And the net arrival rate of a Ricardian export is

$$\delta_j \left(\frac{w_k}{w_j} \right)_m^{\theta} \; - \; \text{Ricardo Share}_j \, \delta_k \left(\frac{w_j}{w_k} \right)_m^{\theta}$$

In a steady state the net arrival rate of a Romerian product is equal to the net arrival rate of a Ricardian product, which is the case when the ratio of the share of Romerian products to the share of Ricardian products is:

$$\frac{\text{Romer Share}_j}{\text{Ricardo Share}_j} = \frac{\kappa_j}{\delta_j \left(\frac{w_k}{w_j} \right)_m^{\theta}}$$

The share of Romerian products in country j is increasing in κ_j and w_j/w_k and decreasing in δ_j.

The same innovation rates also determine the life-cycle of a product. First, all new products are by definition Romerian and gradually become Ricardian products after they are innovated upon and replaced by producers in other countries. Thus the rate at which a given cohort of products switches from Romerian to Ricardian products depends on the rate at which innovators from all countries improve upon imports. Second, the same forces that determine the steady-state share of Romerian products in a country's exports also determines the share of the country in a product's life-cycle. Countries that primarily innovate by creating new varieties will have a large Romerian share in steady-state, and will see its share of a cohort of products fall as its products are innovated upon by other countries. Countries that primarily innovate by improving their imports will have a low Romerian share in steady-state, and will see its share increase over the product's life-cycle.

In sum, the innovation probabilities in each country (κ, λ, δ), the parameters governing the quality-adjusted price of the innovated products (θ and σ), and the trade cost (τ) pin down the common global growth rate and the product life-cycle. These parameters also pin down the real consumption wage, the share of growth from quality upgrading and new varieties, the share of growth from domestic vs. foreign innovation, the importance of Romerian vs. Ricardian trade in each country. In the next section we will show how we infer these parameters from the distribution of export growth and import declines.

3 Innovation and Trade Dynamics

We now show how we infer the relative importance of different sources of innovation from the distribution of export and import growth. We consider three sources of innovations affecting the export and import growth distributions of a country: innovation on its own exports (due to λ), creation of new varieties (due to κ), and innovation on imports (due to δ).

First, suppose a country innovates on an exported product with expected step size S. The expected change in exports is $S^{\sigma-1} - 1$. The expected growth rate of exports of the product, defined as the change in exports of the product divided by the average of the product's exports prior and after innovation, is $2\frac{S^{\sigma-1}-1}{S^{\sigma-1}+1}$.

Now suppose instead the innovators in j create a brand new product. The growth rate of export, again defined as the change in export of the product divided by the average of the product's exports prior and after innovation, is 2. As long as the step size is not too large, the growth rate of an exported product is larger when innovators create new products compared to when the country improves upon its existing exports.

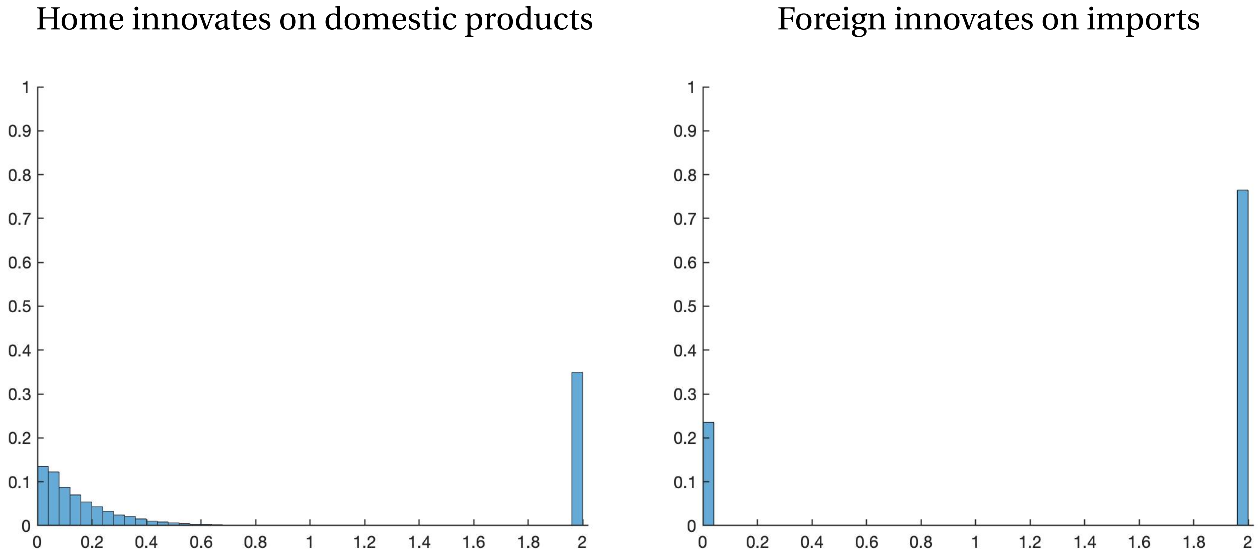
Lastly, consider the case when the country improves upon and replaces the incumbent producer of an imported product in the foreign market. Again, the growth rate of export in the newly exported variety is 2, which is the same as the growth rate when the country creates new products. Consider however the effect of δ_j on the foreign country's exports. The foreign country loses an exported product to the home country, so exports of the home country rise and its imports from the foreign country falls. In contrast, exports of the foreign country do not change when the home country creates new products.

To recap, a country that is successful in innovating will see its exports grow, where the magnitude of the export growth depends on whether the country innovated by improving upon its own products (λ) or via the combination of creating new products (κ) and improving upon the products made by other countries (δ). At the same time, its import growth depends on whether innovation takes the form of new product creation (κ) or taking over another country's exports (δ). We will use this idea in our data inference. To illustrate this, we now highlight the predictions of three polar models, each with one main source of innovation, on trade dynamics.

3.1 Distribution of exports and imports in polar models

Consider a polar two-country model where the home country mostly innovates by improving its own products and the foreign country mostly innovates by innovating upon its imports (the home country's exports). In this polar model, the home country's exports grow when it improves upon these exports, and the foreign country's exports grow when it innovates upon its imports. Both countries also engage in a minimal amount of new product creation, which we need to keep the number of products constant since rising wages leads to the exit of low quality products.[3]

Figure 1: Distribution of export growth, λ vs. δ



Growth rate of exports

Note: Figure shows the simulated distribution of export growth for products with positive growth in a model with two countries with the same real wage and zero trade costs. Export growth is the change in exports of a product divided by average exports of the product at the beginning and end of each period. Vertical axis gives the share of products associated with products at each level of export growth. Left panel is home country which mostly innovates on its own products ($\lambda_j = .41$, $\delta_j = .01$, $\kappa_j = .04$). Right panel is foreign country which mostly innovates on its imports ($\lambda_k = 0$, $\delta_k = .19$, $\kappa_k = .04$).

Figure 1 shows the predictions of this polar model for the distribution of positive export growth across products in the two countries. Putting aside the concentration of positive export growth at $+2$ due to new product creation and previously non-traded products becoming exported after innovations, the distribution of export growth across products in the home country, shown in the left panel in the figure, is concentrated around small changes. In contrast, ex-

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[3] The arrival rates in this polar model are $\lambda_j = .41$, $\delta_j = .01$, and $\kappa_j = .04$ for the country depicted in the left panel, and $\lambda_k = 0$, $\delta_k = .19$, and $\kappa_k = .04$ for the country shown in the right panel. The polar model also assumes $\tau = 1.02$ and that the relative wage and labor supply are one.

port growth in the foreign country, shown in the right panel, is concentrated around $+2$ with virtually no mass at smaller changes. This – aside from a small amount of new product creation – reflects the foreign country innovating upon its imports from the home country and starting to export these products.

We next show a polar model where the home country still mostly innovates on its own products but the foreign country mostly creates new products.[4] The distribution of positive export growth for the two countries are shown in Figure 2. As can be seen, the distribution of positive export growth in Figure 2 where the foreign country creates new products looks virtually identical to the polar model in Figure 1 where the foreign country innovates on its imports. So the distribution of positive export growth distinguishes between a country that innovates on its own products vs one that innovates on its imports, or a country that innovates on its own products vs. one that creates new products. It does not, however, distinguish between a country that innovates on its imports vs. one that creates new products.

Consider now a third polar model, where the home country mostly innovates on imports and the foreign country creates new products.[5] As we've seen already, the distribution of positive export growth looks virtually identical in the two cases. Figure 3, on the other hand, shows that the distribution of *import* growth looks very different in the two countries. There is more mass at the extreme of negative import growth (growth rate = -2) in the country that mostly innovates on its imports. There is some mass at growth in imports = -2 in the foreign country as well that comes from the exit of low quality imports from obsolescence, but the mass at import growth = -2 is almost twice as large in the country that innovates on imports. Intuitively, the home country stops importing a product when a domestic firm innovates upon and replaces the

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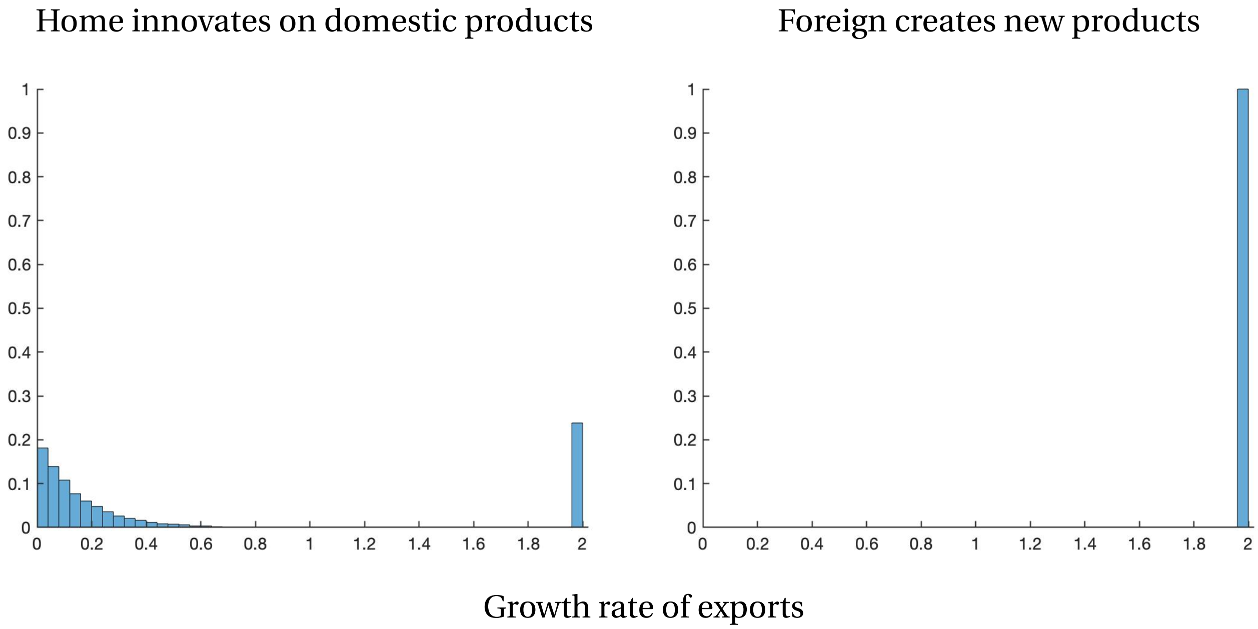
[4] The arrival rates of innovation in this polar model are $\lambda_j = .35$, $\delta_j = .01$, and $\kappa_j = .04$ for the country shown in the left panel, and $\lambda_k = 0$, $\delta_k = .01$, and $\kappa_k = .14$ for the country in the right panel. We also assume $\tau = 1.02$ and that the relative wage and labor supply are one.

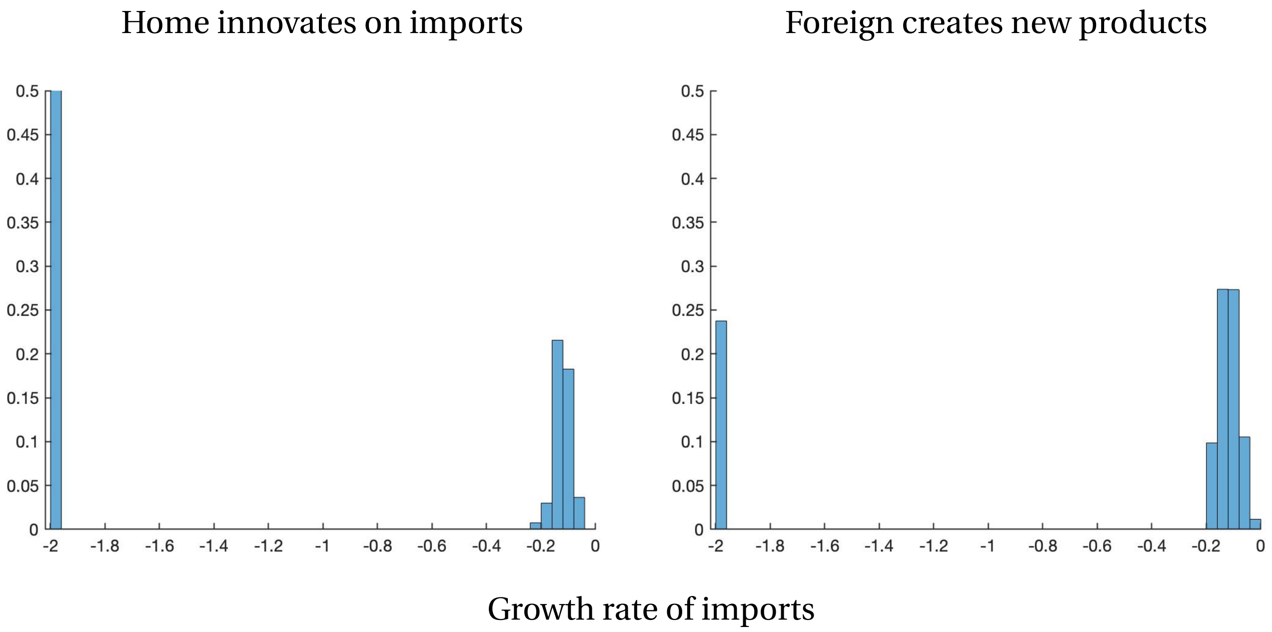
[5] The arrival rates of innovation are $\lambda_j = 0$, $\delta_j = .37$, and $\kappa_j = .04$ in the country depicted on the left panel, and $\lambda_k = 0$, $\delta_k = .01$, and $\kappa_k = .20$ in the country shown on the right panel. We also assume $\tau = 1.02$ and that the relative wage and labor supply are one.

Figure 2: Distribution of export growth, λ vs. κ



Note: Figure shows the simulated distribution of export growth for products with positive growth in a model with two countries with the same real wage and zero trade costs. Export growth is the change in exports of a product divided by average exports of the product at the beginning and end of each period. Vertical axis gives the share of products associated with products at each level of export growth. Left panel is home country which mostly innovates on its own products ($\lambda_j = .35$, $\delta_j = .01$, $\kappa_j = .04$). Right panel is foreign country which mostly creates new products ($\lambda_k = 0$, $\delta_k = .01$, $\kappa_k = .14$).

Figure 3: Distribution of import decline, δ vs. κ



Note: Figure shows the simulated distribution of import growth for products with negative import growth in a model with two countries with the same real wage and zero trade costs. Import growth is the change in imports of a product divided by average imports of the product at the beginning and end of each period. Vertical axis gives the share of products associated with products at each level of import growth. Left panel is home country which mostly innovates on its imports ($\lambda_j = 0$, $\delta_j = .37$, $\kappa_j = .04$). Right panel is foreign country which mostly creates new products ($\lambda_k = 0$, $\delta_k = .01$, $\kappa_k = .20$).

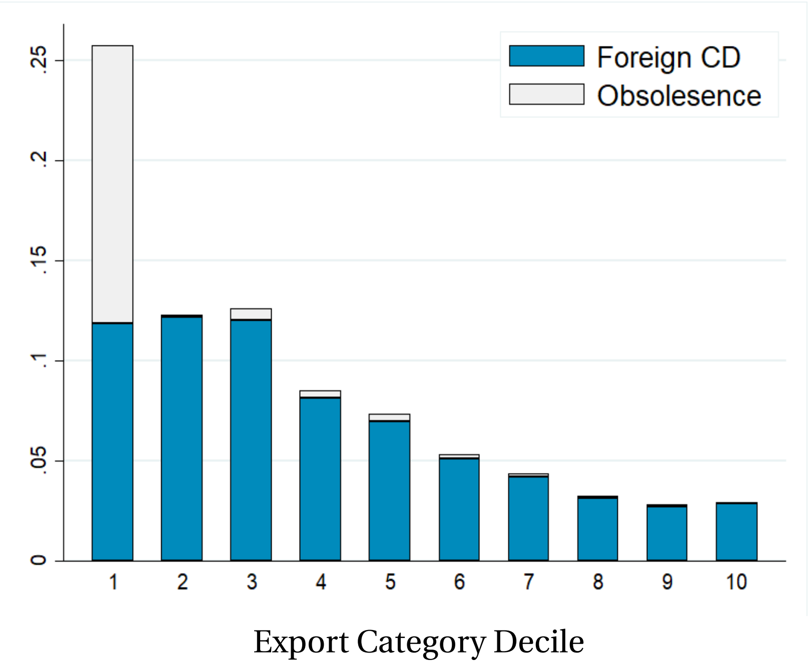
import in the domestic market.

3.2 Products vs. export categories

We have so far focused on products, as the arrival of innovation on products has clear implications for the distribution of the change in exports and imports of individual products. The problem is that we can track products in the model but not necessarily in the data. In the data we observe export *categories*, such as exports and imports in a four digit SIC or six digit NAICS code. Such categories, particularly the large ones, can be a collection of multiple “products” in the model. Though less sharp, the arrival of innovation on products also have implications on the change in exports and imports of export categories.

We mimic an export category in the data by randomly allocating products in the model to a category. We assume that a constant fraction of new products κ_c are allocated to new categories and the remainder to existing categories. The creation of new categories combined with exit of products in existing categories due to obsolescence generates a stationary distribution of products per category. Differences in size across export categories come from heterogeneity in the number of products in the category and in the average quality of products in the category. We pick κ_c to match the size distribution of exports in four digit SIC categories in the US.

Figure 4: Exit rate by decile of export category



Note: Average exit rate of an export *category* by deciles of the export category in home country in the simulated polar model where the home country mostly innovates on its products and the foreign country mostly innovates on its imports. See notes to Figure 1 and text for more details on this polar model.

Figure 4 shows the simulated average exit rate of an export category by size deciles of the export category. This is for the polar model in Figure 1 where the home country innovates on its products and the foreign country innovates on its imports. The home country loses an export category (i) when it loses all the products in that category from obsolescence or (ii) when the foreign country innovates upon and replaces all of the home country's exported products in that category.[6] The probability an export category exits therefore depends on the number of products in the category and on the average quality of these products, along with innovation rates at home and abroad. In particular, categories with fewer products are more likely to exit either due to obsolescence or foreign innovations, while categories with low average product quality are likely to exit due to obsolescence.

Figure 4 shows that exit from innovation by foreign firms is roughly constant for the bottom three deciles of export categories and falls with size thereafter. This suggests that the number of products per category is likely to be small for exports categories in the bottom three deciles. In the data then when we measure the distribution of positive export growth, we will focus on the bottom quartile of export categories as the smaller export categories are likely to consist of a small number of products. Focusing on categories with only few products allows us to attain sharp identification; export and import growth of categories with large products are not very responsive to innovation rates because different types of innovations are likely to hit these large categories simultaneously, obscuring the effects of each force.

Figure 4 also shows that exit from obsolesence is concentrated in the bottom decile of export categories. This is not a problem for the sample of categories with *positive* export growth but it makes inference more difficult for the sample of *import* categories with negative growth (foreign exports); we would like to infer from the amount of negative import growth the extent of innovations on

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[6] When a multi-product category exits due to a combination of obsolescence and foreign innovations, we weight the exit by the number of products in the category that exited due to each cause. For example, if a country loses a two-product category because one product exits due to obsolescence and another due to foreign innovations, we attribute 1/2 of the category exit to obsolescence and 1/2 to foreign innovations.

imports (δ), not the extent of obsolescence. To remove the effect of obsolescence, we will focus on the bottom 25 to 75 percentile of a country's imports when calculating the distribution of negative import growth.

In the model we mimic product categories in the data by assuming that a fraction κ_c of each country's new products are assigned to new product categories and the remainder $1 - \kappa_c$ are randomly assigned to existing product categories. The parameter κ_c thus determines the distribution of the number of products per category across export categories.

4 Data and Estimation

The key data moment is the distribution of positive export growth and negative import growth of a country. We use Feenstra et al. (2005)'s data on bilateral trade at the four digit SIC level. We restrict to manufacturing industries and 20 countries (we group the EU countries, including the United Kingdom, into one country) that collectively account for 95% of world exports. We work with non-overlapping five year periods from 1991 through 2016. In each five year period and country, we normalize the growth rate of total exports and total imports to zero. After we impose this normalization, we measure the normalized growth rate of an export (import) category as the change in exports (import) divided by the average of exports (imports) in the category at the beginning and at the end of the five year period. The growth rate of a new export (import) category is thus 2; the growth rate of an export (import) category that exits is -2.

We measure the distribution of positive export growth for the bottom quartile of export categories in each country at the beginning of each five year period. The specific moment we use is the share of export growth where the growth rate is $< .5$. For the distribution of negative import growth, we restrict the import categories to those between the 25 and 75th percentiles of imports (also for each five year period and the beginning of each five year period). The specific moment we use is the share of negative import growth where the growth rate is

< -1.

Table 3: Empirical Moments

	US	EU	China	ROW	World
TFP (US=1)	1	.816	.441	.611	.679
Trade Share	18.4%	21.5%	16.2%	26.7%	20.9%
Export Growth < 0.5	28.2%	30.8%	16.8%	17.0%	21.9%
Import Growth < -1	5.4%	7.1%	15.0%	11.6%	10.5%

Note: TFP is manufacturing TFP relative to the US. Export growth is the share of export categories with a growth rate $< .5$ among exports with positive growth calculated among exports in the bottom quartile. Import decline is the share of import categories with a growth rate < 1 among imports with negative growth calculated among imports among the bottom 25-75 percentile. Export growth and import decline is average over successive five-year periods from 1991 through 2016 for each country in the four-digit SIC trade data. Growth of total imports and exports normalized to zero for each country and five year period. ROW is the GDP weighted average of the 17 countries in the rest of world. World is the GDP weighted average of the 20 countries in our sample.

The additional data moments we use are TFP, employment, and the trade share. The trade share is the share of exports in manufacturing GDP (from the World Development Indicators). We measure TFP from the Penn World Database and manufacturing employment as the residual of manufacturing GDP (from the World Development Indicators) after accounting for the effect of TFP.

Table 3 summarizes TFP, trade share, the share of small positive export growth, and the share of large negative import decline for the US, EU, China, and the rest of the world.[7] The first two panels in Figure 5 plots the two moments of exports and imports we use, namely the share of large import decline (left panel) and the share of the share of small export growth (middle panel), against the country's TFP. The left panel shows that large import declines, which in the model is

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[7] Table B1 in the Appendix shows the data moments for all 20 countries.

driven by innovation on imports, are more frequent in poor countries compared to rich countries. The middle panel shows that the share of small increases in exports, which in the model reflects the relative importance of innovation on domestic products vs. innovation on imports and new product creation, is larger in rich countries vs. poorer countries. The right panel shows the *residual* of large export increases, namely the ratio of the share of large export increases (1-the share of small export growth shown in the middle panel) to the share of large import declines (shown in the left panel). So the right panel suggests that the residual of large increases in exports, which in the model reflects innovation via the creation of new products, is larger in high TFP countries compared to poorer ones.

The model consists of four parameters for each country (κ, δ, λ, and τ) and four parameters (f, θ, κ_c, and σ) that are the same in all countries. So in total the model has 84 parameters.[8] We assume $\sigma = 3$ and pick f so that the average number of products per country is between 2,500-5000. For the remaining parameters, the inference works as follows.[9] In the first step, we assume a value for the shape parameter of the distribution of the innovation step size θ. Taking as given θ and imposing trade balance for each country, the data on relative TFP, relative employment, and the trade share collectively identifies each country's overall innovation rate (from all three sources of innovation) relative to the US and the trade cost τ. Then, conditional on τ and relative TFP, the share of large changes in import declines (from the data) identifies the innovation rate on imports δ. And conditional on δ, relative TFP, τ, and each country's overall innovation rate, the share of small changes in export growth from the data identifies the share of innovation that takes the form of quality improvement on domestic products λ vs. the combination of innovation on imports δ and the creation of new varieties κ. The aggregate growth rate (assumed to be the same for all countries) and the share of US exports that grow then collectively pin down the

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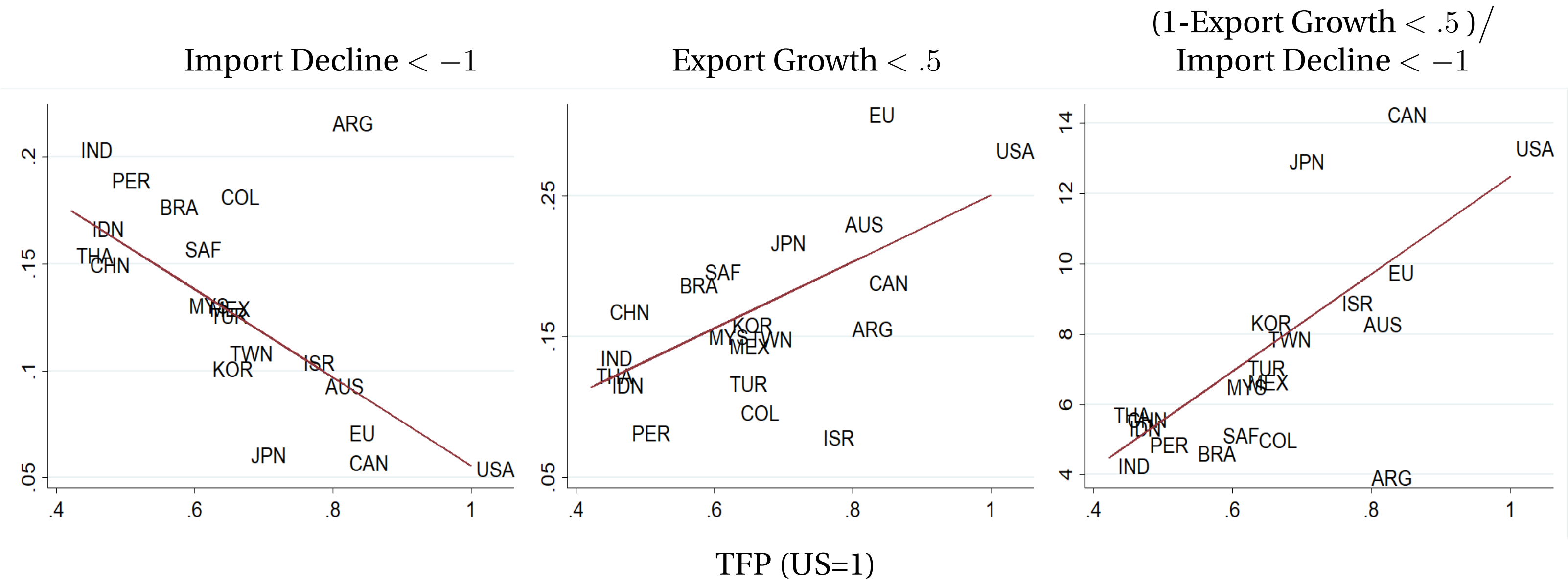
[8] 4 parameters common to all countries and 4 country-specific parameters for each of the 20 countries.

[9] Appendix Section A provides more details on the estimation procedure.

Figure 5: Data: Import Decline and Export Growth vs. TFP



Note: Figure plots the share of import decline with a growth rate < -1 (left panel), the share of positive exports with a growth rate $< .5$ (middle panel), and the ratio of the share of positive exports with a growth rate $> .5$ to the share of import decline with a growth rate < -1 (right panel). Growth rate defined as change in exports of exports divided by the average of exports of the category at the beginning and end of each five year period. Export growth and import decline is average over successive five-year periods from 1991 through 2016 for each country in the four-digit SIC trade data. Growth rate of total exports and imports normalized to zero for each country and five year period.

quality step size of innovation (and thus the shape parameter of the distribution of the step size of innovation θ) and the overall US innovation rate.[10] Finally, we choose κ_c such that the exit rate of an export category in the bottom quartile of exports is 19.2% over five years.[11]

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[10] We use a growth rate of 15.9% per five-year period and 45.4% for the share of US exports that grow over a five year period (based on the US four digit export data).

[11] The average exit rate of an export category in the bottom quartile over five years is 19% for the 20 countries in our four-digit SIC trade data.

5 Parameter Estimates

Table 4 presents the arrival rates of innovations and trade cost in the US, the EU, China, and the rest of the world inferred from the data moments.[12] The top panel shows the arrival rates of innovation, the middle panel shows the probability of *successful* innovation as the product of the innovation arrival rate and the probability that the innovator also takes over the product, and the bottom panel shows the trade cost τ.

Table 4: Estimates of Innovation and Trade Cost

	US	EU	China	ROW	World
Innovation Rate					
Domestic Products λ	71.9%	89.0%	96.7%	71.7%	82.6%
Imported Products δ	4.7%	9.9%	0.4%	18.2%	8.6%
New Products κ	77.8%	20.3%	14.5%	22.8%	30.7%
Successful Innovation Rate					
Domestic Products	49.9%	77.5%	86.7%	63.0%	70.3%
Imported Products	2.8%	6.5%	0.4%	6.6%	4.0%
New Products	41.3%	16.4%	12.1%	17.0%	20.2%
Trade Cost τ	1.82	1.52	1.29	1.92	1.64

Note: Top panel shows the arrival rates of innovation. Middle panel shows the product of the arrival rates of innovation and the probability that the innovator also becomes the producer. Bottom panel shows the gross trade cost. ROW and World are GDP-weighted averages.

We take three messages from the table. First, the probability of *successful* innovation is lower than the arrival rates of innovation, particularly for a high

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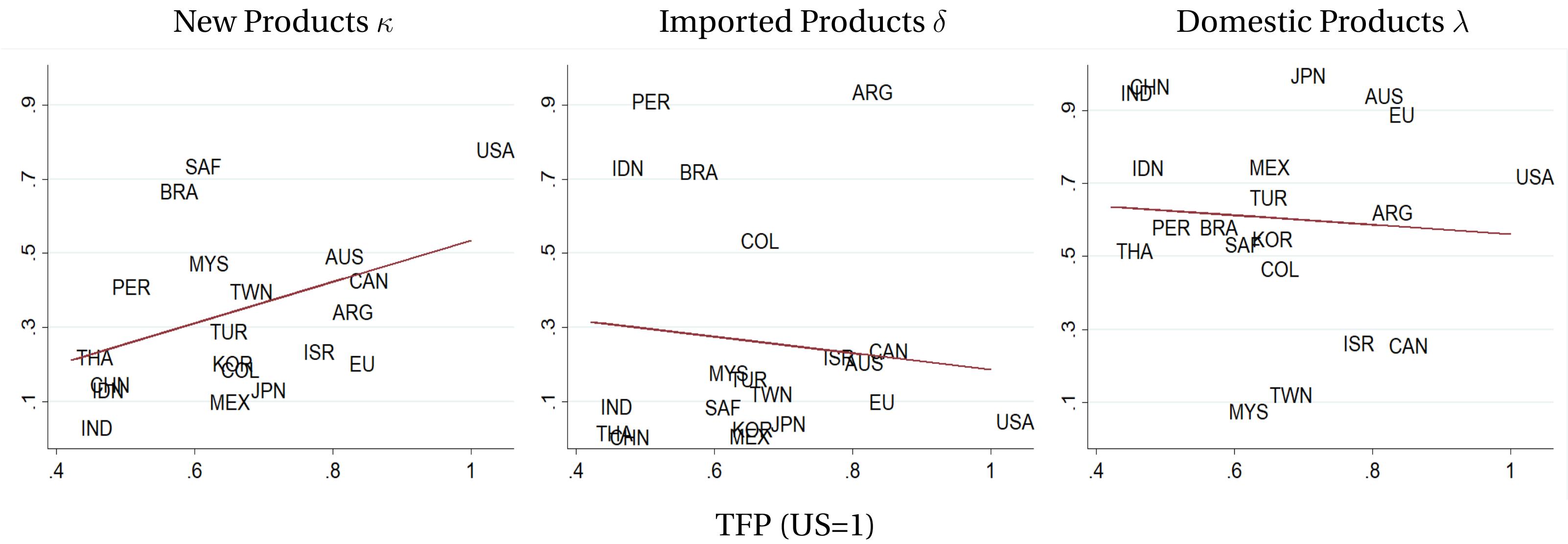
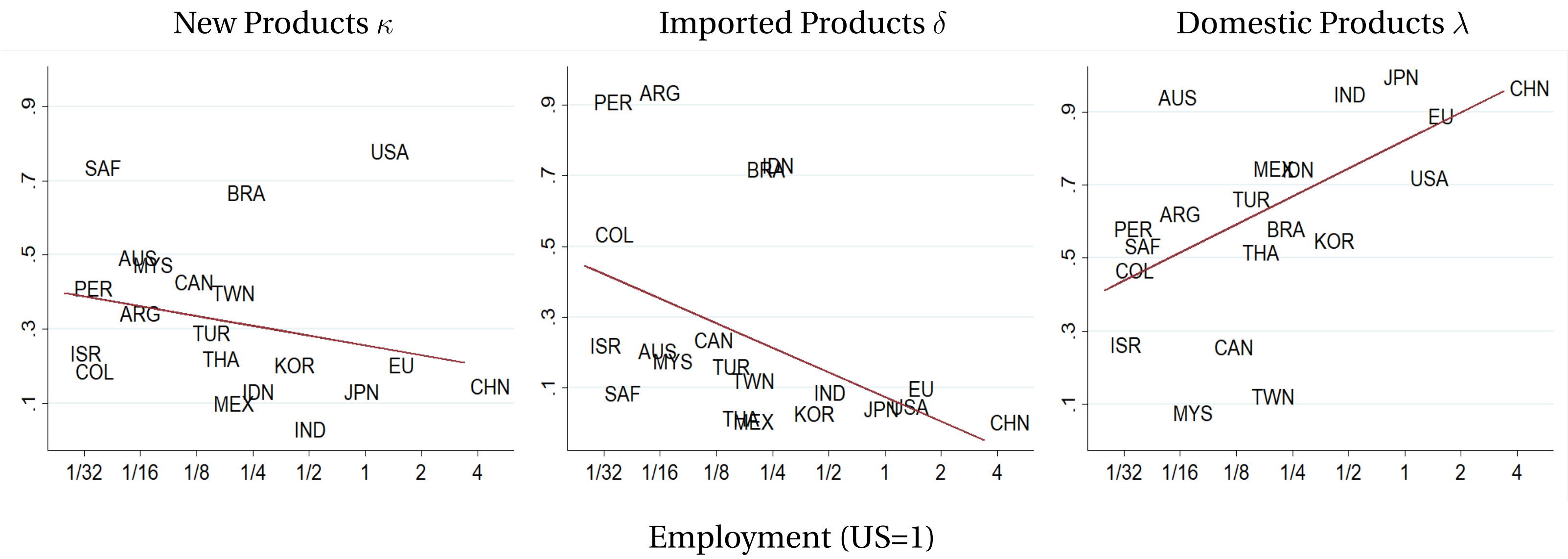
[12] The full set of parameter estimates is found in the Appendix Tables B4. Figure B1 in the Appendix shows the fit of the model implied by the innovation rates and trade costs in Table 4. The figure plots TFP, the trade share, the share of small positive export growth, and the share of large import declines implied by the parameter estimates in Table 4 against the data for the same variables for our 20 countries.

Figure 6: Arrival Rates of Innovation

Arrival Rates of Innovation vs. TFP:



Arrival Rates of Innovation vs. Employment:



Note: Figure shows the arrival rates of new products, innovation on imported products, and innovation on domestic products against TFP (top panel) and total labor supply (bottom panel). Solid red line is the OLS regression line.

wage country such as the US. This is because an innovator in a high wage country is less likely to replace the incumbent from another country, particularly when the incumbent is from a low wage country. Second, the creation rate of new products is much higher in the US compared to other countries. The arrival rate of new products is notably lower in China at 15%. Third, the probabilities of a successful innovation on domestic and imported products are *lower* in the US compared to other countries. The arrival rate of successful innovation on domestic products is 50% in the US and 70% in other countries. The arrival rate of a successful innovation on imports is 2.8% in the US and 4% in other countries.

Figure 6 plots the arrival rates of innovation vs. the country's TFP (top panel) and employment (bottom panel). Compared to lower TFP countries, high TFP countries create new products more frequently, innovate on imported products less frequently, and innovate on domestic products at about the same rate. Compared to smaller countries, large countries innovate on domestic products more frequently and create new products and innovate on imported products less frequently.

6 Accounting for TFP, Growth, Trade, and the Product Life-Cycle

In the model, each country is summarized by the three innovation arrival rates $(\delta, \lambda, \kappa)$ and the trade cost τ. In this section, we show the implication of these parameters we estimate for the distribution of world TFP, the sources of growth, the share of Romerian vs. Ricardian trade of each country, and the global product life-cycle.

6.1 TFP Accounting

We start with the TFP accounting exercise. Specifically, Table 5 shows the share of the TFP gap of each country relative to the US that is "explained" by the difference in λ, δ, and κ of each country relative to the US.[13] The shares do not add up to 100% because differences in labor supply and trade costs, as well as the non-linearities in the model, also affect TFP gaps.

Table 5: TFP Gap relative to US explained by λ, δ and κ

	EU	China	ROW	World
Innovation on Domestic Products λ	-18.9%	-13.1%	6.7%	-7.0%
Innovation on Imported Products δ	-76.0%	57.5%	-15.6%	-3.8%
Creation of New Products κ	230.0%	89.9%	81.2%	121.5%

Note: Table shows share of the TFP gap between a country and the US due to the gap in λ (row 1), δ (row 3), and κ (row 3) between each country and the US. ROW and World are GDP-weighted averages.

We make three observations from the table. First, new variety creation – the Romerian force – is the most important force driving the TFP gap of most countries relative to the US. The difference in κ explains 230% and 90% of the TFP gaps between the EU and the US and between China and the US, respectively. For the average country in the world, new variety creation accounts for 120% of the TFP gap relative to the US. Second, with the notable exception of China, innovations on imported products – the Ricardian force – does not explain lower TFP relative to the US. The difference in the arrival rate of innovation on imported products between the EU and the US and the rest of the world (excluding

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[13] We use the standard approach of chaining. For example, in row 1 we compute the gap in TFP between the country and the US by changing λ of the country to that of the US holding fixed the other forcing variables. Then we compute the change in the TFP gap by changing λ in the US to that of the country in question, again holding the other variables fixed. We take the average of the two estimates of the change in the TFP gap from changing λ, and show the ratio of this number to the actual TFP gap observed in the data.

China) and the US *lowers* the TFP gap vis-a-vis the US. For the average country, innovation on imports explains -4% of the TFP gap. Third, the innovation rate on domestic products also does not explain the TFP gap with the US. The share of the TFP gap with the US for the average country is -7%.

6.2 Growth Accounting

In the model all countries grow at the same rate in the steady state but they differ in the sources behind their growth. In this section, we show the contribution of quality growth vs. new varieties and the contribution of domestic vs. foreign innovation to each country's growth.

The top panel of Table 6 shows the growth contribution of domestic vs. foreign innovation given by equation 6. About 20% of US growth comes from innovation activities of foreign companies while the share of growth from foreign innovation is much higher in other countries. The contribution of foreign innovation to growth is 40% in the EU, 60% in China, and 52% in the rest of the world. So the US is an exception in that US growth mostly comes from domestic innovation.

The bottom panel in Table 6 decomposes growth in each country into the contribution of quality upgrading vs. new products following equation 5. About three-quarters of US growth comes from the introduction of new products. The share of growth from new products is about 50% in other countries. While not as extreme as the share of growth from foreign vs. domestic innovation, the share of growth from new products vs. quality upgrading in the US is also an outlier compared to other countries.

Figure 7 further decomposes the growth contribution of domestic innovation into parts due to domestic innovation in the form of new products (left panel), quality improvements on imports (middle panel), and quality improvement on domestic products (right panel). We make three observations. First, creation of new products explains a large part of TFP growth in countries with

Table 6: Growth Accounting

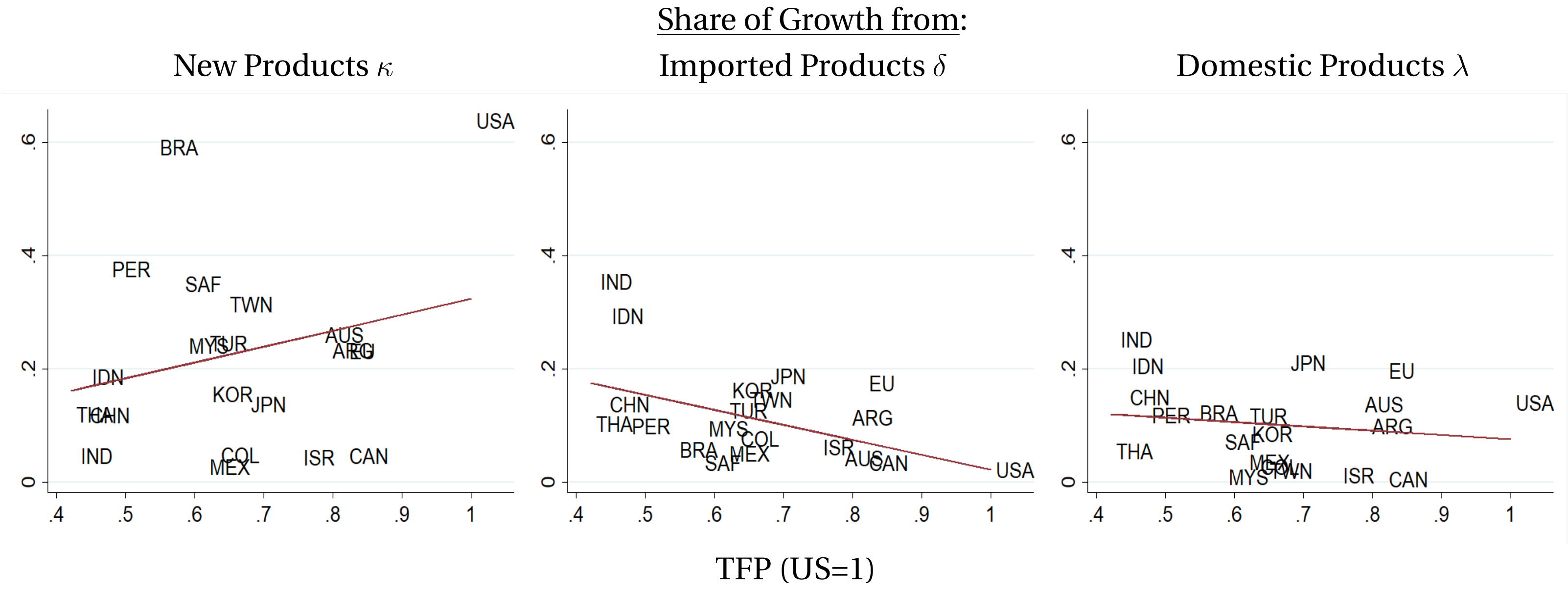
	US	EU	China	ROW	World
Domestic vs. Foreign Innovation					
Domestic Innovation	80.2%	60.5%	40.7%	48.0%	54.7%
Foreign Innovation	19.8%	39.5%	59.3%	52.0%	45.3%
Quality Growth vs. New Products					
Quality Growth	24.9%	51.7%	48.3%	48.5%	44.5%
New Products	75.1%	48.3%	51.7%	51.5%	55.5%

Note: Table shows the share of growth from domestic vs. foreign innovation in the top panel following equation 5 and the share of growth from quality upgrading vs. new products in the bottom panel following equation 6. ROW and World are GDP-weighted averages.

higher TFPs. For instance, κ accounts for more than 60% of the US growth but only 10% of the Chinese growth. Second, the share of growth from innovations on imports tends to be higher for countries with lower TFPs. This is because the marginal cost of production falls sharply when a low wage country successfully innovates upon a product imported from a high wage country. In addition, although low wage countries are less likely to innovate upon their imports, they enjoy much higher quality improvements when they succeed. Third, the share of growth from innovations on domestic products is not correlated with the country's TFP.

Figure 8 plots the growth contribution from foreign innovation. The left panel shows that the contribution of foreign innovation to growth is about the same in rich vs. poor countries. The right panel shows that smaller countries depend a lot more on foreign innovation compared to larger countries. One extreme are countries such as Israel, Colombia, Canada, and Mexico where about 80% of aggregate growth comes from foreign innovation. The other extreme is the US where foreign innovation only accounts for 20% of GDP growth.

Figure 7: Share of Growth from Domestic Innovation



Share of Growth from:

New Products κ Imported Products δ Domestic Products λ

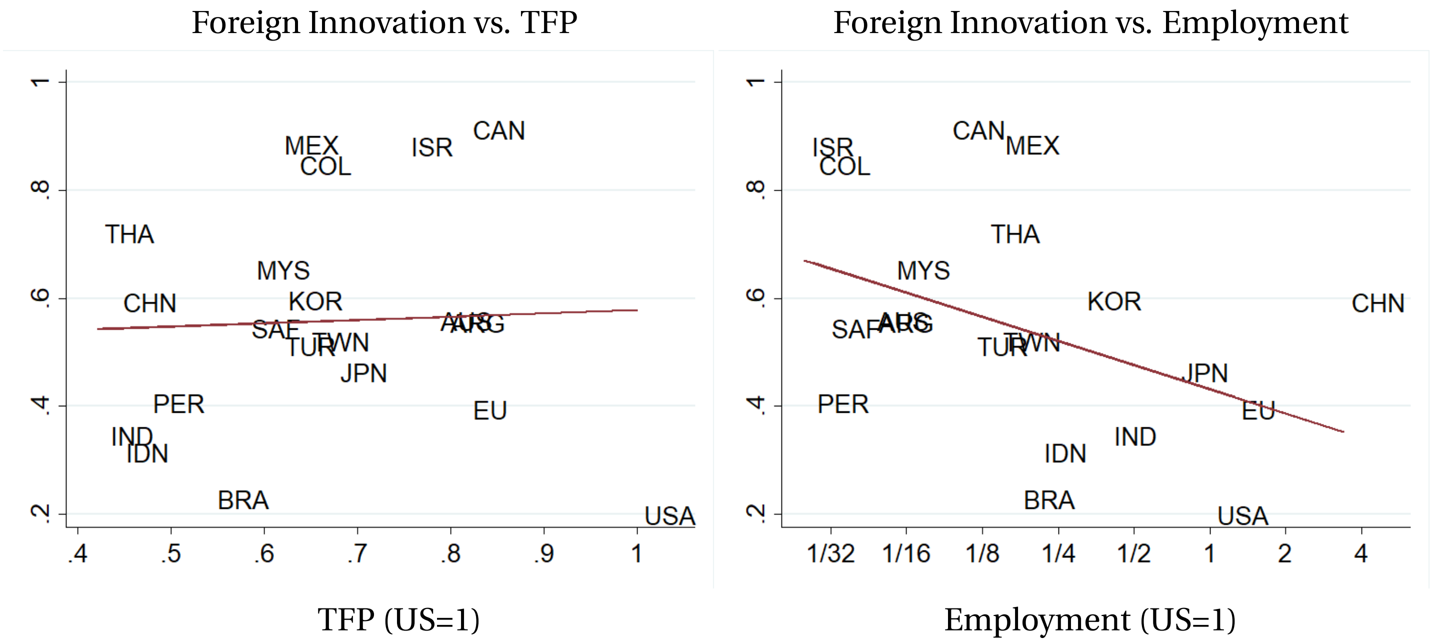
TFP (US=1)

Note: Figure shows the share of growth from creation of new domestic varieties (left panel), domestic innovation on imported products (middle panel), and domestic innovation on domestic products (right panel).

As shown in equation 5, foreign innovation contributes to a country's growth by improving the quality of products currently sold in the country and by introducing new foreign products into the country's market. Figure 9 shows the growth contribution of these two sources of foreign innovation as a function of the country's labor force. The figure shows that the main reason foreign innovation matters more for smaller countries is because of new foreign products. In a typical small country such as Malaysia or Thailand, new foreign products are responsible for 40-50% of the country's growth. In the US, new foreign products account for slightly over 10% of growth. The contribution of quality growth from foreign innovation on products the country already consumes is also higher in smaller countries, but the difference relative to large countries is much smaller.

Figure 10 further decomposes the growth contribution of foreign new products into the contribution of foreign products that are new to the world (left

Figure 8: Share of Growth from Foreign Innovation



Foreign Innovation vs. TFP

Foreign Innovation vs. Employment

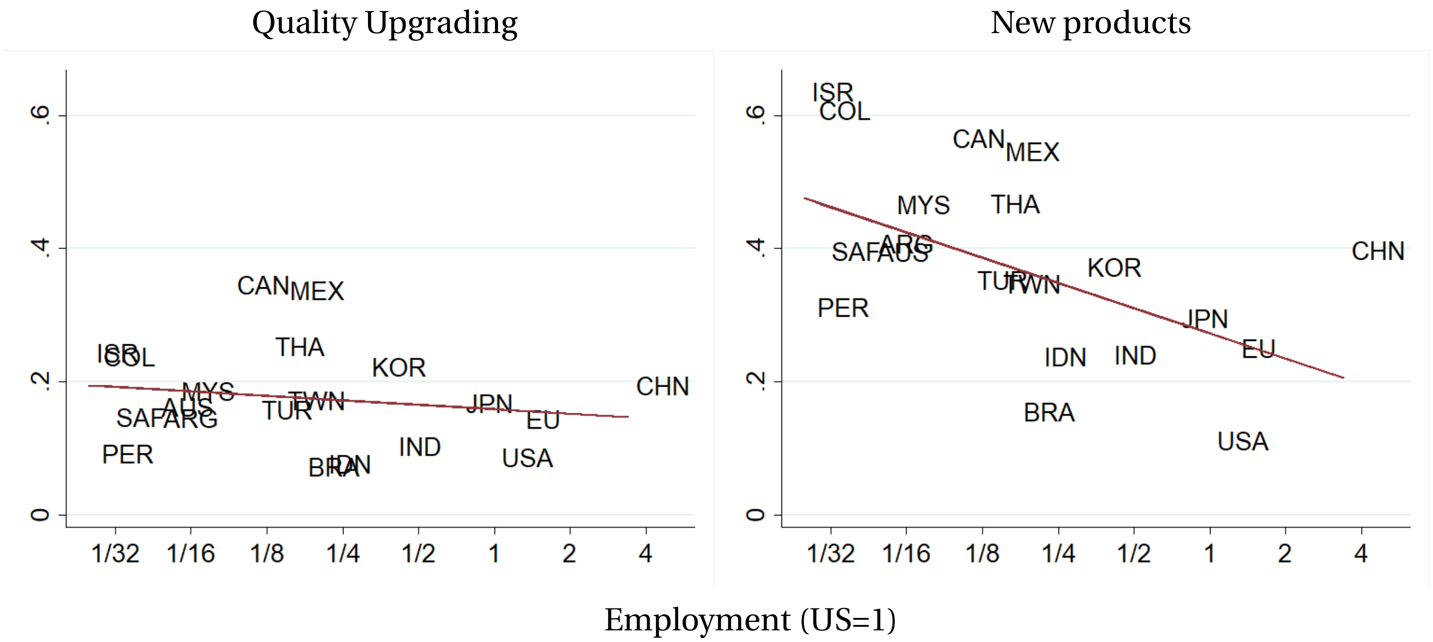
TFP (US=1)

Employment (US=1)

Note: Figure shows the contribution of foreign innovation (see equation 5 to a country's growth vs. the country's TFP (left panel) and labor supply (right panel). Red solid line is OLS regression line.

panel) and foreign products that are new to the country but not to the world (right panel). The latter are products that were previously not sold in a country but that become available to the country's consumers when the product is improved upon by a country with a significantly lower wage than that of the incumbent country. This effect is large for a small country because the profits from selling to the small market often does not justify the fixed cost. As a result, many products, particularly products made by high wage countries, will not be sold in small markets until a low wage country innovates upon and takes over the product. Figure 10 shows that the higher contribution of new foreign products to growth in low TFP countries comes entirely from foreign products that are new only to the country but not the world, and not from new foreign products that are new to the world. In small markets such as a Israel and

Figure 9: Share of Growth from Foreign Innovation:
Quality Upgrading vs. New Products

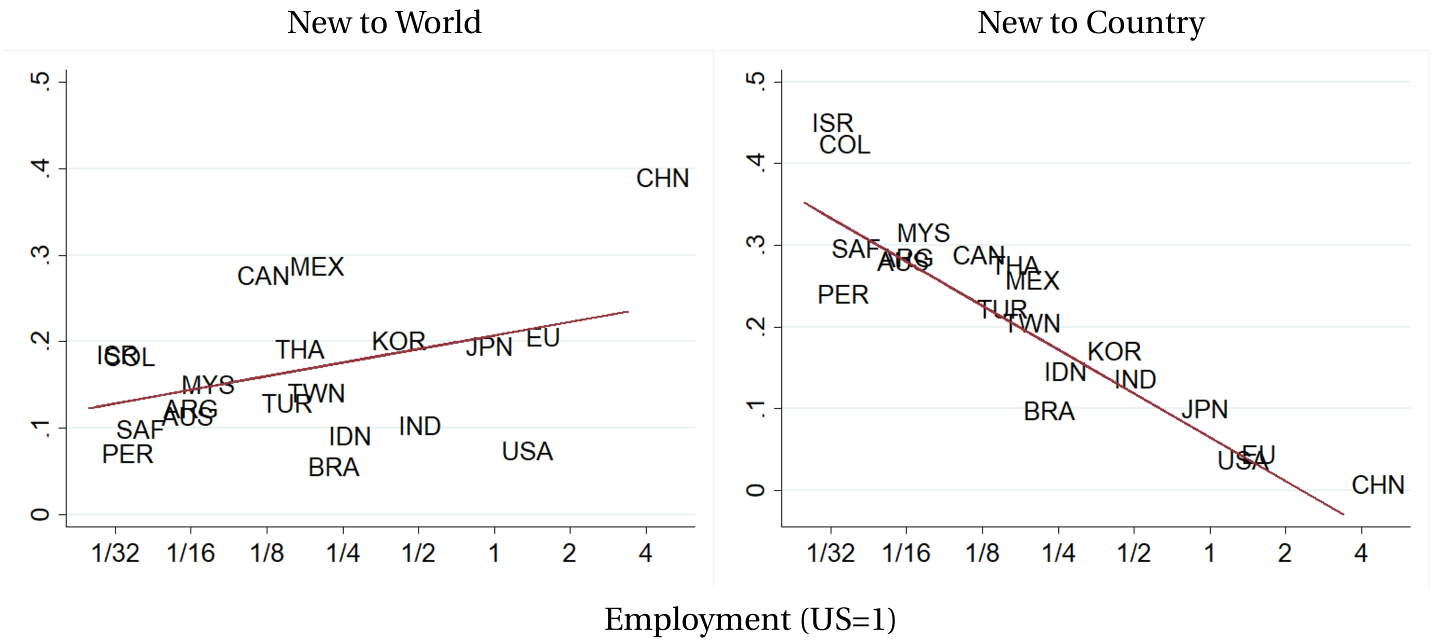


Note: Figure shows the contribution of quality upgrading and introduction of new products (see equation 6 to a country's growth vs. the country labor supply. Red solid line is OLS regression line.

Colombia, the introduction of foreign products that are new to the local market but not new to the world accounts for more than 40% of aggregate growth.

The model predicts that entry of new imports will be more frequent in smaller countries. We in fact observe this pattern in the data. Figure 11 compares the empirical distributions of positive import growth for the US and Colombia. As before, the import growth for a product category is defined as the change in imports of the product category divided by the average of the category's imports prior and after innovation. Notice that the share of import growth equal to 2 is more than four times higher in Colombia compared to the US. Remember that we did not target any moments on (positive) import growth when calibrating the model.

Figure 10: Share of Growth from Foreign New Products



Note: Figure shows the contribution of foreign new products that are also new to the world (left panel) and foreign new products that are only new to the importing country but not to the world (right panel) to a country's growth vs. the country labor supply. Red solid line is OLS regression line.

6.3 Trade Accounting: Ricardian versus Romerian Trade

The innovation parameters also determine the share of Romerian vs. Ricardian products in a country's exports. We remind the reader that we define a Romerian product as one where only one country has the blueprint, and a Ricardian product as one where more than one country has the blueprint for the product.[14] Table 7 shows the export shares of Romerian products in a country's exports, where the rows are the origin countries and the columns are the destination countries. The last column (World) thus shows the Romerian share of

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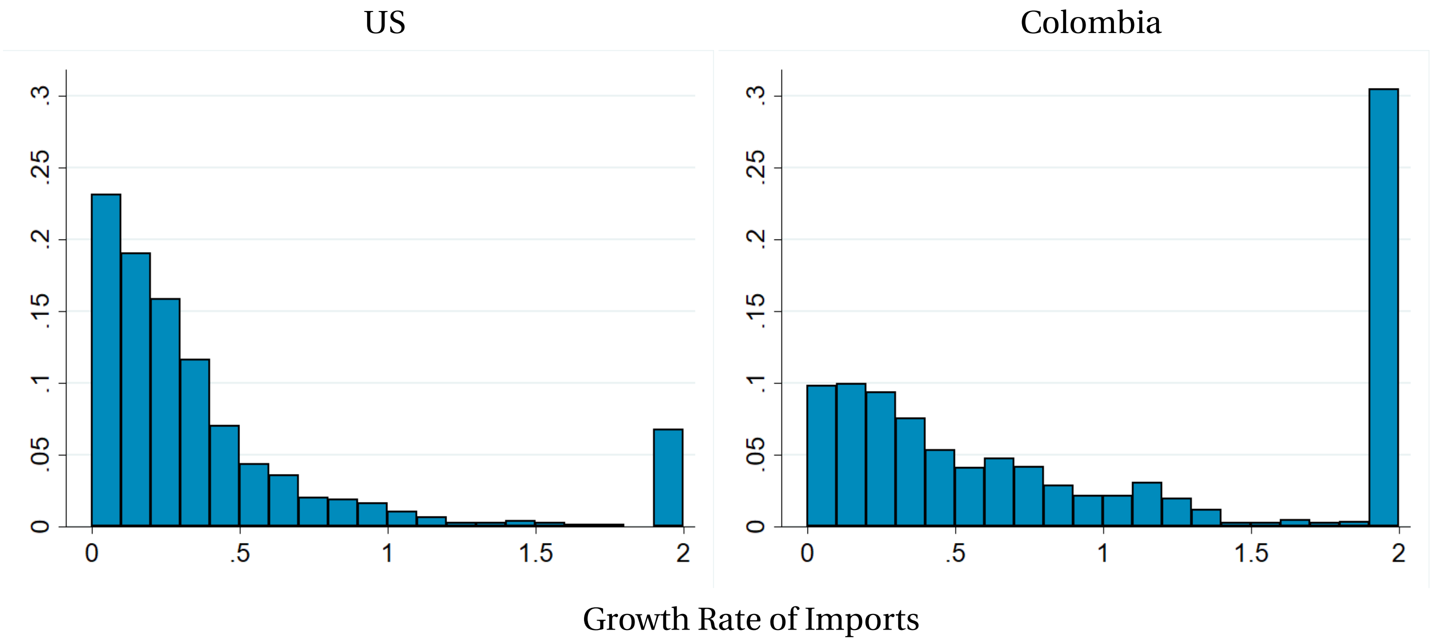
[14] When an innovator in a country attempts to innovate upon a Romerian product produced by another country, but fails to take over the product even in the domestic market due to the wage differences, we consider the blueprint to be lost in the country where the innovator is located. That is, the product remains Romerian in this case.

Figure 11: Empirical Distribution of Positive Import Growth



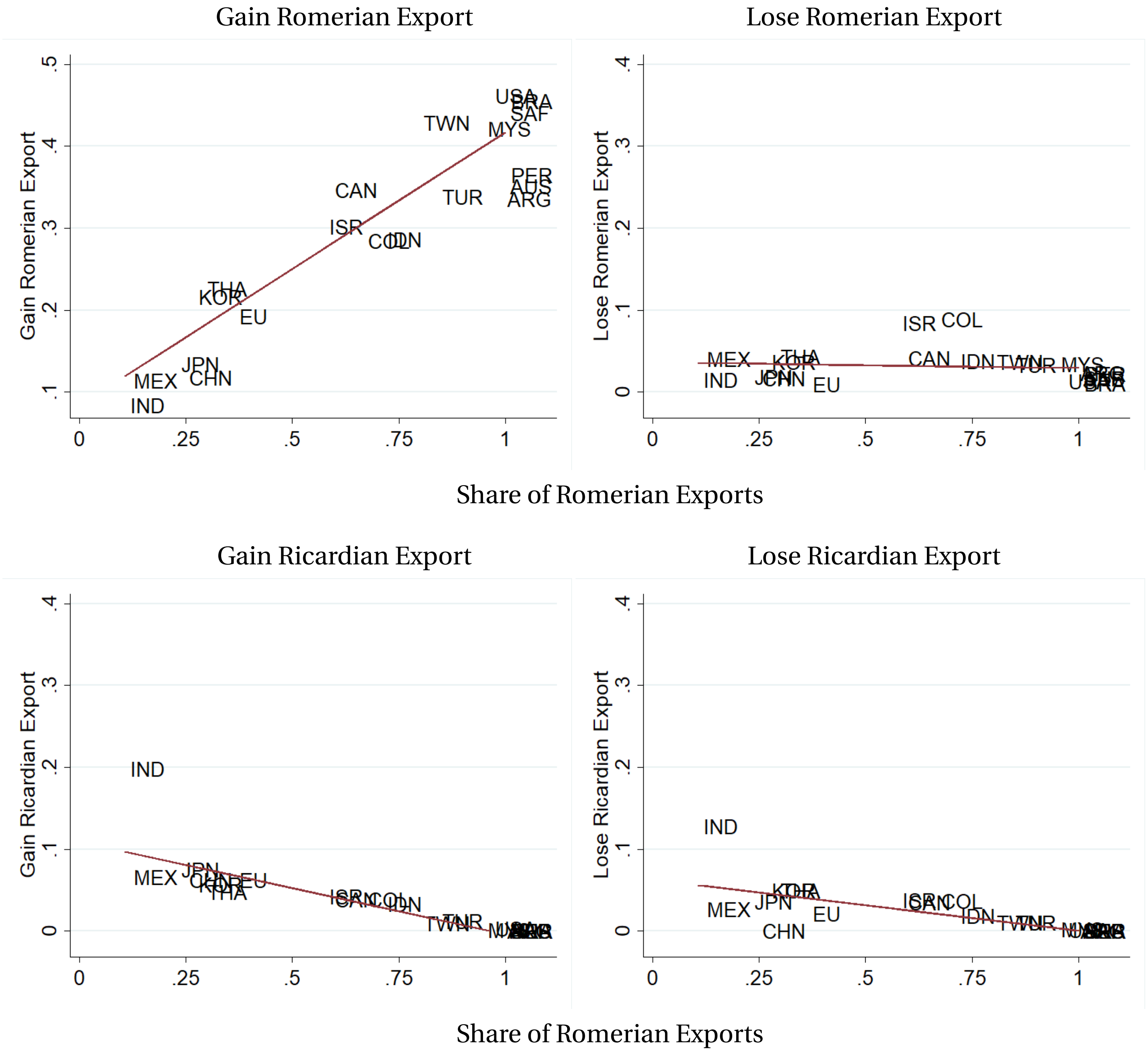
Note: Figure shows the distribution of positive import growth averaged over non-overlapping five year periods from 1991 to 2016 in Colombia and the US in the four-digit trade data. Growth rate defined as change in imports of the import category divided by the average of imports of the category at the beginning and end of the five year period. Total import growth normalized to zero for each country and each five-year period.

each country's total exports.

We highlight the following findings from Table 7. First, US exports are predominatly Romerian while Chinese exports are mainly Ricardian. Second, it is not always the case that rich countries primarily specialize in Romerian goods and non-rich countries specialize in Ricardian goods. Exports from the EU and Japan are mainly Ricardian, while slightly more than half of the exports in the rest of the world are Romerian. Third, there is also no clear evidence that countries sell more Romerian goods to richer countries compared to poorer ones.

Figure 12 decomposes the variation in the share of Romerian vs. Ricardian products across countries into the net growth of Romerian exports (top panel) and Ricardian exports (bottom panel). A country gains a Romerian export when

Figure 12: Decomposing Share of Romerian Trade



Note: Figure shows the probability (per exported product of a country) that a country gains a Romerian product, loses a Romerian product, gains a Ricardian product, and loses a Ricardian product.

Table 7: Export Share of Romerian Products

	US	China	EU and Japan	ROW	World
US	.	97.8%	92.4%	75.1%	96.4%
China	24.8%	.	28.2%	22.0%	24.4%
EU and Japan	22.5%	41.0%	28.9%	13.9%	31.2%
ROW	38.0%	69.7%	55.6%	23.9%	54.8%
World	27.7%	64.6%	40.5%	21.3%	41.8%

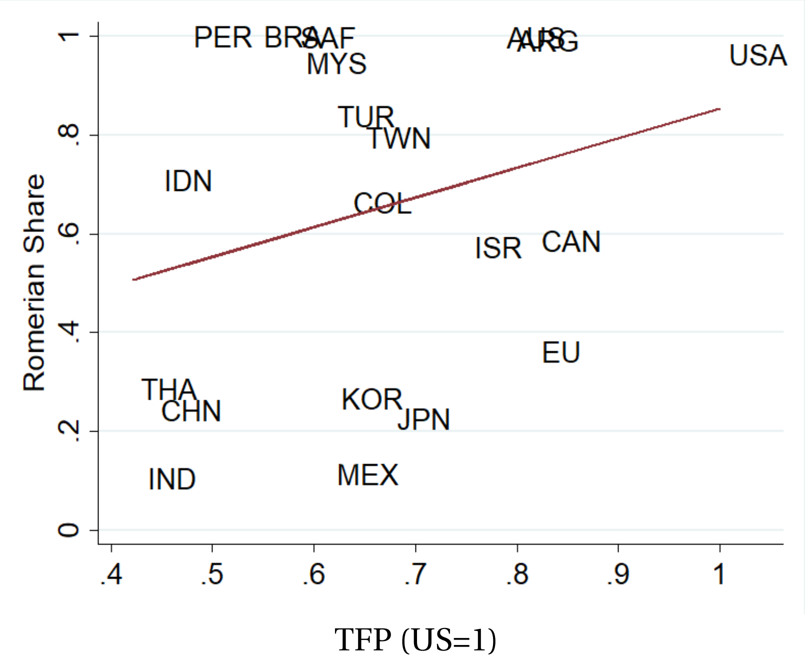
Note: Table shows the share of Romerian products in a country's exports. Origin countries are in the rows and destination countries are in the columns.

it creates a new product and loses a Romerian product when another country improves upon and replaces that product. So the net gain in Romerian products depends on the magnitude of κ in the country vs. δ in the rest of the world. A country gains a Ricardian export when it improves upon and replaces its import and loses a Ricardian export when another country improves upon and replaces their imports. So the net gain in Ricardian products depends on δ in the country vs. δ in the rest of the world.

Figure 12 shows that the heterogeneity across countries in the Romerian share is driven primarily by cross-country differences in the rate at which countries gain a Romerian product, with India and Mexico at one extreme with an arrival rate around 10% and the US at the other extreme with an arrival rate of 45%. The heterogeneity across countries in the rate at which countries gain a Ricardian product is much lower, ranging from 10-20% for India and Mexico to essentially zero for the US. The dispersion in the rate at which countries *lose* an export, either Romerian or Ricardian, is even lower.

Figure 13 plots the Romerian share of exports of a country vs. the country's TFP. The share of Romerian goods in a country's exports is typically higher in rich countries compared to poorer countries. The share of Romerian goods in India and China's exports are 10% and 25%, respectively, while the share in

Figure 13: Romerian Share of Exports vs. TFP



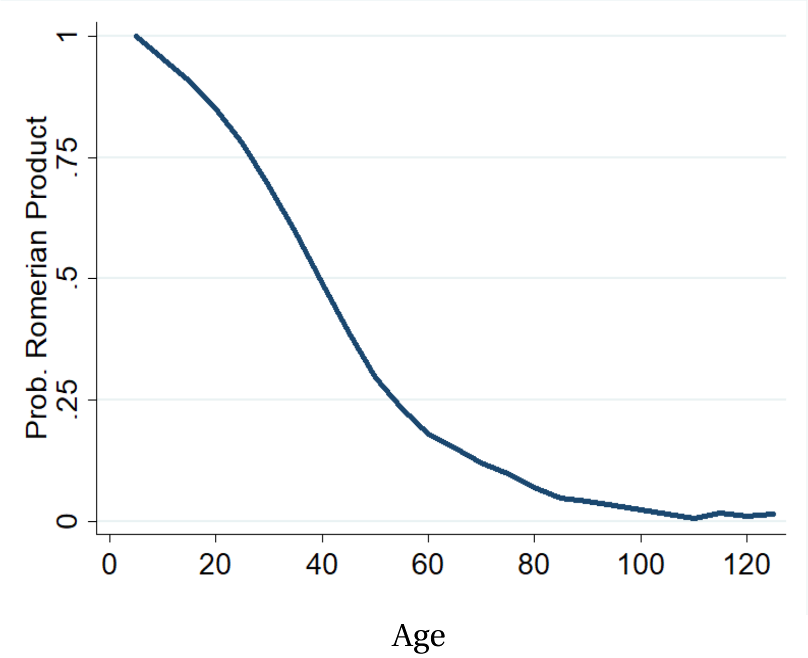
Note: Figure plots the share of Romerian products in a country's exports vs. the country's TFP.

the US is almost 100%. This should not be surprising given the earlier findings that innovation on new products is higher in rich countries compared to poorer countries, and that most of the variation in the Romerian share across countries comes from differences in the arrival rate of new products.

6.4 Product Life-Cycle

In this section, we draw out the implication of the innovation parameters we estimated for the product life-cycle. First, new products are by definition Romerian but they gradually change into Ricardian products as they get improved upon by innovators in other countries. Figure 14 shows the transition from Romerian to Ricardian products over a product's life-cycle. Specifically, it shows the share of a given cohort of products that are Romerian as a function of the

Figure 14: Product Life-Cycle: Share of Romerian Products



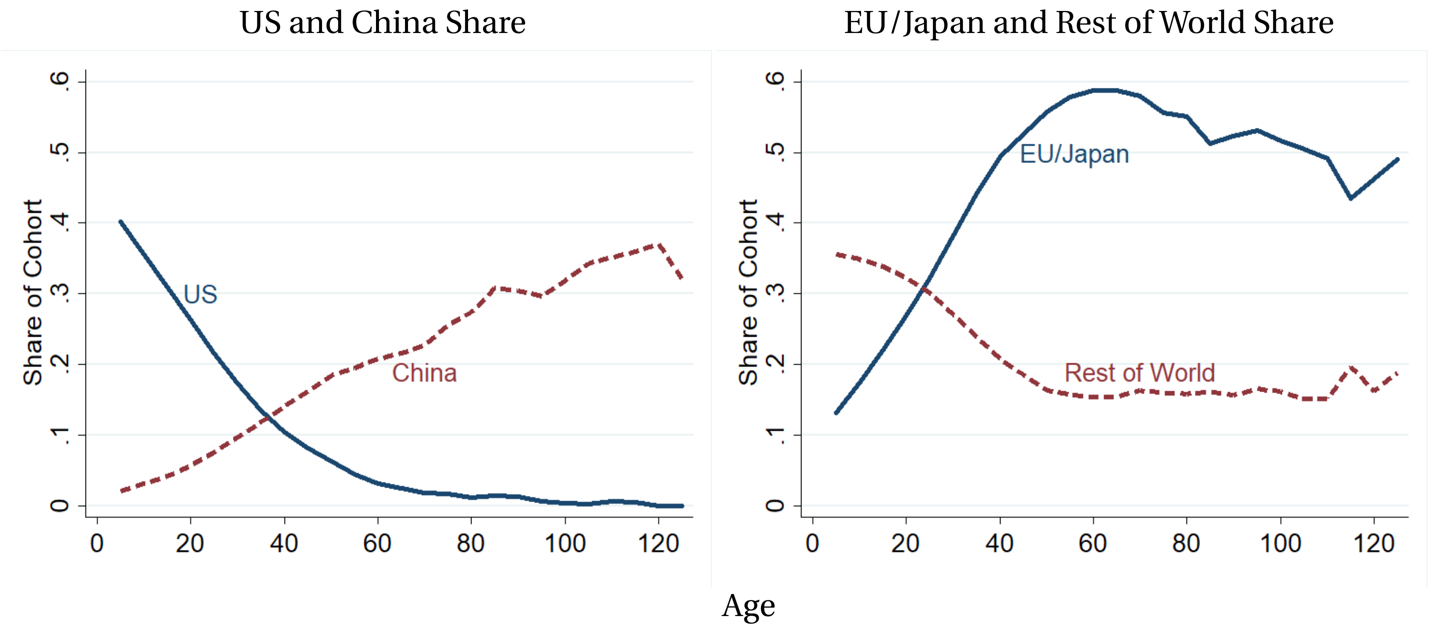
Note: Figure shows the share of Romerian product among all existing products of a given cohort of products in the world as a function of the cohort's age.

cohort's age. The half-life of a Romerian product is about 50 years as other countries innovate and turn the Romerian product into a Ricardian product.

The next figure shows how products move across countries as they age. The left panel in Figure 15 shows the share of of a given cohort of products that belong to the US and China as a function of age. About 40% of all new products are from the US, and only 2% are from China. Over time, the US loses its new products to innovators to other countries: the half-life of a Romerian American product is slightly over 20 years. On the other hand, China gradually gains a larger share of the product of a given cohort. The model predicts that within 40 years, China's share of the products of a given cohort increases six-fold from 2% to more than 12%. So most new products are American and over time more of these products are taken over by Chinese firms.

The right panel in Figure 15 shows the evolution of the share of the cohort

Figure 15: Reallocation of Products Across Countries



Note: Figure shows the share of products that belong to the US, China, EU/Japan, and the rest of the world among all existing products of a given cohort of products in the world as a function of the cohort's age.

belonging to EU and Japan and the rest of the world. The figure shows that the share of the EU and Japan rises over the product life-cycle. This is because the EU and Japan innovate more by improving upon their imports compared to creating new products. So the share of Japan and the EU over the global product life-cycle looks more similar to that of China than the US. The figure also shows that the share of the remaining countries in our sample falls over the product life-cycle, although the decline is less pronounced than the decline of the American share.

7 Conclusion

We endeavored to answer the following questions: How much of existing trade is Romerian (reflecting differentiated varieties) versus Ricardian (reflecting differing quality levels of the same varieties)? Is there a global product cycle whereby new varieties are created in rich countries and later migrate to developing countries? How much do differentiated varieties versus quality levels contribute to TFP differences across countries? How much growth, on average, comes from new variety creation versus quality improvements? How much growth comes from home innovations versus innovations abroad?

We simulated a 20-country model of trade and growth, and inferred the arrival rates of new varieties and creative destruction to fit observed dynamics of export and import growth in each country. Our parameter estimates led us to five tentative answers to the questions we posed:

First, trade flows reflect Ricardian (59%) quality differences modestly more than Romerian (41%) product differentiation. Second, the U.S. disproportionately creates new products and developing countries such as China disproportionately creatively destroy them. Third and related, TFP differences across countries reflect differences in new variety creation rather than in average qualities. Fourth, growth comes a little more from new products (56%) than from quality improvements on existing products (44%). Fifth, a little less than one-half (45%) of growth comes from innovations abroad, though less for the U.S. (20%) and more for small countries (80% to 90%).

We hasten to add several caveats to our analysis. For one, our inference was indirect and could usefully be supplemented by detailed information on products produced by individual countries. For another, we set aside the modeling of endogenous innovation. This means we are silent on important questions such as how trade affects the incentive to innovate, and how trade policy affects growth, TFP differences, and welfare.

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Online Appendix

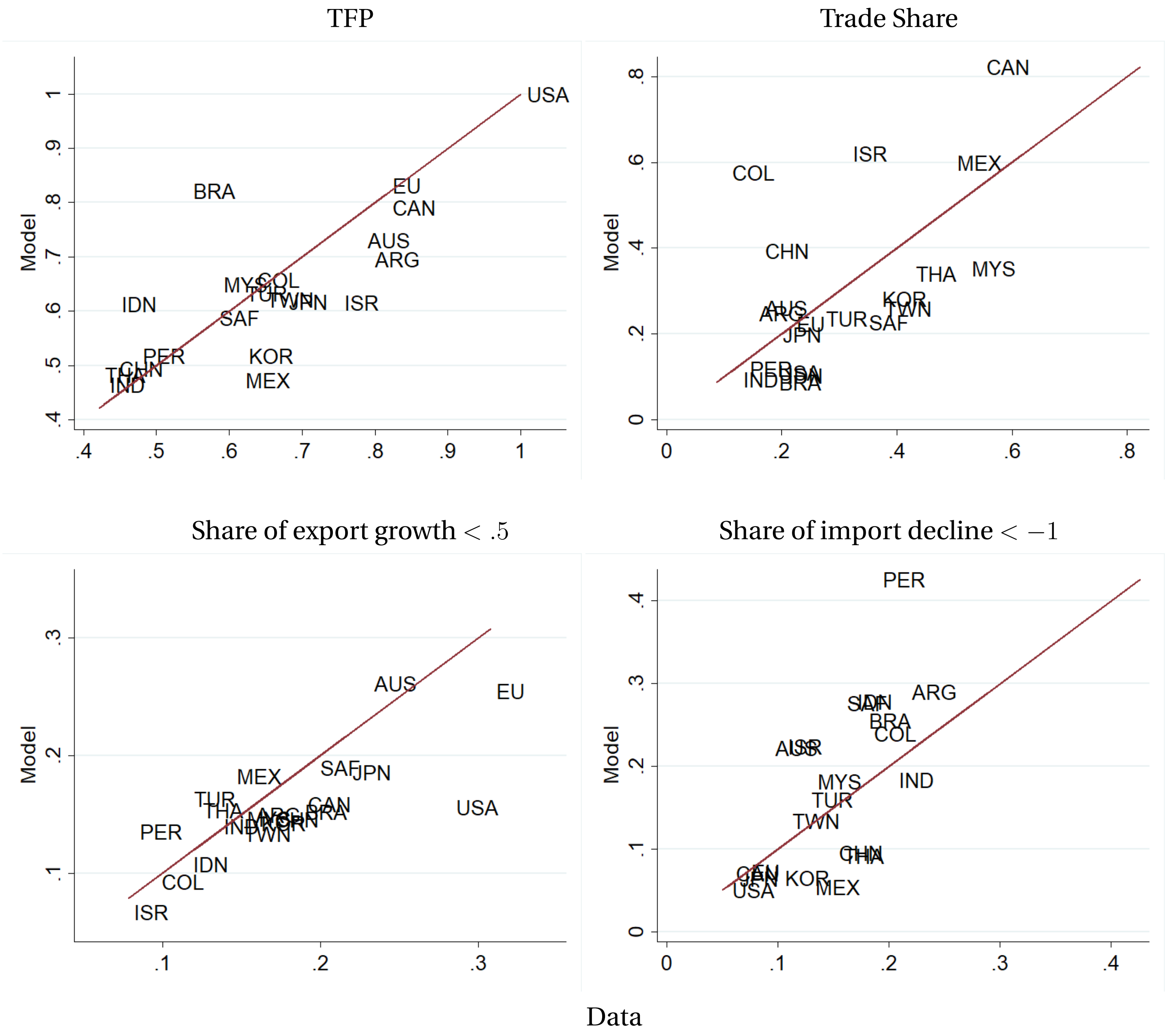
(Not for publication)

A Estimation Procedure

1. Fix σ to 3 and set f such that the average number of products per country is between $2,500$ and $3,000$.
2. Set the initial distribution of qualities and initial random assignment of varieties to categories and specify the vector of model parameters (λ_j, δ_j, κ_j, τ, θ).
3. Solve for the [initial] equilibrium relative wages and TFPs.
    - (a) Specify the initial guess for the vector of wages and TFPs.
    - (b) Based on the guess, determine the trade flows.
    - (c) Compute the TFPs of each country, the relative wages that would balance the trade of each country, and the distance between the guessed and solved wages and TFPs.
    - (d) Update the guess and repeat (b) and (c) until the guess and solution become close.
4. Repeat step 3 for several years until the model attains stationarity while computing period specific moments in every iteration.
    - (a) As determined by κ_c, randomly assign new varieties that are introduced in each period either to new categories at the rate of one product per category or to existing categories that are produced in the country.
5. Compute various moments including product cycles, trade flows of Romerian products, and growth decomposition, along with the objective function.

B Additional Figures and Tables

Figure B1: Model vs. Data



Note: Figure shows the TFP, trade share, share of small export growth, and share of large import declines predicted by the model on the y-axis and in the data on the x-axis.

Table B1: Country Specific Empirical Moments

	TFP (US=1)	Export Growth < 0.5	Import Growth < -1	Trade Share	Relative GDP
US	1	28.2%	5.4%	18.4%	1
China	0.441	16.8%	15%	16.2%	1.504
EU	0.816	30.8%	7.1%	21.5%	1.021
Japan	0.674	21.6%	6.1%	19.2%	0.487
India	0.428	13.5%	20.3%	12.2%	0.166
Korea	0.618	15.9%	10.1%	36.4%	0.189
Indonesia	0.444	11.6%	16.6%	20%	0.091
Brazil	0.542	18.7%	17.7%	18.5%	0.092
Mexico	0.615	14.4%	12.9%	49.5%	0.088
Taiwan	0.644	14.8%	10.8%	36.9%	0.091
Thailand	0.422	12.2%	15.4%	42.4%	0.054
Turkey	0.615	11.7%	12.6%	26.8%	0.069
Canada	0.816	18.8%	5.7%	54.6%	0.072
Malaysia	0.584	15%	13.1%	52%	0.031
Argentina	0.792	15.6%	21.6%	15.1%	0.036
Australia	0.781	23%	9.3%	16.1%	0.035
South Africa	0.579	19.6%	15.7%	34.2%	0.017
Colombia	0.63	9.6%	18.1%	10.5%	0.017
Peru	0.473	8.2%	18.9%	13.5%	0.012
Israel	0.75	7.8%	10.4%	31.4%	0.018

Note: TFP is manufacturing TFP relative to the US. Export growth is the share of export categories with a growth rate $< .5$ among exports with positive growth calculated among exports in the bottom quartile. Import decline is the share of import categories with a growth rate < 1 among imports with negative growth calculated among imports among the bottom 25-75 percentile. Export growth and import decline is average over successive five-year periods from 1991 through 2016 for each country in the four-digit SIC trade data. Growth of total imports and exports normalized to zero for each country and five year period.

Table B2: General Empirical Moments

	Value
Share of categories with positive export, US	45.4%
Average Exit Rate (avg of 20 countries)	19.2%
Growth	15.9%

Note: Row 1 is share of export categories in the US with positive export growth (average over five-year periods from 1991 to 2016). Average exit rate is exit rate of exports in bottom quartile over 20 countries, where the exit rate of each country is the average exit rate over five year periods from 1991 to 2016. Growth is over a five year period.

Table B3: General Model Parameters

	Value
Share of new products in new category κ_c	2.8%
Pareto Shape θ	18.75
Fixed Cost f	0.05

Note: κ_c is the share of new products that are allocated to new export categories. θ is the shape parameter of the distribution of the innovation step size. f is the fixed cost in units of labor to sell in a market.

Table B4: Estimated Innovation Arrival Rates and Trade Cost

	Domestic Products λ	Imported Products δ	New Products κ	Trade Costs τ
US	71.9%	4.7%	77.9%	1.817
China	96.7%	0.4%	14.6%	1.291
EU	89%	9.9%	20.3%	1.52
Japan	99.7%	4%	13.1%	1.886
India	95%	8.8%	3%	2.567
Korea	54.9%	2.6%	20.3%	1.874
Indonesia	74.3%	73%	13.1%	2.165
Brazil	58%	71.9%	66.7%	2.332
Mexico	74.7%	0.6%	9.9%	1.428
Taiwan	12.1%	12%	39.7%	1.832
Thailand	51.7%	1.5%	21.9%	1.877
Turkey	66.1%	16.1%	29%	1.874
Canada	25.5%	23.7%	42.7%	1.103
Malaysia	7.7%	17.7%	47.2%	1.727
Argentina	62.1%	93.5%	34.2%	1.893
Australia	94.2%	20.4%	49.3%	1.98
South Africa	53.4%	8.5%	73.6%	2.207
Colombia	46.6%	53.4%	18.7%	1.342
Peru	58.1%	91%	40.9%	2.579
Israel	26.3%	21.9%	23.5%	1.343

Note: Table shows the arrival rate of innovation on domestic products (column 1), arrival rate on imported products (column 2), arrival rate of new products (column 3), and the gross trade cost (column 4).