# The Selection Effect of International Competition*

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*Abstract*

Building on Eaton and Kortum (2002), we study the relationship between international trade and the TFP of tradeables. We show that the latter is equal to the autarky TFP, augmented by a measure of trade openness. A remarkable consequence is that, differently from Ricardian non-probabilistic frameworks, in this model openness always raises TFP. The result is due to the selection effect of international competition, which makes "some" high- and "many" low-productivity firms exit the market, and is very robust to the assumptions about the distribution of firm productivities. Our analysis delivers a model-based measure of trade openness, allows to easily quantify the magnitude of the selection effect and to estimate TFP levels relative to a benchmark country. For a sample of 19 OECD countries, we find that the contribution of international competition to the TFP of the manufacturing sector was, on average, 9.4% in 2002 (5.8% in 1985). After computing TFP levels relative to the U.S. for all our sample countries, we focus on Italy and compare our estimates with others obtained from development accounting and from official statistics. Results show that dynamics are very similar but also point to some appealing differences in levels.

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# 1 Introduction

In economics there are few theories that have been studied as extensively as the Ricardian model of international trade, which is now almost two centuries old. It is commonly believed that the standard model without externalities and distortions, while implying that trade is welfare improving, does not deliver a positive effect of trade openness on the Total Factor Productivity (TFP). In fact, it is easy to build textbook examples in which one country holds a comparative advantage in the production of low-productivity goods, so that its TFP diminishes after removing trade barriers. Yet, there is growing empirical evidence — especially studies based on firm-level data — pointing out that trade has a significant positive impact on TFP.[1] An intriguing question, then, is: are those textbook examples "theoretically" robust?

In this paper we tackle this issue building on the general version of the Ricardian model of trade developed by Eaton and Kortum (2002, EK hereafter). By describing firm productivities in each country (country technologies) with mutually independent Fréchet distributions, the EK model extends the Ricardian theory to a world with many countries and a continuum of goods. In this probabilistic setting, we demonstrate that international competition induces a selection effect that favors firms with, *on average*, a higher productivity. Therefore, trade openness always raises TFP, marking a key difference with respect to other Ricardian models (such as Dornbusch, Fischer, and Samuelson, 1977). Specifically, we show that the TFP of the tradeable sector in an open economy with perfectly competitive markets is equal to the autarky TFP, augmented by a measure of trade openness. This result is proved using both the assumptions of mutual independence and Fréchet distribution of firm productivities. However, we show that neither assumption is necessary. The result tends, in fact, to be quite general. It holds for correlated Fréchet distributions, with the extent of the productivity gain decreasing as correlation increases. It also holds, under mutual independence, for *any* distribution of country technologies, including the ones used in the literature to describe firm productivities, such as the Pareto, the Weibull, and the uniform.

These results challenge the common belief and call for a reconsideration of the relationship between trade and TFP in the Ricardian model. We show that the comparison between the TFP of an open economy and the TFP under autarky boils down to a comparison between a conditional mean and a simple mean, where the conditioning event is

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[1] Given the huge volume of empirical studies on trade and TFP, and on the related topic of openness and growth, it is impossible to list even just the main surveys. Among the most influential papers see Bernard and Jensen (1999), Frankel and Romer (1999), Bernard, Eaton, Jensen, and Kortum (2003), Dollar and Kraay (2003), and Alacalá and Ciccone (2004). For a recent survey with an emphasis on firm-level data see Bernard, Jensen, Redding, and Schott (2007).

that domestic firms survive international competition. It is this conditioning that "tends" to lift the TFP after openness. By introducing enough correlation among country technologies, we explain that it is still possible to build *ad hoc* examples in which international competition induces an "adverse" selection in favor of firms with low productivity. These examples are the counterparts, in our general setting, of the textbook examples mentioned above. However, we suggest that these examples are theoretically fragile. In fact, no example would survive an arbitrary decrease in the correlation among country technologies, since independence is a sufficient condition for our main result.[2] More importantly, whatever the degree of correlation, *ad hoc* examples cannot be built for large families of theoretical distributions, that are likely to provide very good descriptions of the empirical distributions of firm productivities. Here we illustrate in detail results based on the multivariate Fréchet. We also show, however, that using the multivariate normal confirms the robustness of our main predictions.

Our findings also shed light on the factors that affect the TFP of the tradeable sector in an open economy. An increase in TFP may occur without "genuine" domestic technological progress. It may simply reflect external factors such as improvements in the technologies of competitor countries, loosening trade barriers (including the entry of new competitors), declining foreign input costs, or it may be due to rising domestic costs. The TFP gain from trade (i.e. the ratio between the autarky's and the open economy's TFP) is also increasing in the degree of heterogeneity of both domestic and foreign technologies (the variance of the distributions of firm productivities).

These findings bring this paper close to the literature that emphasizes the role of institutions (or "social infrastructure", as in Hall and Jones, 1999) in explaining TFP differences across countries. Examples include Conway and Nicoletti (2006) and Lagos (2006), who show that higher regulation in the non-tradeable sector and in the labor market lowers the TFP of the tradeable sector. Our analysis shows, in contrast, that regulation in the non-tradeable sector and in the labor market, by rising domestic costs and forcing less efficient firms to exit, has the opposite effect. In addition, the effect of other factors, such as proximity to high-TFP countries (or, in other words, *geography*), also emerges.

This paper is also closely related to Melitz (2003) (and the subsequent literature, including Melitz and Ottaviano, 2008), who also derives a positive relationship between international trade and TFP. Our paper differs in that we obtain this result without resorting to any form of market power, whereas previous studies assume monopolistic competition.[3] Moreover, in Melitz (2003) all and only the firms whose TFP is above a

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[2] In the multivariate analysis, we use distributions in which uncorrelaton implies independence. However, we will also clarify that the validity of our main results goes beyond those distributions.

[3] Another close relative of this paper is the work of Bernard, Eaton, Jensen, and Kortum (2003) who

certain threshold start exporting after trade barriers decline; hence, no low-productivity firm becomes an exporter and no high-productivity firm exits the market. In our paper, instead, both low- and high-productivity firms can export or exit the market, although, of course, with different probabilities. Therefore, removing trade barriers generates some "action" along the whole distribution of firm productivities, not just in the proximity of a threshold. It is exactly to stress this difference that we use the expression *selection effect of international competition*, instead of *self-selection*, as is common in the monopolistic competition literature. In the latter, in fact, low-productivity firms really self-select by refraining from paying a sunk cost, so they cease to produce or export whenever they expect negative profits. Here, instead, it is international competition that forces firms to exit — not only those with low-productivity, but also some with high-productivity.

Our results have also important empirical implications. First, they provide a *Ricardian measure of trade openness*, which is given by the ratio between the value of total absorption and that of the domestic production sold domestically. This ratio gathers all the factors mentioned above, including those related to domestic and foreign costs that are analyzed by Alcalá and Ciccone (2004) using a small-open-economy model. Second, they allow us to quantify the selection effect easily, as its magnitude can be measured using only production and trade data.

In the empirical analysis, we quantify the selection effect for a sample of 19 OECD countries with annual data from 1985 to 2002. When we bring the model to the data, the definition of tradeable sector boils down to the manufacturing sector. We find that, on average, international competition lifted manufacturing TFP by 5.8 percent above the autarky level in 1985; this contribution increased to as much as 9.4 percent in 2002. Over time, there is a neat positive trend, common to all countries. In the cross-section, however, the gain from international competition features large differences.

The theory provides another useful spin-off for the empirical analysis. Our results link model parameters to TFP levels relative to a benchmark country. Hence, by estimating the former (for instance as in EK), we can measure TFP levels, relative to the United States, for the manufacturing sector of the remaining 18 OECD countries of our sample. Our estimates of the model parameters depart from EK in one respect: we show that it is crucial to convert input costs (wages) into a common currency using purchasing-power-parity (PPP), instead of market exchange rates. Using PPP exchange rates is also consistent with the standard development-accounting approach, which is the yardstick for our analysis. With respect to standard methods, our model-based estimates of TFP — which we dub *trade-revealed TFP* — entail two main advantages. First, they are no longer mere residuals. Second, they require data on bilateral trade shares, production and input

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analyze trade and productivity with Bertrand competition, but do not derive a closed-form expression for the aggregate TFP.

costs instead of hard-to-get quantity data on the stock of physical capital. Thus, they may be especially helpful for sectoral analysis, as the necessary data are available even for very fine classifications of industries.[4]

Once we have computed TFP relative levels for all our sample countries, we provide a zoom shot of the manufacturing TFP of Italy relative to that of the United States, comparing our measure of TFP with one obtained from development accounting. One reason to focus on this case study is that standard methodologies often find that Italy is the most productive country in the world — a surprising result given Italy's weak social infrastructure relative to other industrial countries (Hall and Jones, 1997). In addition, data limitations that hamper the application of the development-accounting approach to the manufacturing sector would not allow to extend this comparison to many other countries. The exercise reveals that our methodology, while delivering very similar dynamics compared to development accounting, no longer yields the puzzling result about Italy's high relative TFP.

The rest of the paper is organized as follows. Section 2 offers a brief outline of the EK model and presents our main theoretical results about trade and TFP. In Section 3 we elaborate on our results, providing some intuition and comparing them with those of the Melitz model, and we extend them to more general distributional assumptions. In Section 4 we quantify the effect of openness on TFP. In Section 5 we measure trade-revealed TFPs for the manufacturing sectors of our sample countries. Section 6 illustrates the case study. Section 7 concludes.

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[4] The idea of exploiting the effects of the TFP on production and trade in order to recover a measure of the TFP itself has been applied, independently, also in two recent papers by Waugh (2008) and Fadinger and Fleiss (2008). The former paper obtains a relationship between model parameters and the TFP using a variant of the EK model with traded intermediate goods and non-traded final goods. The latter starts from a model with monopolistic competition and homogeneous firms (while we assume perfect competition and heterogeneous firms) but ends up with an empirical framework that turns out to be similar to ours, as it requires only data on trade flows, production and input costs. Both papers, then, fully exploit the potential of the empirical methodology and measure the TFP for several countries (the former) or for several countries and industries (the latter). Neither of them, however, obtains the whole distribution of firm productivities in a open economy and, therefore, is able to single out the selection effect of international competition.

# 2 Theoretical background

## 2.1 An outline of the Eaton-Kortum model

EK consider a Ricardian framework with $N$ countries ($N > 1$), a continuum of tradeable goods, and constant-returns-to-scale technologies. Denote with $z_i(j) > 0$ the efficiency of country $i$ in producing the tradeable good $j$, with $i \in \{1, ..., N\}$ and $j \in [0, +\infty)$, namely:

$$q_i(j) = z_i(j) \cdot I_i(j) \ , \tag{1}$$

where $q_i(j)$ is the amount of good $j$ produced by the representative firm of country $i$ and $I_i(j)$ is the amount of input needed to produce that output (with the bundle of inputs to be specified later).

The key hypothesis is that each $z_i(j)$ is the realization of a country-specific random variable $Z_i$. Specifically, it is assumed that for any country $i$:

$$Z_i \sim Fréchet\,(T_i, \theta) \ , \tag{2}$$

with $T_i > 0$, $\theta > 1$, with the $\{Z_i\}_{i=1}^N$ mutually independent. Due to the continuum-of-goods assumption and the law of large numbers, hypothesis (2) implies that the share of goods for which country $i$'s efficiency is lower than a real number $z$ is simply the probability: $\Pr(Z_i < z) = F_i(z) = \exp\left(-T_i \cdot z^{-\theta}\right)$, where $F_i$ denotes the cumulative distribution function (c.d.f.) of $Z_i$. Therefore, this hypothesis allows to describe the technology of the tradeable sector of each country with the c.d.f. of $Z_i$ that, in turn, is summarized by two numbers, $T_i$ and $\theta$.[5]

EK show that $T_i$ and $\theta$ are the theoretical counterparts, in a context with many countries and a continuum of goods, of the Ricardian concepts of absolute and comparative advantages. $T_i$, to which we will refer as *state of technology*, captures country $i$'s absolute advantage: an increase in $T_i$, relative to $T_n$, implies an increase in the share of goods that country $i$ produces with a higher efficiency than country $n$. $\theta$, in turn, is inversely related to the dispersion of $Z_i$ (we will refer to it as the *precision of the distribution*);[6]

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[5] Kortum (1997) and Eaton and Kortum (2008) show that the Fréchet distribution emerges from a dynamic model in which, at each point in time: (*i*) the number of ideas that arrive about how to produce a good follows a Poisson distribution; (*ii*) the efficiency conveyed by each idea is a random variable with a Pareto distribution; (*iii*) firms produce goods using always the best idea that has arrived to them. Jones (2005) shows that this set up on the flow of ideas entails two other results: the global production function is Cobb-Douglas and technical change in the long run is labor-augmenting.

[6] Indeed, both $T_i$ and $\theta$ are related to the mean and the variance of $Z_i$. Denoting Euler's gamma function by $\Gamma$, the mean of $Z_i$ is $T_i^{1/\theta} \cdot \Gamma\left[(\theta-1)/\theta\right]$ if $\theta > 1$, while its variance is $T_i^{2/\theta} \cdot \left\{\Gamma\left[(\theta-2)/\theta\right] - \Gamma^2\left[(\theta-1)/\theta\right]\right\}$ if $\theta > 2$. The link between $\theta$ and the variance of $Z_i$ can be recognized considering also that the standard deviation of the log of $Z_i$ is: $\pi/\left(\theta\sqrt{6}\right)$.

its connection with the concept of comparative advantage stems from the fact that, in Ricardo, gains from trade depend on cross-country heterogeneities in technologies. In this perspective, EK demonstrate precisely that a decrease in $\theta$ (i.e. higher heterogeneity) generates larger gains from trade for all countries.

A second set of assumptions concerns costs and trade barriers. The cost of the bundle of inputs in country $i$ is denoted with $c_i$; later, it will be split into wages and prices of intermediate goods, and endogenized. Trade barriers are modeled as Samuelson's iceberg costs: delivering one unit of good from country $i$ to country $n$ requires producing $d_{ni}$ units, with $d_{ni} > 1$ for $i \neq n$ and $d_{ii} = 1$ for any $i$. Arbitrage makes trade barriers obey the triangle inequality, so that $d_{ni} \leq d_{nk} \cdot d_{ki}$ for any $n$, $i$ and $k$.

As for the market structure, the model assumes perfect competition. Together with the hypotheses on costs and technologies, perfect competition implies that the price of one unit of good $j$ produced by country $i$ and delivered to country $n$ is:

$$p_{ni}(j) = \frac{c_i \cdot d_{ni}}{z_i(j)} \ . \tag{3}$$

Of course, consumers in country $n$ will buy each good $j$ from the country that provides it at the lowest price, i.e.:

$$p_n(j) = \min_{i=1,\ldots,N} \{p_{ni}(j)\} \ . \tag{4}$$

Consumers in country $n$ are subject to the usual budget constraint that total spending cannot be larger than total income. They purchase goods in order to maximize a standard CES utility function, with elasticity of substitution given by $\sigma > 0$.

With this set of assumptions, EK prove two fundamental properties of the model. First, the market share of country $i$ in country $n$ — i.e. the ratio between the value of the imports of country $n$ from country $i$, $X_{ni}$, and the value of the total expenditure (or total absorption) of country $n$, $X_n$ — is given by:

$$\frac{X_{ni}}{X_n} = \frac{T_i \cdot (c_i d_{ni})^{-\theta}}{\Phi_n} \ , \tag{5}$$

where:

$$\Phi_n = \sum_{k=1}^{N} T_k \cdot (c_k d_{nk})^{-\theta} \ . \tag{6}$$

The market share of country $i$ in country $n$, then, increases with the state of technology $T_i$ and decreases if the input cost $c_i$ and the trade barriers $d_{ni}$ increase. Its value depends also on the technologies, costs and trade barriers of any other country $k$: it increases with costs $c_k$ and distances $d_{nk}$ and decreases if any of the technologies $T_k$ $(k \neq i)$ increases.

Second, the exact price index of the bundle of tradeable goods in country $n$ resulting from the CES aggregator and the prices $p_n(j)$ is:

$$p_n \equiv \left\{ \int_0^{+\infty} \left[p_n(j)\right]^{(\sigma-1)/\sigma} dj \right\}^{\sigma/(\sigma-1)} = \gamma \cdot \Phi_n^{-1/\theta} \ , \tag{7}$$

where

$$\gamma = \left[ \Gamma\left( \frac{\theta+1-\sigma}{\theta} \right) \right]^{1/(1-\sigma)} \ ,$$

with $\Gamma$ denoting Euler's gamma function and $\sigma < \theta + 1$.

This set-up is completed by adding two further assumptions. The first is that production combines labor and intermediate inputs, where the latter, in turn, comprise the full set of tradeable goods aggregated with the CES function with elasticity $\sigma$. Denoting with $\beta$ the constant share of labor, with $\beta \in (0,1)$, then the cost $c_i$ takes the form:

$$c_i = w_i^{\beta} p_i^{1-\beta} \ , \tag{8}$$

where $w_i$ is the nominal wage in country $i$ and $p_i$ is given by equation (7).[7] The second hypothesis is that there is also a non-tradeable sector in the economy; thus, market shares, prices, and wages defined above are all referred to the tradeable sector.

These two further assumptions enable EK to solve the model for equilibrium prices (relative wages and price indices) and quantities (trade shares) in two polar cases. In one case, labor is mobile between the tradeable and non-tradeable sectors; in the other, it is immobile. In both cases, it is assumed that a constant fraction $\alpha \in (0,1)$ of the aggregate final expenditure is spent on tradeable goods. The solution of the model, then, is given by a system of non-linear equations, with parameters $d_{ni}$, $T_i$, $\theta$, $\alpha$ and $\beta$ (see EK, pp. 1756-1758). Because of non-linearities, there is no closed-form solution, but it is still possible to rearrange the main equations in order to obtain some testable implications, as illustrated in Section 5. In the following, instead, we build on the theoretical model and show how we can use it in order to derive a theoretical expression for the TFP of tradeables.[8]

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[7] Equation (8) implies that labor is the sole "non-produced" production factor, while physical capital is included into intermediate goods. The result, exploited in Sections 5 and 6, that the quantity of physical capital is not needed to estimate TFP levels is by no means dependent from this particular formulation of costs. In fact, labor is as a distinct production factor but, nonetheless, its quantity is not needed and only wages are.

[8] Alvarez and Lucas (2007) generalize the model by considering distinct final and intermediate goods, and distinguishing between tariffs and transport costs. Then, they provide sufficient conditions for existence and uniqueness of the equilibrium.

## 2.2 States of technology and TFP

Reconsidering the assumptions about technology specified by equations (1) and (2), it is clear that the mean of $Z_i$ is linked, but not identical, to the TFP of the tradeable sector of country $i$. In fact, the former is referred to the theoretical distribution of the productivities of *all tradeable goods*, while the latter is referred only to the productivities of the tradeables that are *actually made* by country $i$. In other words, the mean of $Z_i$ reflects the productivities of all potential producers, i.e. it is the TFP under autarky. In an open economy, instead, manufacturing TFP includes only the productivities of the firms that can sell goods at the lowest price in some country, and excludes the productivity of the firms that do not make any goods, because the goods they could make are sold at a lower price by some other country.

To obtain an analytic expression for the TFP of the tradeable sector, we resort to the model and find out which firms are able to make goods efficiently enough. Hence, we get the theoretical distribution of the productivity for the sole firms in country $i$ who engage in the production of some good. Denote such random variable as $\mathrm{TFP}_i$; its c.d.f. then is:

$$G_i\left(z\right)=\Pr\left(Z_i<z|P_{ii}=\min_k P_{ik}\right)\ . \tag{9}$$

The fact that the goods $j$ produced by country $i$ are all and only those for which $p_{ii}\left(j\right)\leq p_{ik}\left(j\right)$ for any $k$ requires a formal proof. First, if $j$ is such that $p_{ii}\left(j\right)\leq p_{ik}\left(j\right)$ for any $k$, then $j$ is certainly produced by country $i$ (i.e., all the goods that country $i$ can sell domestically at the smallest price are actually produced).[9] Second, country $i$ does not produce any other good (i.e., only the goods that country $i$ sells domestically are produced and there is no good $j$ which is sold by country $i$ in another country and not at home). This intuitive result is a consequence of the triangle inequality and its formal proof is deferred to Appendix A.1. Computing $G_i\left(z\right)$ yields the following result:

**Proposition 1** *If technologies are Fréchet distributed (equation (2)) and markets for tradeable goods are perfectly competitive, so that prices are equal to marginal costs (equation (3)), then:*

$$TFP_i\sim Fr\acute{e}chet\left(\Lambda_i,\theta\right)\ ,$$

*where*

$$\Lambda_i=T_i+\sum_{k\neq i}T_k\left(\frac{c_k d_{ik}}{c_i}\right)^{-\theta}\ . \tag{P1}$$

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[9] Given the continuity of the random variables considered here (i.e. of $Z_i$ and, as a consequence, of $P_{ik}$), we can neglect events of the type $p_{ii}\left(j\right)=p_{ik}\left(j\right)$, since they have zero probability.

**Proof.** See Appendix A.1 ■

Thus, $\mathrm{TFP}_i$ is Fréchet distributed. Our empirical measure of TFP will be based on the mean of this random variable:

$$E\left(\mathrm{TFP}_i\right) = \Lambda_i^{1/\theta} \cdot \Gamma\left(\frac{\theta-1}{\theta}\right) , \tag{10}$$

which is a monotone function of $\Lambda_i$.

The first remarkable result is that $\Lambda_i > T_i$ always; therefore $E\left(\mathrm{TFP}_i\right) > E\left(Z_i\right)$. In other words, the model predicts that the TFP of the open economy is always larger that the TFP under autarky. In the next section we concentrate on this result and show that this is a robust and general prediction of this Ricardian model.

Equation (P1) also shows that, in an open economy, $\Lambda_i$ depends not only on $T_i$, but also on the technologies, costs, and trade barriers of all the other countries, as well as on domestic costs. This result can be readily explained. Suppose that $T_k$ increases for some $k \neq i$. Country $k$, then, produces more goods than before (equation (5)), partly to the expenses of the production of country $i$. The goods that keep being produced in country $i$, however, are made with, on average, a higher productivity, which is reflected in the increase in $\Lambda_i$. The effect of $c_i$ and $d_{ik}$ are analogous: larger costs in country $i$ crowd out its production in favor of other countries, but average productivity in this country increases; higher trade barriers between $i$ and other countries narrow the range of goods exported by country $i$, letting survive firms with an higher average productivity. The effect of $c_k$, for $k \neq i$, is clearly opposite. Note that, as $d_{ik}$ go to $+\infty$ for any $k \neq i$ — i.e. as the country tends to autarky — then $\Lambda_i$ tends to $T_i$.

The positive relationship between aggregate productivity and domestic costs contrasts with the results of Lagos (2006) and Conway and Nicoletti (2006). In the EK model, if a country pays higher wages or incurs larger costs because of distorted labor or non-tradeable product markets, then the selection effect of international competition lets only the most productive firms survive, raising aggregate productivity. (Recall, however, that this improvement in productivity comes together with fewer exporters and lower market shares.) On the contrary, in Lagos and in Conway and Nicoletti distorted markets cause an adverse selection of productive units, hampering the efficiency of their allocation and, in turn, reducing aggregate productivity. Assessing the net effect of these distortions on TFP, then, remains essentially an empirical question.[10]

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[10] Chari, Restuccia, and Urrutia (2005) also show that more frictions in the labor market may raise the 'measured' TFP (proxied by income per worker). In their paper, the result occurs because higher firing costs increase the level of training that firms provide to workers, raising the level of human capital and, in turn, that of the measured TFP. They also find that the relationship between the level of employment protection and the TFP across European countries is, indeed, positive.

By recalling the expressions of costs (equation (8)) and prices (equation (7)), Proposition 1 also shows that changes in technologies, costs and trade barriers do not have only a "direct" selection effect on TFP. International competition yields also second- and higher-order effects via changes in input costs. Consider, for instance, an increase in the foreign technology $T_k$. The increase in $T_k$, by making available cheaper goods in country $k$, lowers also its input costs $c_k$ further enhancing its external competitiveness and providing an additional boost to the TFP of country $i$. This effect is partly offset by the availability of cheaper inputs in country $i$ (i.e. by a decline in $c_i$) and reinforced by lower input costs in countries other than $i$ and $k$.[11]

Proposition 1 also shows that the benefits of a technological progress in one country are not spread evenly on the TFP of other countries. The extent to which TFP changes following a change in foreign technologies and costs reflects the size of domestic costs and, inversely, that of domestic trade barriers. For instance, an increase in the technology of the United States will have a stronger (weaker) impact on closer (more distant) countries. By the same token, since the TFP in country $i$ changes as trade barriers change, equation (P1) suggests that looking at the dynamics of TFP growth may misrepresent the picture about "genuine" technological developments during periods in which countries liberalize or place restrictions on international trade.

Equation (P1) is theoretically appealing but also rather difficult to apply in empirical studies, since it requires data on technologies, costs, and trade barriers for all countries. However, a very helpful expression for $\Lambda_i$ can be derived by considering the fact that countries' technologies, costs, and trade barriers combine uniquely into the geographical distribution of production and trade data. In particular, we can prove that:

**Proposition 2** *If costs $c_i$ are given by equation (8) and market shares by equation (5), then:*

$$\Lambda_i = T_i \left( 1 + \sum_{k \neq i} \frac{X_{ik}}{X_{ii}} \right) = T_i \left( 1 + \frac{IMP_i}{PRO_i - EXP_i} \right) \; . \tag{P2}$$

**Proof.** See Appendix A.2 ■

Hence, $\Lambda_i$ is equal to $T_i$ augmented by a factor that depends on the ratio between the value of country $i$'s total imports ($IMP_i$) and the value of its production ($PRO_i$)

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[11] In the version considered here, the model ignores the possibility of technology spillovers across countries. In fact, the $Z_i$'s are independent random variables and the $T_i$'s can change freely. Rodríguez-Clare (2007) extends the model to account for international diffusion of ideas. A similar route is to consider correlated $Z_i$'s (see the next section).

minus the value of its total exports ($EXP_i$). Let us write:

$$\Omega_i = 1 + \frac{IMP_i}{PRO_i - EXP_i} \; ; \tag{11}$$

$\Omega_i$ is a fraction with the total absorption (or total domestic demand) of country $i$ at the numerator and the production sold domestically at the denominator. Therefore, it is a measure of *trade openness* for country $i$. Note that, consistently with equation (P1), $\Lambda_i$ tends to $T_i$ as imports go to zero.

Proposition 2 provides an interesting contribution to the literature concerning the measures of trade openness. Papers exploring the relationship between trade and productivity typically measure trade openness as the sum of nominal imports and exports scaled by the nominal GDP (*nominal openness*). An exception is Alcalá and Ciccone (2004) who scale nominal imports and exports with the GDP in PPP US dollars (*real openness*), on the ground of theoretical motivations. Our analysis finds that the Ricardian trade theory suggests to measure trade openness with $\Omega_i$. Equation (P2), in fact, shows that $\Omega_i$ is the trade-related variable that summarizes the effects of international competition on TFP. By comparing equation (P2) with equation (P1), it is evident that $\Omega_i$ takes into account precisely the same factors (related to domestic and foreign costs) considered by Alcalá and Ciccone.

The wide availability of production and trade data makes it easy to compute $\Omega_i$ and quantify the magnitude of the selection effect. Before turning to the empirical analysis, however, we focus on the prediction that openness raises TFP, provide an intuition about how and why this happens, and explore possible extensions of this result.

# 3 Intuition and extensions

The main implication of Proposition 1 is that TFP always rises when trade barriers are removed. This is a remarkable difference with respect to previous Ricardian models, where the law of comparative advantage may lead a country to specialize in the production of low-productivity goods, so that the resulting aggregate TFP diminishes after openness.

To build an intuition about this new result, let us retain only the essential ingredients of the model and consider a simple case with two countries ($n$ and $i$), no trade barriers (i.e. $d_{ni} = d_{in} = 1$), no intermediate goods ($\beta = 1$), and identical input costs (i.e. $c_n = c_i = 1$).[12] With no trade barriers, producers and exporters coincide. Together with

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[12] Even though costs are endogenous, the assumption $c_n = c_i = 1$ is consistent with the model if we assume, for instance, perfect labor mobility between the tradeable and non-tradeable sectors in each country

the other assumptions, this hypothesis simplifies the analysis by implying that a country $i$ will produce and export good $j$ if and only if $z_i(j) \geq z_n(j)$.

First, this simplification allows us to draw a parallel with the two-country model of Dornbusch, Fischer, and Samuelson (1977). These authors extend the standard two-country Ricardian model of trade to a continuum of goods by considering the function $a(j) = z_i(j)/z_n(j)$, ordering the labels $j$ to make $a$ monotone in $j$, and then assuming strict monotonicity, continuity and differentiability of $a$. In the EK model, instead, $A = Z_i/Z_n$ is no longer a function but a random variable, and the absolute continuity of $Z_i$ and $Z_n$ implies the absolute continuity of $A$ for any couple of countries; therefore, its c.d.f., denoted by $F_A$, is always strictly monotone, continuous and differentiable, making it possible to extend Dornbusch-Fischer-Samuelson two-country model to $N$ countries.[13] Under mutual independence and Fréchet distribution of technologies, the c.d.f. of $A$ is:

$$F_A(x) = \Pr(A < x) = T_n \cdot \left(T_n + T_i \cdot x^{-\theta}\right)^{-1} \text{ for } x > 0 \ .$$

Therefore, the probability that a firm of country $i$ makes and exports a good is:

$$\Pr(Z_i \geq Z_n) = \Pr(A \geq 1) = T_i/(T_i + T_n) \ .$$

Second, in this model any firm can survive or die after openness, and the probability that each firm survives (dies) is increasing (decreasing) in its own productivity. In fact, using both mutual independence and Fréchet distribution of technologies, this probability is simply:

$$\Pr(A \geq 1 | Z_i = z) = \Pr(Z_n \leq z) = \exp\left(-T_n \cdot z^{-\theta}\right) \text{ for } z > 0 \ ,$$

which is always included in the open interval $(0,1)$ and strictly increasing in $z$, for $z > 0$. (Its complement to 1, which is the probability that the firm dies, is always decreasing in $z$.) This is a sharp difference with respect to the model of Melitz (2003) in which that probability is either 0 or 1, depending on whether the firm's productivity is below or above the threshold that separates incumbents from entrants. The reason for this difference is that the EK model is still governed by the law of comparative advantage. Therefore, a high-productivity firm exits the market if the good that it produces is made even more efficiently in the rival country; this happens, however, with a probability that is lower for higher productivities. Similarly, a low-productivity firm survives if its own good is

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and identical marginal productivity of labor in both countries' non-tradeable sectors (see also Eaton and Kortum, p. 1757). It is worth stressing, however, that these simplifying assumptions are by no means necessary for the arguments made in this section.

[13] The random variable $A$ considered here is different from the random variable $A$ in Eaton and Kortum (2002, page 1747), call it $A^{ek}$. It holds that $A^{ek}(x) = F_A^{-1}(x)$, for $x$ in $(0,1)$.

not made more efficiently in the other country — an event, however, whose probability is lower, the lower the productivity.

Third, the model is consistent with the "exceptional export performance" documented by Bernard and Jensen (1999). Let us temporarily re-introduce trade barriers (otherwise all producers would also export). A good $j$ is made in country $i$ if and only if $z_i(j) \geq z_n(j)/d_{in}$. In addition, if $z_i(j) \geq z_n(j) \cdot d_{ni}$, then the good $j$ is also exported by country $i$ to country $n$ (otherwise, the good $j$ is sold only domestically). With mutually independent and Fréchet-distributed technologies, and following steps similar to those illustrated in Appendix A.1 to prove Proposition 1, we can show that the distribution of the productivities of exporters is Fréchet, with parameters $T_i + T_n \cdot d_{ni}^{\theta}$ and $\theta$. Applying Proposition (1) to this simplified set-up, we find that the distribution of the whole set of surviving firms is Fréchet with parameters $T_i + T_n \cdot d_{in}^{-\theta}$ and $\theta$. Since icebergs costs $d_{ni}$ and $d_{in}$ are larger than 1, then the average productivity of exporters is clearly higher than the TFP of the whole economy (that is the average productivity across all the firms that survive international competition, i.e. exporters and producers that sell only domestically).[14] As in monopolistic competition models, the reason why exporters are, on average, more productive is that their goods have to be competitive enough to overcome trade barriers. Similarly to what discussed above, however, a difference emerges in the way this occurs in the two models. In Melitz, exporters and non-exporters are separated by a productivity threshold; therefore, even the worst exporter has always a higher productivity than the best non-exporter. Here, instead, as a consequence of the law of comparative advantage, few "bad" exporters and "good" non-exporters coexist with many "good" exporters and "bad" non-exporters.

Are these predictions robust to the distributional assumptions? Let us go back to the simplified framework with no trade barriers. The main result that TFP rises after openness can formally be written as:

$$E(Z_i | Z_i \geq Z_n) \geq E(Z_i) \ . \tag{12}$$

Inequality (12) makes it clear that the comparison between the TFP of an open economy and the TFP under autarky boils down to a comparison between a conditional mean and a simple mean. The conditioning event is that domestic firms are better (or "sufficiently better", if there are trade barriers and heterogeneous input costs) than foreign firms. This condition is what "tends" to raise TFP after trade openness. The inequality, however, does not hold for all the possible joint distributions of $Z_i$ and $Z_n$. For instance, a simple way to build an example in which (12) is not satisfied — the counterpart of the standard textbook examples of non-probabilistic Ricardian models — is the following. Take any

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[14] By the same token, the average productivity of exporters is also higher than the average productivity of non-exporters.

random variable $Z_i$; then, construct a variable $Z_n$ such that: if $Z_i$ takes high (low) values, then $Z_n$ takes even higher (lower) values. In this example $Z_i \geq Z_n$ only for "low" values of $Z_i$, therefore $E\left(Z_i | Z_i \geq Z_n\right) < E\left(Z_i\right)$. Note that, clearly, $Z_i$ and $Z_n$ are not independent.

The assumption of independence between $Z_i$ and $Z_n$, instead, is sufficient for (12) to hold, irrespectively of the distribution of $Z_i$ and $Z_n$ (see Appendix A.3).[15] In particular, the result holds for all the distributions, like Pareto, Weibull and uniform, that are commonly used to describe productivities (or marginal costs) at the firm level and that entail very simple analytic solutions for this model. In other words, under mutual independence TFP always rises after openness.

At the same time, however, independence is not necessary for TFP to increase. In fact, a simple multivariate extension of the Fréchet distribution that covers all levels of dependence, from independence to perfect correlation, has the following c.d.f.:

$$\Psi_{i,n}\left(z_i, z_n\right) = \exp\left\{-\left[\left(T_i \cdot z_i^{-\theta}\right)^{1/r} + \left(T_n \cdot z_n^{-\theta}\right)^{1/r}\right]^r\right\} , \tag{13}$$

where $\Psi_{i,n}\left(z_i, z_n\right) = \Pr\left(Z_i < z_i, Z_n < z_n\right)$ and $r \in (0, 1]$. This distribution yields two Fréchet as marginals (with parameters respectively equal to $(T_i, \theta)$ and $(T_n, \theta)$) and is suggested in EK for an extension of their model to correlated technologies.[16] The parameter $r$ is an "index of independence" and is inversely related to the correlation between $Z_i$ and $Z_n$: if $r = 1$, then $Z_i$ and $Z_n$ are independent (the case examined above); if $r < 1$, then $Z_i$ and $Z_n$ are positively correlated. As $r$ goes to 0, the correlation between $Z_i$ and $Z_n$ tends to 1; in this case, we know from standard Ricardian theory that there are no comparative advantages to exploit and, therefore, both countries would produce exactly as in autarky. Using (13), we can show that the TFP gain of country $i$, i.e. the increase in its TFP with respect to autarky, is:[17]

$$\frac{E\left(Z_i | Z_i \geq Z_n\right)}{E\left(Z_i\right)} = \left[1 + \left(\frac{T_n}{T_i}\right)^{1/r}\right]^{r/\theta} . \tag{14}$$

Let us analyze it in two separate cases: $T_i = T_n$ and $T_i \neq T_n$.

Figure 1 shows, for $T_i/T_n = 1$, the TFP gain of country $i$ for different values of $\theta$ and $r$.[18] We know from the EK model that welfare gains from trade decrease as $\theta$ increases;

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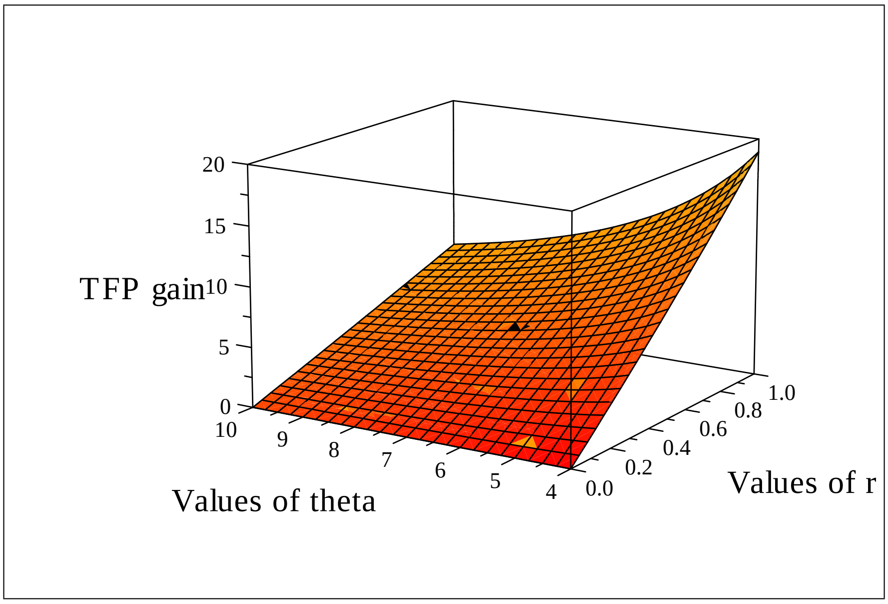
[15] The result that if $Z_i$ and $Z_n$ are independent then inequality (12) always holds, looks like a very basic one. However, we could not find its statement or proof in any book of probability theory we have consulted. Therefore, to facilitate the reader, we show this result formally in Appendix A.3.

[16] Introduced by Tawn (1990), $\Psi_{i,n}$ is also known as asymmetric bivariate logistic distribution and is commonly used in multivariate extreme value theory.

[17] The result can be obtained — after some cumbersome passages — by brute-force calculation of the corresponding integrals. A detailed proof is available from the authors upon request.

[18] Section 4 explains why we have chosen 4 and 10 as the lower and upper bound of $\theta$.

Figure 1: TFP gains from trade with a symmetric country (1)



(1) TFP gains from trade with respect to autarky, in percentages, for different values of $r$ and $\theta$, with $T_i/T_n$= 1.

the figure shows that the same applies to TFP gains. With independent distributions, the TFP gain from trading with a symmetric country, i.e. one that has the same state of technology, goes from 7 percent (with $\theta = 10$) to 19 percent (with $\theta = 4$). In addition, for any value of $\theta$ the extent of the TFP gain is monotonically increasing in $r$, hence it decreases as the correlation between the technologies of $i$ and $n$ increases.

Similarly, Figure 2 shows the increase in TFP gain for different values of $r$ and $T_i/T_n$, given $\theta = 6.67$ (our benchmark calibration in the next sections). Clearly, the TFP gain is larger, the higher the productivity of the competitor country. From country $i$'s viewpoint, the gain from trading with a country whose state of technology is twice as large as the domestic one ($T_i/T_n = 0.5$) can be as high as 18 percent (with independent distributions), and goes down to 0 very slowly as $r$ decreases; for example, with $r = 0.1$ TFP gain is still 11 percent. On the other hand, the TFP gain from trading with a country whose state of technology is half the domestic one ($T_i/T_n = 2$) is at most 7 percent, and goes to zero somewhat more rapidly as $r$ tends to zero. As before, the TFP gain decreases as correlation increases.[19]

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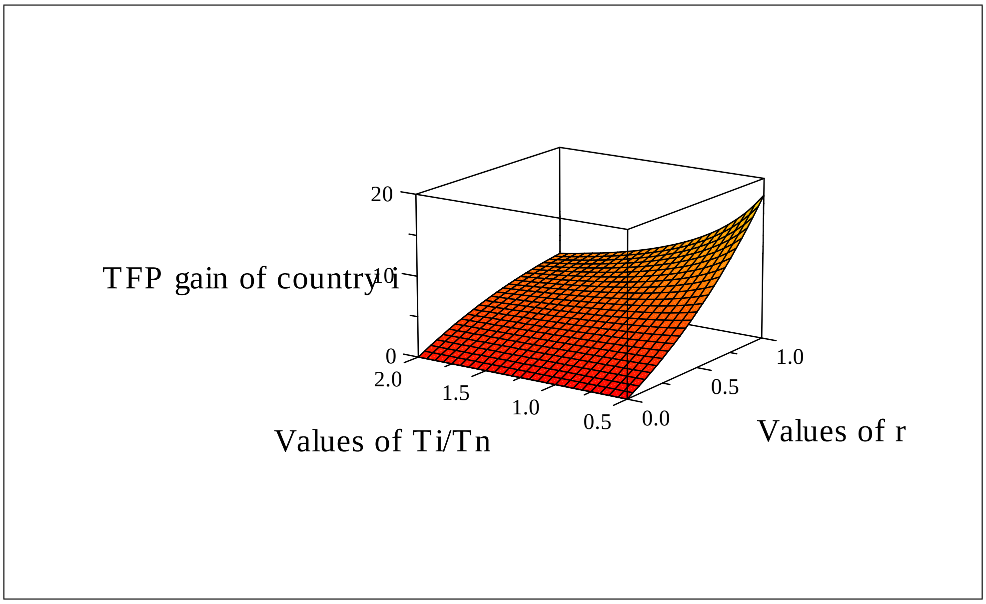
[19] It is worth noticing an important property of the multivariate case. An inspection of equation (14) reveals that the TFP gain for two countries with correlated technologies and given values of $T_i/T_n$, $\theta$ and $r$ (with $r < 1$) is the same as the TFP gain for two countries with independent technologies, a state-of-

Figure 2: TFP gains from trade with an asymmetric country (1)



(1) TFP gains from trade with respect to autarky, in percentages, for different values of $r$ and $T_i/T_n$, with $\theta = 6.67$.

Finally, in order to show that these results hold also beyond the case of the multivariate Fréchet, we briefly illustrate TFP gains with normally distributed technologies. Suppose that $(Z_1, Z_2)$ has a bivariate normal distribution, with the mean and variance of $Z_i$ respectively denoted by $\mu_i$ and $\sigma_i^2$ $(i = 1, 2)$, and where the covariance between $Z_1$ and $Z_2$ is given by $\sigma_{1,2}$. The TFP gain of country 1 is:[20]

$$\frac{E\left(Z_1 | Z_1 \geq Z_2\right)}{E\left(Z_1\right)} = 1 + \frac{\sigma_v}{2\mu_1} \frac{f\left(\frac{\mu_2 - \mu_1}{\sigma_v}\right)}{1 - F\left(\frac{\mu_2 - \mu_1}{\sigma_v}\right)} \ , \tag{15}$$

where $f$ and $F$ are, respectively, the probability density function (p.d.f.) and the c.d.f. of the standard normal variable, and where $\sigma_v = \sqrt{\sigma_1^2 + \sigma_2^2 - 2\sigma_{1,2}}$. Noting that the ratio $f/\left(1 - F\right)$ is the hazard function of the normal distribution and is strictly increasing in its own argument, it is easy to verify that all the main results obtained with the

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technology ratio equal to $\left(T_i/T_n\right)^{1/r}$, and a precision parameter equal to $\theta/r$. Thus, we do not need to generalize Propositions 1 and 2 to the case of correlated Fréchet distributions: one can simply use the TFP gains derived under independence and obtain those under positive correlation with an appropriate rescaling of the parameters.

[20] Differently from the multivariate Fréchet case, here we can obtain the TFP gain by resorting to some well-known properties of the normal distribution, without computing any integral. A very simple proof is presented in Appendix A.4.

multivariate Fréchet are confirmed. Specifically, the TFP gain from openness of a country is always: non-negative; strictly increasing in the autarky TFP of the competitor country ($\mu_2$), and in the degree of heterogeneity of both domestic and foreign production ($\sigma_1^2$ and $\sigma_2^2$); strictly decreasing in the domestic autarky TFP ($\mu_1$) and in the covariance (and, given the variances, in the correlation) between domestic and foreign technologies.

## 4 Quantifying the selection effect

An immediate implication of Propositions 1 and 2 is that the contribution of international competition to the TFP of the tradeable sector — that hereafter is identified with the manufacturing sector — is given by the measure of openness $\Omega_i$ raised to the $1/\theta$ power (one can obtain it by substituting (P2) into (10) and dividing by the mean of $Z_i$). With some simple algebra, one can further show that the effect of international competition on the real wage in the manufacturing sector ($w_i/p_i$), a measure of welfare for this model, is equal to $\Omega_i$ raised to the $1/\beta\theta$ power (see also equation (15) in EK).

$\Omega_i$ can be quantified using production and trade data.[21] For $\theta$, the literature suggests two different strategies. One is proposed by EK, who estimate $\theta$ using several testable implications of the model, finding values between 3.6 and 12.9, with 8.28 being their preferred estimate. A second strategy is proposed by Alvarez and Lucas (2007), who calibrate $\theta$ by exploiting a property of the theoretical model. Namely, the prediction that market shares are given by equation (5) emerges also from a model à la Armington (1969), i.e. a model in which goods produced in different countries are treated as different goods. The connection between the two models is: $\theta = \sigma_a - 1$, where $\sigma_a$ is the Armington elasticity. Based on the literature on import elasticities (see Broda and Weinstein, 2006, for recent estimates), Alvarez and Lucas consider a range of values of $\theta$ between 4 and 10, with 6.67 being their preferred estimate. Both strategies take $\theta$ time-invariant; Finicelli, Pagano, and Sbracia (2008) provide evidence supporting this assumption.

We have two strategies available also for what concerns $\beta$. EK calibrate it as the cross-country average of the labor share in gross manufacturing production. For the period 1985-2002, such calibration would provide annual values of $\beta$ between 0.19 and 0.22. This calibration implies that labor is the sole production factor and capital goods are comprised into intermediate goods. Alvarez and Lucas (2007), instead, calibrate $\beta$ as the cross-country average of the value added over the gross manufacturing production. By doing so, these authors consider labor plus capital goods as the single production factor, which they label as 'equipped labor'.

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[21] For a detailed description of the data used in this paper, see Appendix A.5.

Table 1: Contribution of international competition to TFP in selected years (1)

| | 1985 | 1990 | 1995 | 2002 | 1985-2002 (mean) |
|---|---|---|---|---|---|
| Australia | 3.4 | 3.2 | 4.2 | 4.9 | 3.9 |
| Austria | 7.5 | 9.1 | 10.0 | 14.5 | 10.4 |
| Belgium | 20.2 | 19.5 | 22.7 | 34.1 | 23.4 |
| Canada | 6.4 | 6.7 | 9.8 | 9.8 | 8.8 |
| Denmark | 9.5 | 10.3 | 11.5 | 16.4 | 11.7 |
| Finland | 4.2 | 4.7 | 5.0 | 5.6 | 5.1 |
| France | 3.4 | 4.5 | 4.8 | 5.8 | 4.7 |
| Germany | 4.0 | 4.3 | 4.1 | 5.8 | 4.5 |
| Greece | 4.7 | 6.2 | 6.7 | 7.0 | 6.5 |
| Italy | 2.6 | 2.8 | 3.5 | 4.2 | 3.3 |
| Japan | 0.5 | 0.6 | 0.6 | 0.8 | 0.6 |
| Netherlands | 13.4 | 15.5 | 15.6 | 20.7 | 16.8 |
| New Zealand | 5.6 | 6.1 | 6.3 | 7.4 | 6.2 |
| Norway | 8.5 | 8.5 | 8.7 | 8.8 | 8.7 |
| Portugal | 2.7 | 5.8 | 6.9 | 9.1 | 6.7 |
| Spain | 2.2 | 3.6 | 4.2 | 5.6 | 4.2 |
| Sweden | 5.9 | 6.0 | 7.4 | 7.6 | 7.0 |
| United Kingdom | 4.9 | 5.3 | 6.1 | 7.3 | 5.9 |
| United States | 1.4 | 1.6 | 1.8 | 2.2 | 1.8 |
| Cross-country mean | 5.8 | 6.5 | 7.4 | 9.4 | 7.4 |

(1) Values of $\Omega_i^{1/\theta} - 1$, in percentage, for each country $i$.

In our benchmark estimates, we follow Alvarez and Lucas for both $\theta$ (set to 6.67) and $\beta$. For the latter parameter, in particular, this calibration provides annual values between 0.31 and 0.34.

Table 1 shows the contributions of international competition to the TFP for all our sample countries, both in selected years and for the whole sample period. On average across countries and years, international competition raises manufacturing TFP by 7.4 percent above its autarky level. Across countries, the gain from international competition ranges from 0.6 percent for Japan to 23 percent for Belgium. Results for Belgium and the Netherlands (17 percent), however, are likely to be somewhat overestimated — an artifact of their role as entrepôt countries. Over time, the average contribution of international competition exhibits a neat positive trend (from 5.8 percent in 1985 to 9.4 percent in 2002), which is common to all countries.

The estimates of $\Omega_i^{1/\theta}$ for different values of $\theta$ can be derived with simple back-of-the-envelope calculations. Setting $\theta = 8.28$ (the preferred estimate of EK), in particular, the values reported in Table 1 would be slightly smaller. For instance, the average gain across countries and years would be around 6 percent.

Analogously, it easy to obtain from Table 1 the effect on the real wage in the manufacturing sector. For instance, setting $\theta = 6.67$ and $\beta = 0.33$ we find that, on average across countries and years, international competition raises the real wage by about 20 percent with respect to what would have been observed under autarky (the rule of thumb is that, with $\beta = 0.33$, the effect on the real wage is approximately three times larger than the effect on TFP). To understand this result, suppose that the nominal wage is constant. Then, the price level in the manufacturing sector would decline by 20 percent with respect to the closed economy. Because of perfect competition, here the entire productivity gain is translated into lower prices; that accounts for about 7 percentage points. Moreover, there is also an indirect effect stemming from the fact that a share $1 - \beta$ of the manufacturing goods serves also as intermediate goods. Hence, the TFP effect on the price level is amplified by the availability of lower-price intermediate inputs. In this example, with $\beta = 0.33$ the whole TFP effect has an impact that is three times larger than its direct effect. Clearly, if the nominal wage is not constant, the effect on the price level will be larger or smaller that 20 percent, depending on whether the nominal wage declines or rises after openness. Changes to the nominal wage, however, do not modify relative prices (one could simply choose the nominal wage as the numéraire) and, therefore, the effect on the real wage remains equal to 20 percent.

Before proceeding with the empirical analysis, it is worth recalling that the gains from trade discussed above reflect entirely and solely the selection effect of international competition. The model does not yield, for instance, a scale effect, which would lift TFP by letting more efficient firms to increase their production. Neither is it possible to know whether trade openness benefits countries by raising their states of technology (e.g. due to positive spillover effects), as the model rules out any technology spillover. Assessing the overall gains from trade, then, requires a generalization of the model that, however, is beyond the scope of the present paper and that we defer to future studies.

## 5 A measure of TFP

Propositions 1 and 2 offer an intriguing possibility: they allow to translate estimates of the model parameters into estimates of the manufacturing TFP. As discussed in Section 1, one advantage of this method for measuring TFP is that it requires data on input costs and trade flows instead of data on the stock of physical capital. The latter is not necessary because the model shows that it is the cost of inputs that matters for bilateral trade shares and not their quantities — a feature that makes this methodology reminiscent of the dual method for computing TFP growth rates (Hsieh, 2002).

Before proceeding, we recall one feature of the model that has an important empirical implication. Equations (5) and (7) show that market shares and relative prices are invariant with respect to a linear transformation of the states of technology. This means that we will only be able to obtain estimates of the *relative states of technology* (i.e. of the ratios $T_i/T_n$) and, in turn, of *TFP relative levels*. For this reason, we will present results for $T_i$ and $E\left(\mathrm{TFP}_i\right)$ relative to a benchmark country, which is chosen to be the United States.

In order to measure manufacturing TFP, we proceed in three stages. First, we follow EK and use a testable implication of the theory to estimate an index of the competitiveness for each country $i$ — a variable that depends on the country's state of technology and labor costs. Second, we use these competitiveness measures and data on nominal wages to extract states of technology. For reasons that will be clearer later, throughout this second stage we depart from EK by converting nominal wages in US dollars using PPP exchange rates instead of market exchange rates. Finally, we use equations (10) and (P2) to get our trade revealed TFP. The robustness of the results is then analyzed in Appendix A.6.

## 5.1 Competitiveness and trade barriers

Rearranging equations (5), (6), (7) and (8), and taking logs, EK obtain the following testable implication:

$$\log\left[\left(\frac{X_{ni}}{X_{nn}}\right)\left(\frac{X_{ii}/X_i}{X_{nn}/X_n}\right)^{\frac{1-\beta}{\beta}}\right] = S_i - S_n - \theta\log\left(d_{ni}\right) \ , \tag{16}$$

where:

$$S_i \equiv \frac{1}{\beta}\log\left(T_i\right) - \theta\log\left(w_i\right) \ . \tag{17}$$

The left-hand side (LHS) of equation (16) is a "normalized" share of the imports of country $n$ from country $i$. It is related to trade barriers and to the variable $S_i$ that, in turn, can be thought of as a competitiveness indicator of country $i$, since it represents its state of technology adjusted for labor costs. Equation (16) does not allow to get separate estimates of $T_i$ and $\theta$. However, once that $\theta$ is calibrated as explained in Section 4, one can estimate the $S_i$'s from equation (16) and, then, extract the $T_i$'s from the $S_i$'s using equation (17) and data on nominal wages.

The LHS of equation (16) can be measured using production and trade data and a calibration for $\beta$ (see Section 4). In the right-hand side (RHS), trade barriers can be modeled using the proxies suggested by the gravity literature. Following EK, we select geographic distance, borders, language, trade agreements, and a destination effect; hence, we put:

$$\log d_{ni} = d_k + b + l + e + m_n \ , \tag{18}$$

where we have suppressed the dummy variables associated with each effect for notational simplicity. In equation (18), $d_k$ $(k = 1, ..., 6)$ is the effect of the distance between $n$ and $i$ lying in the $k$th interval;[22] $b$ is the effect of $n$ and $i$ sharing a border; $l$ is the effect of $n$ and $i$ sharing the language; $e$ is the effect of $n$ and $i$ both belonging to the European Economic Community (EEC), from 1985 to 1992, or to the European Union (EU), from 1993 onwards; $m_n$ $(n = 1, ..., 19)$ is an overall destination effect.

By imposing the specification (18) for trade barriers, equation (16) becomes:

$$\log\left[\left(\frac{X_{ni}}{X_{nn}}\right)\left(\frac{X_{ii}/X_i}{X_{nn}/X_n}\right)^{\frac{1-\beta}{\beta}}\right] = S_i - S_n' - \theta d_k - \theta b - \theta l - \theta e \ , \tag{19}$$

where $S_n' = S_n + \theta m_n$. When we estimate the destination dummies $S_n'$, we cannot separate the competitiveness effect $S_n$ from the one incorporated into the trade barrier $\theta m_n$. Under these assumptions, then, the best estimates of the competitiveness effects are the source dummies $S_i$. Note also that, to avoid perfect multicollinearity, we need a restriction on the sets of dummy variables; hence, we require that $\sum_n S_n = \sum_n S_n' = 0$. Therefore, the coefficients of these dummy variables measure the differential competitiveness effect with respect to the average (equally-weighted) country.

We estimate equation (19) by ordinary least squares for each year of the period 1985-2002. Table 2 shows the result of these regressions for the initial and final year of our sample, and for 1990, which is the benchmark year of EK. The results about trade barriers show that increased distance inhibits trade. The magnitudes of the distance effects present a declining trend over the sample period, consistent with countries becoming more integrated. In addition, the decline is sharper for the biggest distances. The negative impact of distance is mitigated by countries sharing a border, speaking the same language, and joining the EEC/EU, although this last effect is very small (and not significantly different from zero).

Estimates of the source dummies $S_i$ indicate that in 1985 Japan was the most competitive country followed by the United States, while towards the end of the sample period these two countries inverted their ranking; on the other hand, Greece and Belgium stand out as the least competitive countries during the entire sample period. Overall, most of the countries in the sample achieved their highest competitiveness relative to the United States towards the end of the 1980s. Their competitiveness decreased thereafter until the year 2000, and showed some signs of a recovery in 2001-2002.

Estimates of $-\theta m_n$ (obtained as the difference between $S_n$ and $S_n'$) provide a measure of how cheap is exporting manufacturing goods in the destination country $n$ (relative to

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[22] Intervals are specified in Table 2, with distance calculated in miles.

Table 2: Bilateral trade equation in selected years (1)

| | | Year: 1985 | | Year: 1990 | | Year: 2002 | |
|---|---|---|---|---|---|---|---|
| Variable | Coefficient | Estimate | s.e. | Estimate | s.e. | Estimate | s.e. |
| Distance [0,375) | -θd1 | -3.33 | (0.16) | -3.34 | (0.16) | -2.98 | (0.18) |
| Distance [375,750) | -θd2 | -3.85 | (0.11) | -3.80 | (0.11) | -3.44 | (0.15) |
| Distance [750,1500) | -θd3 | -4.19 | (0.08) | -4.04 | (0.09) | -3.64 | (0.14) |
| Distance [1500,3000) | -θd4 | -4.61 | (0.16) | -4.24 | (0.15) | -3.96 | (0.19) |
| Distance [3000,6000) | -θd5 | -6.22 | (0.09) | -6.10 | (0.08) | -5.67 | (0.08) |
| Distance [6000,maximum) | -θd6 | -6.72 | (0.10) | -6.60 | (0.10) | -6.12 | (0.09) |
| Border | -θb | 0.62 | (0.14) | 0.61 | (0.13) | 0.67 | (0.12) |
| Language | -θl | 0.49 | (0.14) | 0.57 | (0.13) | 0.46 | (0.12) |
| EEC/European Union | -θe | -0.22 | (0.13) | 0.11 | (0.12) | 0.12 | (0.17) |
| Source country effect ($S_i$): | | | | | | | |
| Australia | S1 | -0.35 | (0.15) | -0.43 | (0.15) | 0.21 | (0.14) |
| Austria | S2 | -1.30 | (0.12) | -1.20 | (0.12) | -1.58 | (0.11) |
| Belgium | S3 | -1.89 | (0.12) | -1.61 | (0.12) | -2.66 | (0.11) |
| Canada | S4 | 0.16 | (0.15) | 0.30 | (0.14) | -0.01 | (0.14) |
| Denmark | S5 | -1.28 | (0.12) | -1.34 | (0.12) | -1.72 | (0.11) |
| Finland | S6 | -0.76 | (0.13) | -0.57 | (0.13) | -0.28 | (0.11) |
| France | S7 | 1.01 | (0.12) | 0.98 | (0.12) | 1.22 | (0.11) |
| Germany | S8 | 1.92 | (0.12) | 1.91 | (0.12) | 2.00 | (0.11) |
| Greece | S9 | -2.24 | (0.13) | -2.49 | (0.12) | -2.36 | (0.11) |
| Italy | S10 | 1.29 | (0.13) | 1.33 | (0.12) | 1.52 | (0.11) |
| Japan | S11 | 3.49 | (0.14) | 3.51 | (0.13) | 3.50 | (0.13) |
| Netherlands | S12 | -0.61 | (0.12) | -0.92 | (0.12) | -1.19 | (0.11) |
| New Zealand | S13 | -1.08 | (0.15) | -1.27 | (0.15) | -1.03 | (0.14) |
| Norway | S14 | -1.72 | (0.13) | -1.45 | (0.12) | -1.52 | (0.15) |
| Portugal | S15 | -1.11 | (0.13) | -1.30 | (0.13) | -1.42 | (0.12) |
| Spain | S16 | -0.08 | (0.13) | -0.13 | (0.12) | 0.41 | (0.11) |
| Sweden | S17 | 0.04 | (0.13) | 0.15 | (0.13) | 0.10 | (0.11) |
| United Kingdom | S18 | 1.11 | (0.13) | 1.10 | (0.12) | 1.14 | (0.12) |
| United States | S19 | 3.42 | (0.14) | 3.43 | (0.14) | 3.67 | (0.13) |
| Destination country effect (-θ$m_i$): | | | | | | | |
| Australia | -θm1 | -1.02 | (0.15) | -0.86 | (0.15) | -0.30 | (0.14) |
| Austria | -θm2 | -1.11 | (0.12) | -1.34 | (0.12) | -2.24 | (0.11) |
| Belgium | -θm3 | -4.88 | (0.12) | -4.04 | (0.12) | -7.24 | (0.11) |
| Canada | -θm4 | -0.17 | (0.15) | 0.05 | (0.14) | -0.33 | (0.14) |
| Denmark | -θm5 | -2.28 | (0.12) | -2.24 | (0.12) | -3.36 | (0.11) |
| Finland | -θm6 | -0.21 | (0.13) | 0.04 | (0.13) | 0.76 | (0.11) |
| France | -θm7 | 2.14 | (0.12) | 2.00 | (0.12) | 2.55 | (0.11) |
| Germany | -θm8 | 2.53 | (0.12) | 2.65 | (0.12) | 3.00 | (0.11) |
| Greece | -θm9 | -2.11 | (0.13) | -2.39 | (0.12) | -1.75 | (0.11) |
| Italy | -θm10 | 2.38 | (0.13) | 2.65 | (0.12) | 3.01 | (0.11) |
| Japan | -θm11 | 5.18 | (0.14) | 5.11 | (0.13) | 5.55 | (0.13) |
| Netherlands | -θm12 | -2.41 | (0.12) | -2.81 | (0.12) | -3.61 | (0.11) |
| New Zealand | -θm13 | -2.51 | (0.15) | -2.71 | (0.15) | -2.00 | (0.14) |
| Norway | -θm14 | -2.32 | (0.13) | -1.93 | (0.12) | -1.37 | (0.15) |
| Portugal | -θm15 | -0.09 | (0.13) | -1.05 | (0.13) | -1.14 | (0.12) |
| Spain | -θm16 | 1.48 | (0.13) | 1.05 | (0.12) | 1.60 | (0.11) |
| Sweden | -θm17 | 0.05 | (0.13) | 0.22 | (0.13) | 0.54 | (0.11) |
| United Kingdom | -θm18 | 1.07 | (0.13) | 1.31 | (0.12) | 1.48 | (0.12) |
| United States | -θm19 | 4.30 | (0.14) | 4.31 | (0.14) | 4.86 | (0.13) |

(1) Estimates of equation (19) using OLS; standard errors in brackets.

the cross-country mean). The values of $-\theta m_n$ reflect the presence of tariffs and non-tariff costs that have to be paid by foreigners to sell a good in the domestic market, such as local distribution costs, legal obligations, product standards, and many others. Over the entire sample period, the country ranking of $-\theta m_n$ is similar to that $S_n$; for instance, the cost of exporting is smallest for goods sold in Japan and largest in Belgium.[23]

## 5.2 States of technology

From the estimates of $S_i$ derived above, we can extract the states of technology $T_i$ by inverting equation (17); namely:

$$T_i = \left[\exp\left(S_i\right) \cdot w_i^{\theta}\right]^{\beta} \ . \qquad (20)$$

This equation requires data on nominal wages and a choice about the exchange rate to be used to convert wages in a common currency.

Following EK, nominal wages are adjusted for education in order to account for the different degrees of "worker quality" in the countries of our sample. Specifically, we set:

$$w_i = comp_i \cdot \exp\left(-g \cdot h_i\right) \ , \qquad (21)$$

where $comp_i$ is the nominal compensation per worker obtained from the OECD; $g$ is the return on education, which we set equal to 0.06 as EK; $h_i$ is the average years of schooling.[24] Data on schooling come from de la Fuente and Doménech (2006), who provide average years of schooling for OECD countries from 1960 to 1995 (in five-year intervals); for the missing data, we interpolate and extrapolate using the most recent update of the dataset first presented in Barro and Lee (2000).

The left side of Table 3 shows the states of technology using wages converted in US dollars with market exchange rates as in EK. Let us first focus on 1990, which is the benchmark year in EK. Overall, the country ranking provided by the $T_i$ for that single year appears reasonable, with the United States and Japan topping the list, the main industrial countries following soon after, and Portugal at the bottom place. However, when we turn

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[23] Eaton and Kortum (2002) estimate equation (19) by generalized least squares, using only 1990 data, obtaining similar results in terms of sign and significance of the coefficients and ranking of the countries. (See, in particular, their discussion concerning the apparently surprising result about the high degree of openness of Japan.) The small differences between our results and theirs are due only to the different values of $\beta$ chosen and to the older update of the OECD data used in their paper, and not to the different estimation method.

[24] Setting $g = 0.06$ is a conservative calibration according to Bils and Klenow (2000). Therefore, in Appendix A.6 we present also results with the somewhat larger (and non-linear) values of the return on education used by Hall and Jones (1999) and Caselli (2005).

Table 3: States of technology in selected years (1)

| | $T_i$ with wages in current US dollars | | | | $T_i$ with wages in PPP US dollars | | | |
|---|---|---|---|---|---|---|---|---|
| | 1985 | 1990 | 1995 | 2002 | 1985 | 1990 | 1995 | 2002 |
| Australia | 0.058 | 0.081 | 0.086 | 0.047 | 0.091 | 0.068 | 0.091 | 0.091 |
| Austria | 0.043 | 0.158 | 0.219 | 0.076 | 0.113 | 0.123 | 0.124 | 0.105 |
| Belgium | 0.065 | 0.269 | 0.337 | 0.110 | 0.175 | 0.219 | 0.203 | 0.162 |
| Canada | 0.179 | 0.256 | 0.157 | 0.111 | 0.233 | 0.219 | 0.205 | 0.186 |
| Denmark | 0.048 | 0.171 | 0.207 | 0.101 | 0.075 | 0.075 | 0.081 | 0.088 |
| Finland | 0.072 | 0.324 | 0.272 | 0.133 | 0.108 | 0.129 | 0.144 | 0.162 |
| France | 0.191 | 0.558 | 0.627 | 0.275 | 0.381 | 0.375 | 0.377 | 0.389 |
| Germany | 0.155 | 0.539 | 0.720 | 0.280 | 0.353 | 0.366 | 0.343 | 0.348 |
| Greece | 0.072 | 0.324 | 0.272 | 0.133 | 0.108 | 0.129 | 0.144 | 0.162 |
| Italy | 0.115 | 0.435 | 0.252 | 0.146 | 0.366 | 0.344 | 0.302 | 0.249 |
| Japan | 0.242 | 0.725 | 1.544 | 0.534 | 0.331 | 0.402 | 0.392 | 0.401 |
| Netherlands | 0.071 | 0.175 | 0.236 | 0.091 | 0.161 | 0.142 | 0.148 | 0.123 |
| New Zealand | 0.030 | 0.047 | 0.052 | 0.025 | 0.100 | 0.059 | 0.058 | 0.056 |
| Norway | 0.074 | 0.220 | 0.184 | 0.152 | 0.065 | 0.087 | 0.085 | 0.114 |
| Portugal | 0.005 | 0.018 | 0.026 | 0.020 | 0.047 | 0.045 | 0.042 | 0.054 |
| Spain | 0.060 | 0.253 | 0.231 | 0.119 | 0.269 | 0.251 | 0.261 | 0.253 |
| Sweden | 0.137 | 0.468 | 0.322 | 0.214 | 0.192 | 0.197 | 0.175 | 0.232 |
| United Kingdom | 0.137 | 0.380 | 0.360 | 0.373 | 0.316 | 0.335 | 0.373 | 0.449 |
| United States | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

(1) Values obtained from equation (20).

to the dynamics, results become quite odd. Consider, for instance, Japan. In 1985, its state of technology is just 24 percent of that of the United States; in the following 10 years, it records an amazing growth, achieving a maximum in 1995, when it is 50 percent higher than the state of technology of the United States; then it collapses abruptly and, in 2002, it is back to half of the level of the United States. Equally implausible swings are also recorded for several other countries. More importantly, states of technology estimated as in EK display an extremely high correlation with nominal exchange rates vis-à-vis the US dollar. For the cross-country average, this correlation is equal to $-0.78$ when calculated on levels and to $-0.94$ when calculated on first log-differences (the negative values imply that a depreciation is associated with a decrease in the state of technology). For most countries, these correlations would not be significantly different from 1 and these results remain essentially the same with all the reasonable calibrations of $\beta$, $\theta$, and $g$.[25]

How can we explain these odd results? Let us reconsider the example of Japan. Between 1985 and 1995, the yen recorded a striking appreciation: its value with respect to the US dollar increased by over 150 percent, from about 240 to 94 yen per US dollar. As a consequence, Japanese nominal wages converted in US dollars increased sharply with respect to other countries and, especially, the United States. On the other hand, export

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[25] In a companion paper, Finicelli, Pagano, and Sbracia (2008) offer a detailed analysis of this question together with other issues concerning the empirical estimates of the EK model.

shares adjusted very slowly and displayed only a small and gradual decline. In terms of the theoretical model of Section 2, these dynamics imply that, given the large increase in its input costs, Japan must have recorded a very large improvement in its technology in order to maintain its export shares almost unchanged.

These considerations raise two issues. First, the EK model is a static general equilibrium framework. Therefore, the model neglects the adjustment of prices and quantities during the transition to a new equilibrium following, for instance, an exchange-rate shock. Second, the model assumes perfect competition. Therefore, producers sell goods at their marginal costs and do not apply mark-ups that could help buffering the impact of exchange-rate shocks. While an extension of the model to embed imperfect competition is beyond the scope of this paper,[26] we can address the former issue by converting input costs into a common currency using PPP exchange rates, as calculated by the OECD, as a measure of equilibrium exchange rates (using an average over a large number of previous years would yield similar results). This is also consistent with the standard practice in development-accounting, which will be the yardstick for our trade-revealed TFPs.

The right side of Table 3 shows the new states of technology derived by converting wages in US dollars with PPP exchange rates. Results are clearly more stable and, as we will see below, consistent with the dynamics of TFP levels. The cross-country average correlation of the new states of technology with nominal exchange rates vis-à-vis the US dollar collapses to a statistically insignificant 0.01 when calculated on levels and to $-0.18$ when calculated on first log-differences. Correlations of the new states of technology with PPP exchange rates are also very low (equal to $-0.03$ for levels and to $-0.22$ first for log-differences). These results suggest that market exchange rates dominated the estimates of the states of technology because of their very large volatility — a volatility that, as it is well known, does not have an empirical counterpart in production, price, and trade data. Note also that the states of technologies are apparently low, equal to 0.19 for the cross-country average, with a maximum of 0.45 for the United Kingdom in 2002. However, in order to obtain TFPs, these values must be raised to the $1/\theta$ power and multiplied by the correction factor (equation (10)). Once that these calculations are performed, we will see that low $T_i$'s are perfectly consistent with reasonable values of TFPs.

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[26] Important steps along this direction have been taken by Bernand, Eaton, Jensen, and Kortum (2003) and Eaton and Kortum (2008). The former paper introduces a framework with Bertrand competition; in this model, each destination is still served by the lowest-cost producer, but the price it charges is the cost of the second-cheapest potential producer. The latter paper provides an extension to market structures characterized by Cournot and monopolistic competition.

### 5.3 Trade-revealed TFPs

With the estimates of the states of technology derived above, we are now equipped to calculate TFP levels relative to a benchmark country. Recalling the meaning of the $X_{ik}$ and using equations (10), (P2) and (11), the relative TFP of country $i$ with respect to the United States, denoted with $\lambda_i$, can be written as:

$$\lambda_i = \left( \frac{T_i}{T_{us}} \frac{\Omega_i}{\Omega_{us}} \right)^{1/\theta} , \tag{22}$$

where the subscript $us$ stands for the United States.

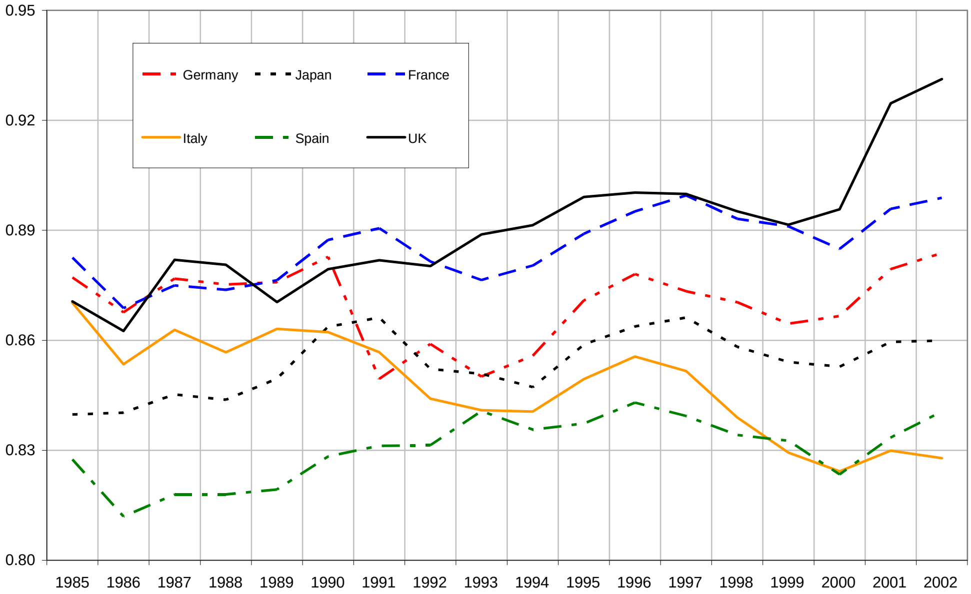
Figure 3 presents our estimates of $\lambda_i$ for the main industrial countries: Japan, the United Kingdom, and the four largest euro area countries; the level of the United States is, of course, identically equal to 1 over the whole sample period. The figure shows that up to the early 1990s, trade-revealed TFPs of the manufacturing sector are close to each other, fluctuating at around 87 percent of the level of the United States. Afterwards, they become more dispersed. Overall, the 18 OECD countries of our sample have a manufacturing TFP equal, on average, to 80 percent of the level of the United States. The country with the largest average TFP in the sample period is the United States, followed by Belgium, the United Kingdom and France; Portugal, New Zealand, and Australia have the lowest average TFP (detailed results for all countries and years are in Appendix A.6).

The manufacturing TFP of Italy and, for opposite reasons, that of the United Kingdom display an interesting behavior. Manufacturing TFP in these two countries is essentially identical in 1985 and then diverges. During the whole sample period, Italy looses ground with respect to all the main industrial countries. In 2001-2002, its manufacturing-TFP level is the lowest among the economies of this group, overcome also by that of Spain; on the other hand, manufacturing TFP in the United Kingdom tops the group, with a level not too far from that of the United States. A rising productivity in the United Kingdom with, as it is well known, a shrinking manufacturing sector is a piece of evidence consistent with our theoretical results. Specifically, increasing international competition may have forced less efficient UK firms to exit the market, raising the aggregate TFP. In fact, results from Section 4 also show that the United Kingdom is the country that benefited, among the countries represented in Figure 3, of the largest increase in the contribution of international competition to TFP (from 4.9 in 1985 to 7.3 percent in 2002; Table 1).

## 6 A case study: Italy relative to the US

The standard approach to compute TFP levels, the development-accounting methodology, requires an assumption on the production function and data on the volume of output and

Figure 3: Trade-revealed TFP, relative to the US, of some industrial countries (1)



(1) Values of $\lambda_i$ obtained from equation (22)

inputs. The measurement of physical capital is the step in which data limitations are more binding. From the OECD STAN database, the main source of comparable cross-country data on production at the sectoral level, the *volume of net capital stock* — the most common proxy for physical capital — is available for the whole sample period (1985-2002) for the manufacturing sector of only four countries (Denmark, France, Italy, and Spain). The *volume of gross capital stock* — a measure in which capital depreciation is neglected and different capital assets are not weighted — is available only for six additional countries (which do not include major countries such as the United States and Japan).[27] Similar problems arise if one tries to calculate the stock of capital starting from manufacturing investments. The OECD STAN database provides the *volume of fixed investment* in the manufacturing sector for 11 countries during our sample period (again, there are no data for large countries such as Japan and the United Kingdom). The *value of manufacturing investment*, instead, is available for almost all countries (15 out of 19) but, in this case, one faces the critical issue of finding an appropriate price deflator.

Due to these difficulties in obtaining development-accounting measures of TFP levels

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[27] Very few countries publish series on the level of *productive capital stock*, the most appropriate variable to include into a production function, as this measure is not yet recognized in the System of National Accounts. Schreyer and Webb (2006) provide a very useful survey of definitions and data availability of capital stock measures.

for all our sample of countries, it is worth focusing on a specific pair of countries for which sufficiently rich data are available. Therefore, in this section we focus on Italy versus the United States, a particularly interesting case because of the surprising result from development accounting that Italy's TFP is the highest in the world (see Klenow and Rodríguez-Clare, 1997, and Hall and Jones, 1999). Moreover, data are available to allow us an improved analysis, in which we can measure the labor input more precisely for both countries by considering working hours (another time series that is rarely available at sectoral level) and we can also compare trade-revealed TFP growth rates with those provided by national authorities.

A development-accounting exercise for the manufacturing sector would typically assume that output in country $i$ ($Y_i$) is given by:

$$Y_i = A_i K_i^{\eta} H_i^{1-\eta} \ ,$$

where $A_i$ is the TFP, $K_i$ is the stock of physical capital, and $H_i$ is the stock of human-capital augmented labor (with all the variables referring to the manufacturing sector). We assume that each worker has been trained with $h_i$ years of schooling; then, human-capital augmented labor is given by:

$$H_i = L_i \cdot \exp\left(-g \cdot h_i\right), \tag{23}$$

where $L_i$ is the total number of worked hours (which is available from the Bank of Italy for Italy and the US Bureau of Labor Statistics, BLS, for the United States) and $g = 0.06$ as in the previous section.

Setting $\eta = 1/3$ — which is broadly consistent with national accounts of developed countries — and using data on output per worker, capital/output ratios, and schooling, one can calculate the level of manufacturing TFP from the production function:

$$A_i = \left(\frac{Y_i}{L_i}\right)^{1-\eta} \left(\frac{K_i}{Y_i}\right)^{-\eta} \left(\frac{H_i}{L_i}\right)^{-(1-\eta)} \ . \tag{24}$$

Except for the years of schooling, which refer to the whole economy, data are referred to the manufacturing sector. In particular, we measure the capital stock with the perpetual inventory method as in Caselli (2005).[28] We calculate TFP levels for Italy and the United States separately and, then, we take the ratio.

Figure 4 shows the manufacturing TFP of Italy relative to that of the United States obtained with this methodology (the curve labeled "Development accounting") and compares it with our trade-revealed TFP (the curve labeled "Trade-revealed"). A casual look at the picture unravels that the time pattern of the two curves is remarkably similar.

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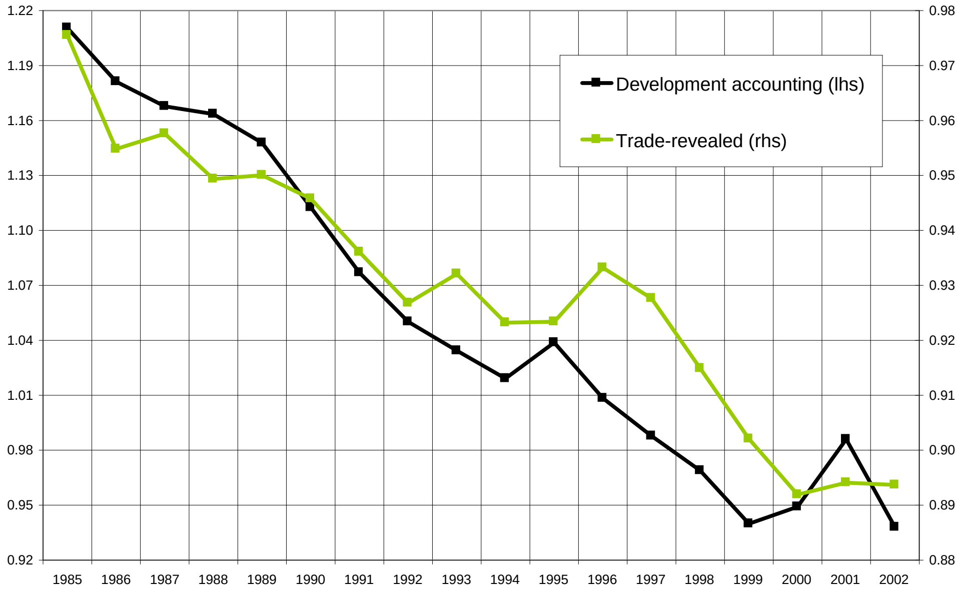
[28] Appendix A.5 provides details on data sources and methodology.

Figure 4: Manufacturing TFP of Italy relative to the US (including worked hours)



Note, however, that the two curves are measured on different axes, so the scales are quite different. At the beginning of the sample period, the development-accounting TFP ratio is equal to 1.21, meaning that Italy was far more productive that the United States. Afterwards, the relative productivity of Italy records a gradual and steep decline and, in 2002, it is 6 percentage points lower than that of the United States, with a cumulative loss of 27 percentage points. On the other hand, the trade-revealed TFP is lower than 1 even in 1985 and records a gradual, but much smaller decrease in the sample period (9 percentage points, to 89 percent in 2002).

An alternative comparison is to estimate the total change in relative TFP by cumulating estimates of TFP *growth rates* for the manufacturing sector from national authorities (BLS for the United States and ISTAT for Italy). Data show an average annual TFP growth rate of 1.4 percent for the United States and of 0.8 percent for Italy. Therefore, by setting 1985 equal to 100 for both countries and cumulating annual changes it turns out that in 2002 Italy's TFP was 11 percentage points lower than in the US, a cumulative change not far from the one obtained with our trade-revealed TFP, but significantly lower than the one obtained from the development-accounting methodology.

In this case study, TFP differences yielded by our approach seem to provide a reasonable picture of the differences in efficiencies between Italy and the United States. Not only trade-revealed TFPs do not yield the odd result that Italy is more productive than the United States, but, over the sample period, differences in TFPs are not as large as those that emerge with the development-accounting methodology. Since the development-accounting TFP is a mere residual — a "measure of our ignorance" as Caselli (2005) put it — the overwhelmingly large differences in cross-country TFP levels coming from that approach may be just the outcome of excessively large errors in the measurement of production factors.

# 7 Conclusion

We have shown that the Ricardian model — in its general version developed by Eaton and Kortum — yields a remarkable and very robust implication: trade openness always raises TFP. While this result is similar to the one obtained by Melitz (2003) with monopolistic competition, our analysis highlights some important differences about the way in which the increase occurs. For instance, in Melitz all and only the firms whose TFP is higher than a certain threshold will export; in EK, the law of comparative advantage implies that few "bad" exporters and "good" non-exporters coexist with many "good" exporters and "bad" non-exporters. Thus, despite sharing the main conclusion, the two models yield differences that could be exploited by future empirical studies to discriminate between the two theories.

By linking model parameters to the TFP of the tradeable sector, our results deliver also a useful methodology to measure the latter. Clearly, however, the link could also be exploited backward: from measures of the TFP of the tradeable sector, one could then retrieve model parameters. Therefore, this link offers an alterative way to calibrate the key technology parameters.

The comparison between the trade-revealed and the development-accounting methodology that we have performed for the TFP of Italy relative to that of the United States seems also promising. The dynamics of the two variables turn out to be very similar, but an appealing difference in levels emerges: the trade-revealed TFP no longer yields the puzzling result that Italy is the most productive country in the world. The good fit of TFP data that we have obtained may also be interpreted as a preliminary and (admittedly) very indirect validation of the EK model.

# A Appendix

## A.1 Proof of Proposition 1

Before computing $G_i(z)$ from equation (9), we show that the goods produced by country $i$ are all and only those for which it holds $p_{ii}(j) \leq p_{ik}(j)$ for any $k$. If $p_{ii}(j) \leq p_{ik}(j)$ for any $k$, then good $j$ is produced by country $i$ and sold at home. Hence, we only need to show that there is no good $j$ which is produced by country $i$, exported in a country $n \neq i$, and not sold at home. Clearly, if such a good is not sold at home, it means that there is another country, call it $k$ ($k \neq i$), that sells it in country $i$ at a lower cost. More formally, then, we need to show that there is no good $j$ such that: ($i$) $p_{ii}(j) > p_{ik}(j)$ for some $k$; and ($ii$) $p_{ni}(j) < p_{nl}(j)$ for some $n$ and for any $l \neq i$. Suppose, by contradiction, that there exists such a good $j$. The inequality ($i$) means that: $c_i/z_i(j) > c_k d_{ik}/z_k(j)$. The inequality ($ii$) is equivalent to: $c_i d_{ni}/z_i(j) < c_l d_{nl}/z_l(j)$ for any $l \neq i$. Now take $l = k$. Then: $c_i d_{ni}/z_i(j) < c_k d_{nk}/z_k(j)$. However, from the first inequality we can also obtain: $c_i d_{ni}/z_i(j) > c_k d_{ik} d_{ni}/z_k(j) \geq c_k d_{nk}/z_k(j)$, where the last part follows from the triangle inequality and contradicts the inequality ($ii$).

We now turn to the computation of $G_i(z)$. To find the distribution of the TFP of country $i$ (TFP$_i$), we consider first the price distribution of the goods that country $i$ "submits" to country $n$. Denote this random variable with $P_{ni}$ and its c.d.f. with $W_{ni}$. Recalling that $p_{ni}(j) = c_i d_{ni}/z_i(j)$ for any good $j$, EK show that:

$$W_{ni}(p) = \Pr(P_{ni} \leq p) = 1 - F_i\left(\frac{c_i d_{ni}}{p}\right) = 1 - \exp\left[-T_i (c_i d_{ni})^{-\theta} p^{\theta}\right] \ ,$$

where $F_i$ is the c.d.f. of $Z_i$. By setting:

$$\phi_{ni} = T_i (c_i d_{ni})^{-\theta} \ ,$$

we can write the p.d.f. of $P_{ni}$ as:

$$w_{ni}(p) = \phi_{ni} \cdot \theta \cdot p^{\theta-1} \cdot \exp\left(-\phi_{ni} \cdot p^{\theta}\right) \ ;$$

thus, $P_{ni}$ has a Weibull distribution.

Now let us turn to TFP$_i$, whose distribution is:

$$G_i(z) = \Pr\left(Z_i < z | P_{ii} = \min_k P_{ik}\right) = \frac{\Pr\left(P_{ii} = \min_k P_{ik} \ , \ Z_i < z\right)}{\Pr\left(P_{ii} = \min_k P_{ik}\right)} \ .$$

The denominator corresponds to equation (8) of EK for $n = i$; namely:

$$\begin{aligned}
\Pr\left(P_{ii} = \min_k P_{ik}\right) &= \Pr\left(P_{ii} \leq P_{i1}, ..., P_{ii} \leq P_{iN}\right) = \\
&= \frac{T_i c_i^{-\theta}}{\sum\limits_{k=1}^{N} T_k \left(c_k d_{ik}\right)^{-\theta}} .
\end{aligned}$$

The numerator is:

$$\begin{aligned}
\Pr\left(P_{ii} = \min_k P_{ik}\ ,\ Z_i < z\right) &= \Pr\left(P_{ii} \leq P_{i1}, ..., P_{ii} \leq P_{iN}, Z_i < z\right) = \\
&= \Pr\left(Z_1 \leq \frac{Z_i c_1 d_{i1}}{c_i}, ..., Z_N \leq \frac{Z_i c_N d_{iN}}{c_i},\ Z_i < z\right) = \\
&= \int\limits_{z_k \leq \frac{z_i c_k d_{ik}}{c_i}\ \forall k \neq i} .... \int\limits_{z_i \leq z} \prod_{k=1}^{N} f_k\left(z_k\right) dz_1 ... dz_k = \\
&= \int_0^z \prod_{k \neq i} F_k\left(\frac{z_i c_k d_{ik}}{c_i}\right) \cdot f_i\left(z_i\right) dz_i = \\
&= \int_0^z T_i \cdot \theta \cdot z_i^{-(\theta+1)} \cdot \exp\left[-T_i - \sum_{k \neq i} T_k \left(\frac{c_k d_{ik}}{c_i}\right)^{-\theta} z_i^{-\theta}\right] \cdot dz_i = \\
&= \frac{T_i c_i^{-\theta}}{\sum\limits_{k=1}^{N} T_k \left(c_k d_{ik}\right)^{-\theta}} \cdot \int_0^z \Lambda_i \cdot \theta \cdot z_i^{-(\theta+1)} \cdot \exp\left(-\Lambda_i \cdot z_i^{-\theta}\right) dz_i\ ,
\end{aligned}$$

where $\Lambda_i$ is given by equation (P1).

By using the expressions found for the numerator and the denominator of $G_i\left(z\right)$, we have that:

$$\Pr\left(Z_i < z | P_{ii} = \min_k P_{ik}\right) = \int_0^z \Lambda_i \cdot \theta \cdot x^{-(\theta+1)} \cdot \exp\left(-\Lambda_i \cdot x^{-\theta}\right) dx\ ;$$

in other words, $\text{TFP}_i \sim \textit{Fréchet}\left(\Lambda_i, \theta\right)$.

## A.2 Proof of Proposition 2

Plugging the expression of costs (equation (8)) into equation (P1), and multiplying and dividing by $T_i$ we can write:

$$\Lambda_i = T_i + T_i \sum_{k \neq i} \frac{T_k}{T_i} \left( \frac{w_k}{w_i} \right)^{-\theta\beta} \left( \frac{p_k}{p_i} \right)^{-\theta(1-\beta)} d_{ik}^{-\theta} \ .$$

Using equation (5), we can obtain:

$$\frac{X_{ik}}{X_{ii}} = \frac{X_{ik}/X_i}{X_{ii}/X_i} = \frac{T_k}{T_i} \left( \frac{w_k}{w_i} \right)^{-\theta\beta} \left( \frac{p_k}{p_i} \right)^{-\theta(1-\beta)} d_{ik}^{-\theta} \ .$$

Therefore, substituting back into $\Lambda_i$ we find:

$$\Lambda_i = T_i \left( 1 + \sum_{k \neq i} \frac{X_{ik}}{X_{ii}} \right) \ .$$

## A.3 Conditional mean under independence

In this section we prove that $E\left(Z_i | Z_i \geq Z_n\right) \geq E\left(Z_i\right)$ for any $Z_i$ and $Z_n$ independent random variables (which we take with absolutely continuous distributions and support in $\mathbb{R}$) with, for obvious reasons, $\Pr\left(Z_i \geq Z_n\right) > 0$. Let us denote with $f_i$ and $f_n$ the p.d.f. of $Z_i$ and $Z_n$; $f_{i,n} = f_i \cdot f_n$ denotes the p.d.f. of the random vector $(Z_i, Z_n)$.

We can write:

$$\begin{aligned} E\left(Z_i | Z_i \geq Z_n\right) &= \frac{1}{\Pr\left(Z_i \geq Z_n\right)} \int_{\mathbb{R}} z_i \left[ \int_{z_i \geq z_n} f_{i,n}\left(z_i, z_n\right) dz_n \right] dz_i \\ &= \frac{1}{\Pr\left(Z_i \geq Z_n\right)} \int_{\mathbb{R}} \int_{\mathbb{R}} z_i \cdot f_{i,n}\left(z_i, z_n\right) \cdot I_S\left(z_i, z_n\right) dz_i dz_n \ , \end{aligned}$$

where $I_S$ denotes the indicator function of the set $S$ and:

$$S = \left\{ (z_i, z_n) : z_i \geq z_n \right\} \ .$$

Hence, $E\left(Z_i | Z_i \geq Z_n\right) \geq E\left(Z_i\right)$ if and only if:

$$\int_{\mathbb{R}} \int_{\mathbb{R}} z_i \cdot f_{i,n}\left(z_i, z_n\right) \cdot I_S\left(z_i, z_n\right) dz_i dz_n \geq E\left(Z_i\right) \cdot \Pr\left(Z_i \geq Z_n\right) \ . \tag{25}$$

We now show the intermediate result that:

$$\int_{\mathbb{R}} z_i \cdot f_i\left(z_i\right) \cdot I_{[z_n, +\infty)}\left(z_i\right) dz_i \geq E\left(Z_i\right) \cdot \Pr\left(Z_i \geq z_n\right) \ , \forall z_n \in \mathbb{R}. \tag{26}$$

We consider three cases: $(i)$ if $\Pr(Z_i \geq z_n) = 0$, then both sides of the inequality are equal to zero; $(ii)$ if $\Pr(Z_i \geq z_n) = 1$, then both sides of the inequality are equal to $E(Z_i)$; $(iii)$ if $0 < \Pr(Z_i \geq z_n) < 1$, then:

$$E(Z_i | Z_i \geq z_n) \geq z_n \geq E(Z_i | Z_i < z_n) \ ,$$

that is:

$$\frac{1}{\Pr(Z_i \geq z_n)} \int_{\mathbb{R}} z_i \cdot f_i(z_i) \cdot I_{[z_n,+\infty)}(z_i)\, dz_i \geq \frac{1}{\Pr(Z_i < z_n)} \int_{\mathbb{R}} z_i \cdot f_i(z_i) \cdot I_{(-\infty,z_n)}(z_i)\, dz_i \ .$$

Multiplying both sides by $\Pr(Z_i \geq z_n) / \Pr(Z_i < z_n)$ and adding to both of them the term:

$$\Pr(Z_i \geq z_n) \cdot \int_{\mathbb{R}} z_i \cdot f_i(z_i) \cdot I_{[z_n,+\infty)}(z_i)\, dz_i \ ,$$

completes the proof that (26) holds.

We can then integrate the inequality (26) with respect to the distribution of $Z_n$:

$$\int_{\mathbb{R}} \left[ \int_{\mathbb{R}} z_i \cdot f_i(z_i) \cdot I_{[z_n,+\infty)}(z_i)\, dz_i \right] \cdot f_n(z_n)\, dz_n \geq E(Z_i) \cdot \int_{\mathbb{R}} \Pr(Z_i \geq z_n) \cdot f_n(z_n)\, dz_n \ .$$

We now use the independence assumption. First, for what concern the LHS, we have that:

$$\begin{aligned} \int_{\mathbb{R}} \Pr(Z_i \geq z_n) f_n(z_n)\, dz_n &= \int_{\mathbb{R}} \left[ \int_{\mathbb{R}} f_i(z_i) I_{[z_n,+\infty)}(z_i)\, dz_i \right] \cdot f_n(z_n)\, dz_n \\ &= \int_{\mathbb{R}} \int_{\mathbb{R}} f_{i,n}(z_i, z_n) \cdot I_S(z_i, z_n)\, dz_i dz_n \\ &= \Pr(Z_i \geq Z_n) \ . \end{aligned}$$

Finally, using again the independence assumption, we can rewrite the RHS as:

$$\int_{\mathbb{R}} \int_{\mathbb{R}} z_i \cdot f_{i,n}(z_i, z_n) \cdot I_A(z_i, z_n)\, dz_i dz_n \ ,$$

and this proves the necessary and sufficient condition (25).

### A.4 TFP gains with normal technologies

Given that $(Z_1, Z_2)$ has a bivariate normal distribution, it is easy to verify a very useful property: the variables $U = Z_1 + Z_2$ and $V = Z_1 - Z_2$ are normally distributed and independent from each other. Note also that the standard deviation of $V$ is $\sigma_v = \sqrt{\sigma_1^2 + \sigma_2^2 - 2\sigma_{1,2}}$.

Hence, we can write $Z_1 = (U+V)/2$, while the event $Z_1 \geq Z_2$ is equivalent to $V \geq 0$. Therefore:

$$\begin{aligned} E\left(Z_1 | Z_1 \geq Z_2\right) &= E\left(\frac{U+V}{2} | V \geq 0\right) \\ &= \frac{1}{2} E\left(U\right) + \frac{1}{2} E\left(V | V \geq 0\right) \\ &= \frac{\mu_1 + \mu_2}{2} + \frac{1}{2}\left[\mu_1 - \mu_2 + \frac{\sigma_v \cdot f\left(\frac{\mu_2 - \mu_1}{\sigma_v}\right)}{1 - F\left(\frac{\mu_2 - \mu_1}{\sigma_v}\right)}\right] , \end{aligned}$$

where the last step follows from the properties of normal and truncated normal random variables. Then, equation (15) immediately obtains after simplifying and dividing by $\mu_1$.

## A.5 Data sources

This section describes the data sources used in the paper, which refer to the manufacturing sector of the 19 OECD countries listed in Table 3.

*Manufacturing production and trade data:* The data source for production, total imports, and total exports of manufacturing goods in local currency is the OECD-STAN database. Bilateral manufacturing imports from each of the other 18 countries, as a fraction of total manufacturing imports, are taken from the Statistics Canada's World Trade Analyzer. The reconciliation between ISIC and SITC codes follows Eurostat-RAMON (http://europa.eu.int/comm/eurostat/ramon/index.cfm).

*Gravity data:* Geographic distances and the border dummy are taken from Jon Haveman's International Trade Data (http://www.macalester.edu/research/ economics/PAGE/ HAVEMAN/Trade.Resources/TradeData.html). Language groups are the same as in Eaton and Kortum (2001), namely: (*i*) English (Australia, Canada, New Zealand, United Kingdom, United States); (*ii*) French (Belgium and France); (*iii*) German (Austria and Germany).

*Wages and schooling data:* Annual compensation per worker in the manufacturing sector is taken from the OECD-STAN database. Years of schooling are obtained by de la Fuente and Doménech (2006); for the missing data, we interpolate and extrapolate using the most recent update of the dataset first presented in Barro and Lee (2000). Wages are then calculated from equation (21) as explained in the main text.

*Development-accounting methodology and data:* Capital stock data are obtained from real investment data using the perpetual inventory method as

$$K_t = I_t + (1 - \delta) K_{t-1}$$

where $I_t$ is real investment and $\delta$ is the depreciation rate, which we set at 0.06 as in Caselli (2005). Real investment in PPP in the manufacturing sector is computed as RGDPL·POP·KI·IM, where RGDPL is real income per capita in PPP, POP is the population, KI is the total investment share in total income, and IM is the investment share of the manufacturing sector in total investment. The variables RGDPL, POP, and KI are from the Penn World Tables 6.2; IM is computed from OECD STAN. Following a standard practice, initial capital stock is computed as $K_0 = I_0 / (\delta + \kappa)$, where $I_0$ is the first available value in the investment series (which start in 1970 for both Italy and the Unites States) and $\kappa$ is the geometric growth rate of investments over the first decade.

Real output in PPP in the manufacturing sector ($Y_t$) is computed as RGDPL·POP·YM, where YM is the manufacturing value added share in total value added, from OECD STAN.

The number of employees in the manufacturing sector ($L_t$) comes from OECD STAN. The total amount of working hours per worker in the same sector, used in the case study of Section 6, are from the Bank of Italy for Italy and the Bureau of Labor Statistics for the United States.

## A.6 Results and sensitivity analysis

The empirical analysis in Section 5 leads to a measure of TFP relative levels for the manufacturing sector of the main industrial countries, which are shown in Table 4. In this section we examine the sensitivity of our main *intermediate result*, the states of technology, to alternative values of the parameters $\theta$, $\beta$, and $g$ — i.e. those parameters for which different calibrations are also available in the literature.

We focus on the following options. As an alternative to $\theta = 6.67$, we consider $\theta = 8.3$ (the preferred estimate of EK), and $\theta = 4$ and $\theta = 10$, the lower and upper bound of the range of reasonable values of this parameter according to Alvarez and Lucas (2007) (see also Section 5.2 for a brief discussion). $\beta$, the ratio between value added and production in the benchmark estimates, is otherwise measured by the ratio between labor compensation and production as in EK. For the return on education $g$, equal to 0.06 in the benchmark estimates, we consider also the non-linear calibration used by Hall and Jones (1999) and Caselli (2005): namely, we set $g$ equal to 0.13 for $h_i \leq 4$, 0.10 for $4 < h_i \leq 8$, and 0.07 for $h_i > 8$.

As states of technology vary both across countries and over time, we can analyze

Table 4: Trade-revealed TFPs (relative to the United States)

| | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Australia | 71.2 | 68.5 | 68.5 | 68.5 | 67.9 | 67.9 | 68.2 | 68.2 | 67.7 | 68.4 | 71.4 | 71.1 | 71.3 | 72.2 | 70.5 | 70.7 | 71.3 | 71.6 | 69.7 |
| Austria | 76.5 | 75.6 | 76.4 | 76.3 | 77.2 | 78.4 | 78.3 | 78.0 | 77.6 | 77.9 | 79.0 | 80.0 | 79.7 | 79.0 | 78.6 | 78.7 | 79.2 | 79.9 | 78.1 |
| Belgium | 91.3 | 90.8 | 91.7 | 92.0 | 92.4 | 93.7 | 93.8 | 92.4 | 93.4 | 94.5 | 94.9 | 95.3 | 95.3 | 94.6 | 94.6 | 94.8 | 97.2 | 99.9 | 94.0 |
| Canada | 84.3 | 83.0 | 83.0 | 83.1 | 83.0 | 83.6 | 84.2 | 84.2 | 84.3 | 84.2 | 85.0 | 85.2 | 85.0 | 84.3 | 84.3 | 83.1 | 83.7 | 83.4 | 83.9 |
| Denmark | 73.2 | 72.0 | 72.9 | 73.2 | 73.1 | 73.7 | 73.6 | 73.3 | 73.1 | 73.8 | 75.1 | 75.4 | 76.2 | 76.0 | 76.8 | 76.6 | 78.3 | 79.1 | 74.7 |
| Finland | 73.6 | 72.5 | 74.1 | 73.7 | 74.7 | 75.8 | 74.7 | 74.2 | 74.4 | 75.7 | 77.2 | 77.8 | 77.8 | 78.0 | 76.9 | 77.1 | 78.3 | 78.7 | 75.8 |
| France | 88.3 | 86.9 | 87.5 | 87.4 | 87.6 | 88.7 | 89.1 | 88.1 | 87.6 | 88.0 | 88.9 | 89.5 | 89.9 | 89.3 | 89.1 | 88.5 | 89.6 | 89.9 | 88.6 |
| Germany | 87.7 | 86.8 | 87.7 | 87.5 | 87.6 | 88.3 | 84.9 | 85.9 | 85.0 | 85.6 | 87.1 | 87.8 | 87.3 | 87.0 | 86.5 | 86.7 | 87.9 | 88.4 | 87.0 |
| Greece | 74.0 | 72.9 | 74.1 | 73.8 | 75.6 | 76.9 | 76.3 | 75.6 | 75.4 | 76.2 | 78.4 | 78.4 | 79.0 | 79.7 | 79.1 | 78.6 | 79.6 | 79.7 | 76.8 |
| Italy | 87.0 | 85.3 | 86.3 | 85.7 | 86.3 | 86.2 | 85.7 | 84.4 | 84.1 | 84.1 | 84.9 | 85.6 | 85.2 | 83.9 | 82.9 | 82.4 | 83.0 | 82.8 | 84.8 |
| Japan | 84.0 | 84.0 | 84.5 | 84.4 | 85.0 | 86.4 | 86.6 | 85.2 | 85.1 | 84.7 | 85.9 | 86.4 | 86.6 | 85.8 | 85.4 | 85.3 | 86.0 | 86.0 | 85.4 |
| Netherlands | 85.1 | 84.7 | 85.6 | 84.3 | 84.1 | 84.8 | 84.4 | 84.0 | 84.3 | 84.3 | 85.2 | 86.0 | 86.8 | 85.2 | 85.0 | 85.5 | 86.6 | 86.3 | 85.1 |
| New Zealand | 73.8 | 70.9 | 70.1 | 67.0 | 67.4 | 68.3 | 68.0 | 67.6 | 67.5 | 68.4 | 68.0 | 68.9 | 69.5 | 67.9 | 68.1 | 68.3 | 69.2 | 68.2 | 68.7 |
| Norway | 71.0 | 71.2 | 72.4 | 72.4 | 72.9 | 74.1 | 74.6 | 74.0 | 73.2 | 74.0 | 73.8 | 74.8 | 75.4 | 74.4 | 75.1 | 75.6 | 77.0 | 76.8 | 74.0 |
| Portugal | 64.1 | 62.6 | 64.1 | 63.3 | 64.1 | 65.4 | 65.2 | 65.2 | 63.8 | 63.7 | 65.2 | 66.4 | 66.7 | 66.2 | 66.5 | 67.6 | 68.4 | 68.8 | 65.4 |
| Spain | 82.7 | 81.2 | 81.8 | 81.8 | 81.9 | 82.8 | 83.1 | 83.1 | 84.1 | 83.6 | 83.7 | 84.3 | 83.9 | 83.4 | 83.3 | 82.3 | 83.3 | 84.1 | 83.0 |
| Sweden | 81.5 | 80.2 | 81.0 | 80.9 | 81.3 | 81.7 | 80.6 | 80.2 | 79.8 | 80.4 | 81.2 | 83.2 | 82.9 | 82.4 | 81.7 | 83.0 | 83.6 | 84.6 | 81.7 |
| United Kingdom | 87.1 | 86.3 | 88.2 | 88.1 | 87.0 | 87.9 | 88.2 | 88.0 | 88.9 | 89.1 | 89.9 | 90.0 | 90.0 | 89.5 | 89.1 | 89.6 | 92.5 | 93.1 | 89.0 |
| United States | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Mean (w/out the US) | 79.8 | 78.6 | 79.4 | 79.1 | 79.4 | 80.3 | 80.0 | 79.5 | 79.4 | 79.8 | 80.8 | 81.4 | 81.6 | 81.0 | 80.7 | 80.8 | 81.9 | 82.3 | 80.3 |

Table 5: Correlation of alternative calibrations with benchmark estimates (1)

| | | Choice of beta | | | | | |
|---|---|---|---|---|---|---|---|
| | | lab comp / production | | | value added / production | | |
| Choice of g | g=0.06 | theta=4 | 0.81 | 0.95 | theta=4 | 0.95 | 0.98 |
| | | theta=6.67 | 0.93 | 0.98 | theta=6.67 | 1.00 | 1.00 |
| | | theta=8.3 | 0.95 | 0.99 | theta=8.3 | 0.99 | 1.00 |
| | | theta=10 | 0.96 | 0.99 | theta=10 | 0.98 | 0.99 |
| | non-linear g | theta=4 | 0.72 | 0.93 | theta=4 | 0.85 | 0.97 |
| | | theta=6.67 | 0.83 | 0.96 | theta=6.67 | 0.90 | 0.99 |
| | | theta=8.3 | 0.85 | 0.97 | theta=8.3 | 0.89 | 0.99 |
| | | theta=10 | 0.86 | 0.97 | theta=10 | 0.88 | 0.98 |

(1) The number on the left (right) of each cell is obtained by computing, for each country (year), the time-series (cross-country) correlation between the $T_i$'s resulting from an alternative calibration and the corresponding benchmark estimates and, then averaging across countries (years).

the sensitivity of the results in the following way. First, we compute, for each country, the time-series correlation between the $T_i$'s obtained with an alternative calibration and the corresponding benchmark estimates. Second, we compute, for each year, the cross-country correlation between the $T_i$'s obtained with an alternative calibration and the corresponding benchmark estimates. High values of the correlation in the first (second) case would grant that time-series (cross-country) regressions using an alternative calibration instead of the benchmark estimates would provide similar results. High values of the correlations in both cases would imply that one can safely use the benchmark or an alternative calibration in a panel-data analysis.[29] Table 5 summarizes the results of this robustness analysis by showing the average across countries of the time-series correlations (the number on the left of each cell) and the average over time of the cross-country correlations (on the right of each cell) for all the different calibrations.

Consider first the time-series correlations (the numbers on the left of each cell). The north-east panel of Table 5 shows that changing $\theta$ does not have a significant impact on the estimates. Using the preferred calibration of EK ($\theta = 8.3$) provides $T_i$'s whose average correlation with the benchmark $T_i$'s is as high as 0.99; at worse, that is when $\theta = 4$, the

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[29] By the relationship between $T_i$'s and TFPs, the correlation analysis on the TFPs would give similar results.

correlation remains as high as 0.95. Measuring $\beta$ with the ratio between labor compensation and production has a somewhat larger impact, even though correlation remains quite high, at around 0.95, except the case in which $\theta = 4$ that provides a correlation equal to 0.81 (north-west panel of Table 5). Using the non-linear return on education has apparently the largest impact on the $T_i$'s, with correlation declining to around 0.90 (south-east panel of Table 5). However, this outcome is entirely due to the effect of a different $g$ on the $T_i$'s of Greece, whose states of technology become negatively correlated with the benchmark estimates (the sole case in which we find a negative correlation in all our robustness checks). If we exclude this country, the average correlation when we change $g$ (and maintain the same $\theta$ and $\beta$) rises to 0.99 (instead of 0.90) and when we change also $\theta$ correlation rises to around 0.93 (instead of being lower than 0.90). Similarly, when we change both $g$ and $\beta$ (south-west panel of Table 5), the lowest correlation is equal to 0.72 with $\theta = 4$ and is lower than 0.90 for the remaining three values of $\theta$. However, when we exclude Greece, the lowest correlation rises to 0.78 (with $\theta = 4$) and to over 0.90 with the other three values of $\theta$.

On the other hand, the cross-country correlations (the numbers on the right of each cell) show that the linear relationship across countries (and, e.g., the country ranking) is not very sensitive to alternative calibrations. The correlation is, in fact, always higher than 0.90. (Measures of ranking correlation, such as Spearman's rank correlation coefficient, would provide analogous results). These results confirm that our estimates are broadly robust to changes in the benchmark calibration.

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