The Selection Effect of International Competition*

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Abstract

We analyze the probabilistic foundations of the relationship between trade and TFP in the Ricardian model. Under general assumptions about the autarky distributions of firm productivities, trade openness raises TFP due to the selection effect of international competition, which makes "some" high- and "many" low-productivity firms exit the market. Our theoretical findings also allow to quantify the selection effect and estimate TFP levels relative to a benchmark country. We find that international competition raised the manufacturing TFP of 19 OECD countries by 9.4% in 2002 (5.8% in 1985), with large cross-country differences. In a case study, we show that the dynamics of our TFP estimates resemble those from development accounting, with 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 declines after removing trade barriers (for an example, see Appendix A.1 in Finicelli, Pagano, and Sbracia, 2008a). 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] Some intriguing issues, then, arise: are those textbook examples "theoretically" robust? Under what conditions does TFP rise or decline?

In this paper we tackle these issues 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, heterogeneous firms, and a continuum of goods. In this probabilistic framework, we demonstrate that international competition induces a selection effect that favors firms with, *on average*, 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 is, in fact, 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 warrant a reconsideration of the relationship between trade and TFP in the Ricardian model. We show that the comparison between the TFP under autarky and the TFP of an open economy boils down to a comparison between a simple mean and a conditional mean, where the conditioning event is that domestic firms survive international competition. It is this conditioning that "tends" to lift the TFP after trade openness. By introducing enough correlation among country technologies, we explain that it is still pos-

[1] 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).

sible to construct *ad hoc* examples in which international competition induces an "adverse" selection in favor of firms with low productivity. These examples are the counterparts, in this probabilistic set-up, 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, commonly used to describe 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 that our main predictions hold.

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 higher regulation, 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 Chaney, 2008, and 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 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

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

[3] Another close relative of this paper is the work of Bernard, Eaton, Jensen, and Kortum (2003) who analyze trade and productivity with Bertrand competition, but do not derive a closed-form expression for the aggregate TFP.

different probabilities. Therefore, removing trade barriers generates some "action" along the whole distribution of firm productivities, not just in the proximity of some 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 self-select by refraining from producing or exporting 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 model-based 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 the impact on TFP of all the factors mentioned above, including those related to domestic and foreign costs that are analyzed by Alcalá and Ciccone (2004) with 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. Hence, we quantify this effect for a sample of 19 OECD countries with annual data from 1985 to 2002. When we bring the model to the data, our definition of tradeable sector boils down to the manufacturing sector. We find that, on average, international competition lifted manufacturing TFP 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.

Although the thrust of this paper is theoretical, we explore another useful spin-off of the model for the empirical analysis. Our propositions 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 of our empirical 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 value data on bilateral trade flows and production as well as input costs instead of hard-to-get quantity data on the stock of physical capital. Thus, they help to develop sectoral analysis, as the necessary data are available even for very fine classifications of industries.[4]

[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

We also 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. We focus on this country pair because, despite the weakness of Italy's social infrastructure, standard methodologies find that Italy is the most productive country in the world (Hall and Jones, 1997). Our methodology, while delivering very similar dynamics compared to development accounting, is not impaired by this puzzling result.

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.

2 Theoretical background

2.1 An outline of the Eaton-Kortum model

EK consider a Ricardian framework with N countries ($N > 1$) and a continuum of tradeable goods produced by heterogeneous firms with 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: $q_i(j) = z_i(j) \cdot I_i(j)$, 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: $Z_i \sim Fréchet\,(T_i, \theta)$,with $T_i > 0$, $\theta > 1$, and $\{Z_i\}_{i=1}^{N}$ mutually independent. Due to the continuum-of-goods assumption and assuming the law of large numbers holds, 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, the technology of the tradeable sector of each country i is described with the c.d.f. of Z_i that, in turn, is

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 an open economy and, therefore, is able to single out the selection effect of international competition.

summarized by two numbers, T_i and θ.[5]

EK show that T_i and θ 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. θ, in turn, is inversely related to the dispersion of Z_i (we will refer to it as the *precision of the distribution*);[6] 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 θ (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: $p_{ni}(j) = c_i d_{ni} / z_i(j)$. In country n each good j is purchased from the country that provides it at the lowest price, i.e.:

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

Consumers are subject to the usual budget constraint that total spending cannot be larger than total income. They buy 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)

[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] T_i and θ are related to the mean and the variance of Z_i. Denoting Euler's gamma function by Γ, the mean of Z_i is $T_i^{1/\theta} \cdot \Gamma[(\theta-1)/\theta]$ if $\theta > 1$, while its variance is $T_i^{2/\theta} \cdot \left\{\Gamma[(\theta-2)/\theta] - \Gamma^2[(\theta-1)/\theta]\right\}$ if $\theta > 2$.

of country n, X_n — is given by:

$$\frac{X_{ni}}{X_n} = \frac{T_i \cdot (c_i d_{ni})^{-\theta}}{\Phi_n} \text{ , where: } \Phi_n = \sum_{k=1}^{N} T_k \cdot (c_k d_{nk})^{-\theta} \ . \tag{1}$$

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 technologies T_k increase.

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:

$$p_n = \gamma \cdot \Phi_n^{-1/\theta} \text{ , where: } \gamma = \left[\Gamma\left(\frac{\theta + 1 - \sigma}{\theta}\right)\right]^{1/(1-\sigma)} , \tag{2}$$

with Γ 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 σ. Denoting with β the constant share of labor, with $\beta \in (0, 1)$, then the cost c_i takes the form:

$$c_i = w_i^{\beta} p_i^{1-\beta} , \tag{3}$$

where w_i is the nominal wage in country i and p_i is given by equation (2).[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, θ, α and β (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]

[7] Equation (3) 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, 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 tradeable goods 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 TFP_i; its c.d.f. then is:

$$G_i(z) = \Pr\left(Z_i < z | P_{ii} = \min_k P_{ik}\right) , \tag{4}$$

where P_{ik} is the random variable that describes the prices $p_{ik}(j)$ for any i and k (including $i = k$). The fact that the goods j produced by country i are all and only those for which $p_{ii}(j) \leq p_{ik}(j)$ for any k requires a formal proof. First, if j is such that $p_{ii}(j) \leq p_{ik}(j)$ 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 $G_i(z)$ yields the following result:

Proposition 1 *If technologies are Fréchet distributed and markets for tradeable goods are perfectly competitive, then:*

$$TFP_i \sim Fréchet\left(\Lambda_i, \theta\right) ,$$

where

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

Proof. See Appendix A.1 ■

[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 $p_{ii}(j) = p_{ik}(j)$, since they have zero probability.

Thus, the variable TFP_i is Fréchet distributed and its mean:

$$E(\text{TFP}_i) = \Lambda_i^{1/\theta} \cdot \Gamma\left(\frac{\theta - 1}{\theta}\right) , \tag{5}$$

which is a monotone function of Λ_i, provides a theoretical expression for the TFP.

The first remarkable result is that $\Lambda_i > T_i$ always; therefore $E(\text{TFP}_i) > E(Z_i)$. 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 the Ricardian model.

Equation (P1) also shows that, in an open economy, Λ_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 (1)), partly to the expenses of the production of country i. The goods that keep being produced in country i, however, are made with a higher productivity, which is reflected in the increase in Λ_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 Λ_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 forces inefficient firms to exit, raising aggregate productivity. (Note, 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]

By recalling the expressions of costs (equation (3)) and prices (equation (2)), 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-

[10] Chari, Restuccia, and Urrutia (2005) unravel another mechanism through which more frictions in the labor market 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 provide evidence that the relationship between the level of employment protection and the TFP across European countries is positive.

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 Λ_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 (3) and market shares by equation (1), 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, Λ_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) minus the value of its total exports (EXP_i). Let us write:

$$\Omega_i = 1 + \frac{IMP_i}{PRO_i - EXP_i} \ ; \tag{6}$$

Ω_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

[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).

measure of *trade openness* for country i. Note that, consistently with equation (P1), Λ_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 Ω_i. Equation (P2), in fact, shows that Ω_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 Ω_i takes into account the factors related to domestic and foreign costs that are considered by Alcalá and Ciccone.

The wide availability of production and trade data makes it easy to compute Ω_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 the other assumptions, this hypothesis simplifies the analysis by implying that a country i will produce and export good j if and only if $z_i(j) \geq z_n(j)$.

Note, first, that 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

[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 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.

$a(j) = z_i(j)/z_n(j)$, 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, 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 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 state $T_i + T_n \cdot d_{ni}^{\theta}$ and precision θ. Applying Proposition 1 to this simplified set-up, we find that the distribution of the whole set of surviving firms is Fréchet with state $T_i + T_n \cdot d_{in}^{-\theta}$ and precision θ. Since icebergs costs d_{ni} and d_{in} are larger than 1, then the average productivity of exporters is higher than the TFP of the whole economy (that is the average

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

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:

$$E\left(Z_i | Z_i \geq Z_n\right) \geq E\left(Z_i\right) \ . \tag{7}$$

Inequality (7) 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 (7) is not satisfied — the counterpart of the standard textbook examples of non-probabilistic Ricardian models — is the following. Take any 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 Z_i and Z_n are not independent.[15]

The assumption of independence between Z_i and Z_n, instead, is sufficient for (7) to hold, irrespectively of the distribution of Z_i and Z_n (see Online Appendix for details). 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. A simple multivariate extension of the Fréchet distribution that covers all levels of dependence,

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

[15] Note that after trade openness welfare increases also in countries where TFP declines. The reason is that a lower TFP is more than compensated by lower consumer prices. Demidova and Rodríguez-Clare (2008) show examples in which, for the opposite reason, welfare falls despite higher productivity. They also build a monopolistic competition model for a small economy, in which they provide a decomposition of welfare gains into four components: productivity, terms of trade, varieties, and heterogeneity across varieties.

from independence to perfect correlation, has the following c.d.f.:

$$\Psi_{i,n}(z_i, z_n) = \exp\left\{-\left[\left(T_i \cdot z_i^{-\theta}\right)^{1/r} + \left(T_n \cdot z_n^{-\theta}\right)^{1/r}\right]^r\right\} , \tag{8}$$

where $\Psi_{i,n}(z_i, z_n) = \Pr(Z_i < z_i, Z_n < z_n)$ and $r \in (0, 1]$. This distribution yields two Fréchet as marginals (with parameters respectively equal to (T_i, θ) and (T_n, θ)) 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 (8), we can show that the TFP gain of country i, i.e. the increase in its TFP with respect to autarky, is:[17]

$$\frac{E(Z_i | Z_i \geq Z_n)}{E(Z_i)} = \left[1 + \left(\frac{T_n}{T_i}\right)^{1/r}\right]^{r/\theta} . \tag{9}$$

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 θ and r.[18] We know from the EK model that welfare gains from trade decrease as θ increases; 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 θ 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 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]

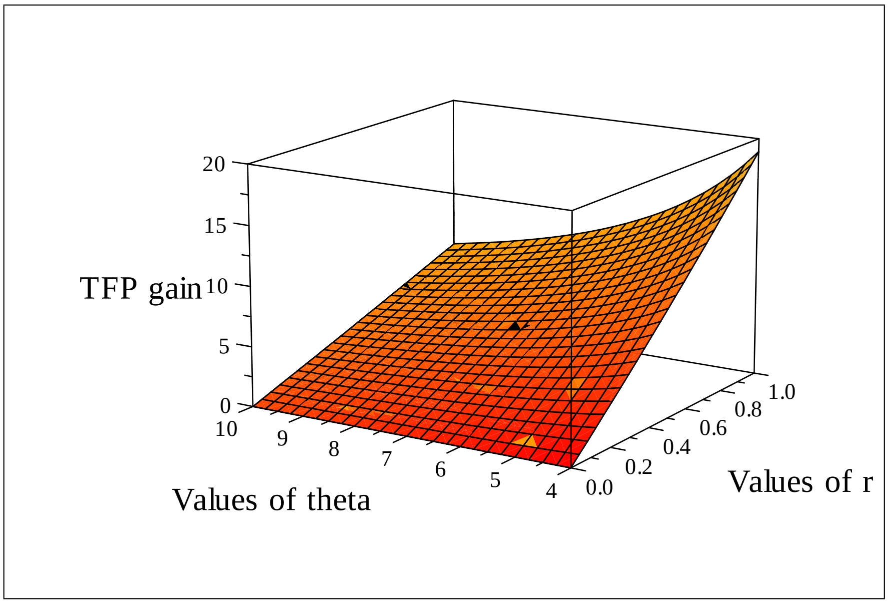
[16] Introduced by Tawn (1990), $\Psi_{i,n}$ is also known as asymmetric bivariate logistic distribution and is commonly used in multivariate extreme value theory.

[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 θ.

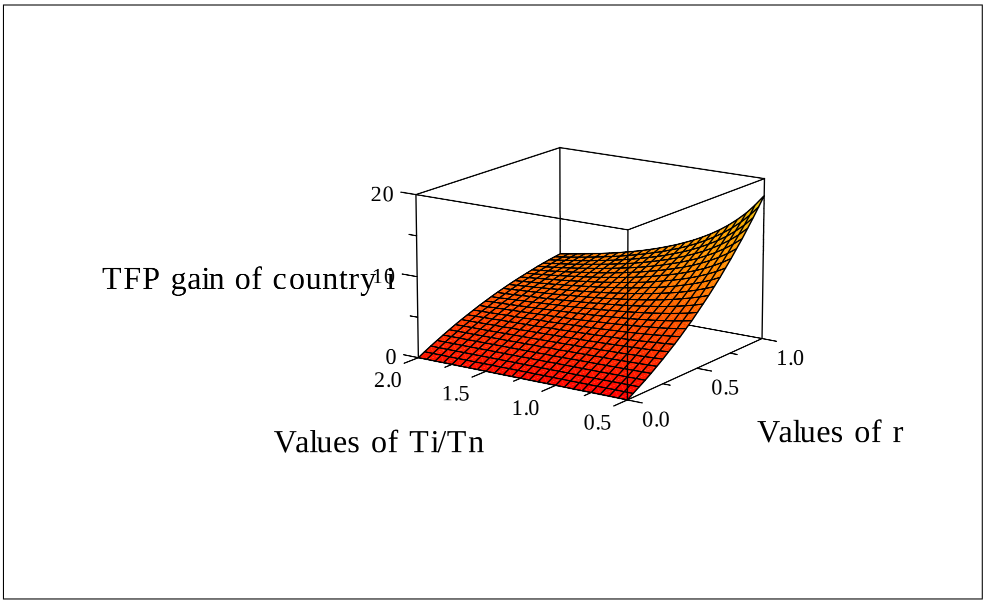
[19] It is worth noticing an important property of the multivariate case. An inspection of equation (9) reveals

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 θ, with $T_i/T_n = 1$.

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 μ_i and σ_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]

$$\frac{E\left(Z_1 | Z_1 \geq Z_2\right)}{E\left(Z_1\right)} = 1 + \frac{\sigma_v}{2\mu_1} \frac{f\left(\frac{\mu_2 - \mu_1}{\sigma_v}\right)}{1 - F\left(\frac{\mu_2 - \mu_1}{\sigma_v}\right)}\ , \tag{10}$$

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 $f/(1-F)$ 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 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 (μ_2), and in the degree of heterogeneity of both domestic and foreign production (σ_1^2 and σ_2^2); strictly decreasing in the domestic autarky TFP (μ_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 Ω_i raised to the $1/\theta$ power (one can obtain it by substituting (P2) into (5) 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 Ω_i raised to the $1/\beta\theta$ power (see also equation (15) in EK).

Ω_i can be quantified using production and trade data.[21] For θ, the literature suggests two different strategies. One is proposed by EK, who estimate θ using several testable implications of the model, finding values between 3.6 and 12.9, with 8.28 being their preferred

that the TFP gain for two countries with correlated technologies and given values of T_i/T_n, θ and r (with $r < 1$) is the same as the TFP gain for two countries with independent technologies, a state-of-technology ratio equal to $(T_i/T_n)^{1/r}$, and a precision parameter equal to θ/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.3.

[21] For a detailed description of data sources, see Appendix A.4.

estimate. A second strategy is proposed by Alvarez and Lucas (2007), who calibrate θ by exploiting a property of the theoretical model. Namely, the prediction that market shares are given by equation (1) 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 σ_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 θ between 4 and 10, with 6.67 being their preferred estimate. Both strategies take θ time-invariant; Finicelli, Pagano, and Sbracia (2008b) provide evidence supporting this assumption.

There are two strategies available also for what concerns β. 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 β 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 β 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'.

In our benchmark estimates, we follow Alvarez and Lucas for both θ (set to 6.67) and β. 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 of 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 θ 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

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.

$\beta = 0.33$, 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 in 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 evaluate benefits of trade due to positive technology spillovers, as these are ruled out by the model. 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 map estimates of the model parameters into estimates of the manufacturing TFP. 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, let us recall that, by equations (1) and (2), market shares and relative prices are invariant with respect to a linear transformation of the states of technology. This implies that, as in EK, we can only obtain estimates of the *relative states of technology* (i.e. of the ratios T_i/T_n) and, in turn, of *relative TFP levels*. For this reason, we will present results for T_i and $E\left(\text{TFP}_i\right)$ relative to 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. In this stage, for reasons that will be clearer later, we depart from EK by converting nominal wages into US dollars at PPP exchange rates, instead of market exchange rates. Finally, we use equations (5) and (P2) to get our trade revealed TFP.[22]

5.1 Competitiveness and trade barriers

Rearranging equations (1), (2) and (3), and taking logs, EK obtain the following testable implication:

$$\log\left[\left(\frac{X_{ni}}{X_{nn}}\right)\left(\frac{X_{ii}/X_i}{X_{nn}/X_n}\right)^{\frac{1-\beta}{\beta}}\right] = S_i - S_n - \theta\log\left(d_{ni}\right)\ , \tag{11}$$

where:

$$S_i \equiv \frac{1}{\beta}\log\left(T_i\right) - \theta\log\left(w_i\right)\ . \tag{12}$$

The left-hand side (LHS) of equation (11) 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 (11) does not allow to get separate estimates of T_i and θ. However, once θ is calibrated as explained in Section 4, one can estimate the S_i's

[22] Appendix A7 in Finicelli, Pagano, and Sbracia, 2008a, provides a battery of robustness tests.

from equation (11) and, then, extract the T_i's from the S_i's using equation (12) and data on nominal wages.

The LHS of equation (11) can be measured using production and trade data and a calibration for β (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:

$$\log d_{ni} = d_k + b + l + e + m_n \ , \tag{13}$$

where we have suppressed the dummy variables associated with each effect for notational simplicity. In equation (13), d_k $(k = 1, ..., 6)$ is the effect of the distance between n and i lying in the kth interval;[23] 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 (13) for trade barriers, equation (11) becomes:

$$\log \left[\left(\frac{X_{ni}}{X_{nn}} \right) \left(\frac{X_{ii}/X_i}{X_{nn}/X_n} \right)^{\frac{1-\beta}{\beta}} \right] = S_i - S'_n - \theta d_k - \theta b - \theta l - \theta e \ , \tag{14}$$

where $S'_n = S_n + \theta m_n$. When we estimate the destination dummies S'_n, we keep together the competitiveness effect S_n and the trade barrier θm_n. 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.

For each year of the period 1985-2002, we estimate equation (14) by ordinary least squares on the cross-section of 342 informative observations (as the equation is vacuous when $n = i$). 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 not significantly different from zero (not surprisingly, since most countries in the sample are European).

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

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

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

Variable	Coefficient	Year: 1985 Estimate	s.e.	Year: 1990 Estimate	s.e.	Year: 2002 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 ($-\theta m_i$):							
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 (14) using OLS; standard errors in brackets.

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 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.[24]

5.2 States of technology

From the estimates of S_i derived above and data on nominal wages, we can extract the states of technology T_i by inverting equation (12), i.e. $T_i = \exp(\beta S_i) \cdot w_i^{\beta\theta}$.

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: $w_i = comp_i \cdot \exp(-g \cdot h_i)$, 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.[25] 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 to the dynamics, results become quite odd. Consider, for instance, Japan. In 1985, its state of technology relative to the United States is just 24 percent; in the following 10 years, it grows

[24]Eaton and Kortum (2002) estimate equation (14) 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 calibration of β and to the older update of the OECD data used in their paper, and not to the different estimation method.

[25]Setting $g = 0.06$ is a conservative calibration according to Bils and Klenow (2000). See Appendix A.7 in Finicelli, Pagano, and Sbracia (2008a) for 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 of $T_i = \left[\exp\left(S_i\right) \cdot w_i^{\theta}\right]^{\beta}$.

amazingly topping at 150 percent in 1995; then it falls back down to 53 percent in 2002. Equally implausible swings are also recorded for several other countries. More importantly, these estimates exhibit 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 vis-à-vis the US dollar 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 β, θ, and g.[26]

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 shares adjusted very slowly and displayed only a small and gradual decline. In terms of the model, the large increase in Japan's input costs must have been matched by a very large improvement in its own technology in order to maintain its export shares almost unchanged.

These considerations raise two issues. First, the EK model is a static general equilibrium

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

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,[27] we address the former issue by converting input costs into a common currency using PPP exchange rates as a measure of equilibrium exchange rates (using average exchange rates 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 into US dollars with PPP exchange rates calculated by the OECD. Results are clearly more stable. 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 (5)). Once that these calculations are performed, we find that these low T_i's are perfectly consistent with reasonable values of TFPs.

5.3 Trade-revealed TFPs

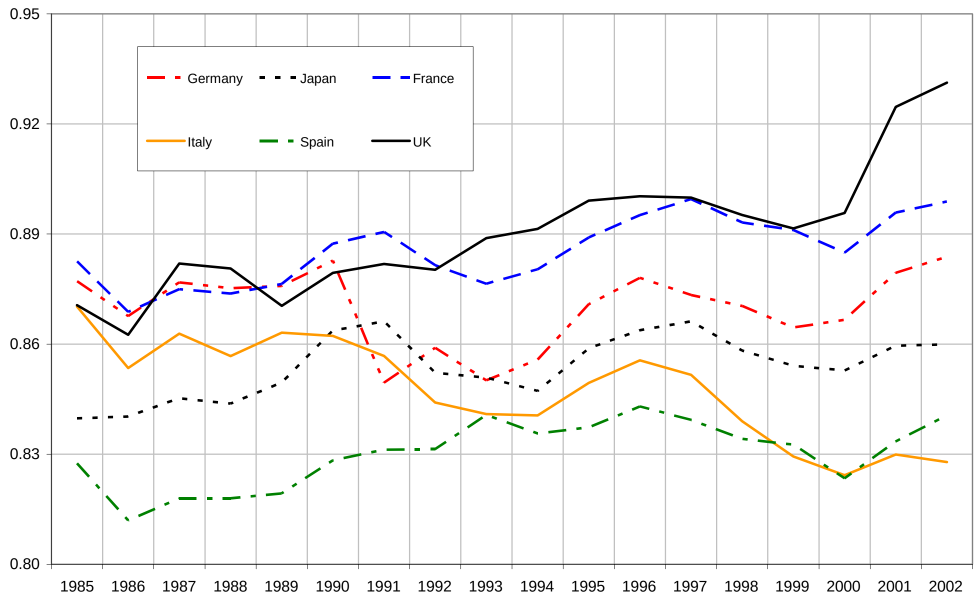
With the estimates of the states of technology derived above, we are now equipped to calculate TFP levels relative to a benchmark country. Recalling the meaning of the X_{ik} and using equations (5), (P2) and (6), the relative TFP of country i with respect to the United States, denoted with λ_i, can be written as:

$$\lambda_i = \left(\frac{T_i}{T_{us}} \frac{\Omega_i}{\Omega_{us}} \right)^{1/\theta} , \qquad (15)$$

where the subscript us stands for the United States.

[27] 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.

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



(1) Values of λ_i obtained from equation (15)

Overall, the 18 OECD countries in our sample have a manufacturing TFP equal, on average, to 80 percent the level of the United States. The country with the largest average TFP in the sample period is the United States (identically equal to 1 over the whole sample period), followed by Belgium, the United Kingdom and France. Portugal, New Zealand, and Australia have the lowest average TFPs (see Appendix A.7 in Finicelli, Pagano, and Sbracia for detailed results for all countries and years). Figure 3 presents our estimates of λ_i for the main industrial countries: Japan, the United Kingdom, and the four largest euro area countries. The figure shows that up to the early 1990s, trade-revealed manufacturing TFPs are close to each other, fluctuating at around 87 percent. Afterwards, their dispersion increases.

The divergent paths of TFPs in Italy and the United Kingdom are noteworthy. 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 TFP is the lowest among the economies in this group, surpassed also by Spain; on the other hand, TFP in the United Kingdom tops the group, and is not too distant from that of the United States. The rising productivity in the United Kingdom and the well known shrinking dimension of the manufacturing sector are consistent with our theoretical results. Specifically, increasing international competition may have forced less efficient UK firms to exit the market, raising aggregate TFP. In fact, results from Section 4 also show that the United Kingdom is the country that, among those represented in Figure 3, benefited from 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

Are results from the trade-revealed methodology consistent with those from standard methodologies? In this section we focus on the Italian case, which is particularly interesting because of the surprising finding from development accounting that Italy's TFP is the highest in the world (see Klenow and Rodríguez-Clare, 1997, and Hall and Jones, 1999, for some results and Lagos, 2006, for a discussion). Moreover, data are available to allow us an improved analysis, in which for both Italy and the United States we can measure the labor input more precisely by considering working hours (data that are rarely available at sectoral level) and we can also compare trade-revealed TFP growth rates with those provided by national authorities. On the other hand, data limitations that hamper the implementation of the development-accounting methodology would prevent extending such comparison to all our sample of countries.[28]

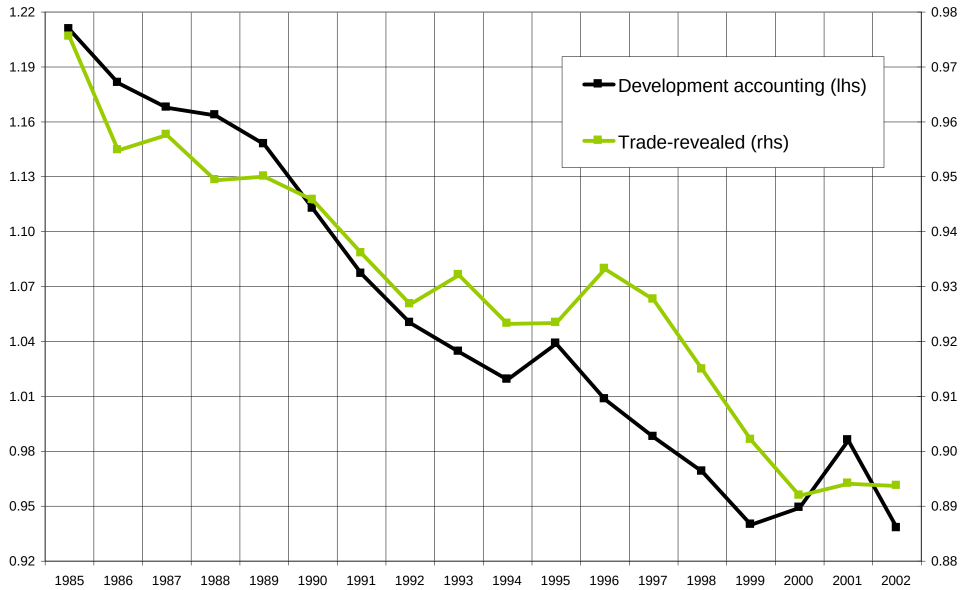
A development-accounting exercise for the manufacturing sector would typically assume that output in country i (Y_i) is given by: $Y_i = A_i K_i^{\eta} H_i^{1-\eta}$, where A_i is the TFP, K_i is the stock of physical capital, and H_i is the stock of human-capital augmented labor (with all the variables referring to the manufacturing sector).

It is assumed that each worker has been trained with h_i years of schooling; then, human-capital augmented labor is given by: $H_i = L_i \cdot \exp(-g \cdot h_i)$, 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

[28] The measurement of physical capital is the step in which data limitations are binding. For instance, from OECD STAN, the main source of comparable cross-country data on production at the sectoral level, the *volume of net capital stock* — a common proxy for physical capital — is available for the whole sample period 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). Similar problems arise if one tries to calculate the stock of capital from manufacturing investments. OECD STAN provides the *volume of fixed investment* in the manufacturing sector of 11 countries during our sample period (and, again, not for large countries such as Japan and the United Kingdom). The *value of manufacturing investment* is available for almost all countries (15 out of 19) but, then, one faces the critical issue of finding an appropriate price deflator. Schreyer and Webb (2006) provide a useful survey of definitions and data availability of capital stock measures.

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



can calculate the level of manufacturing TFP from the production function:

$$A_i = \left(\frac{Y_i}{L_i}\right)^{1-\eta} \left(\frac{K_i}{Y_i}\right)^{-\eta} \left(\frac{H_i}{L_i}\right)^{-(1-\eta)} . \tag{16}$$

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).[29]

Figure 4 shows the TFP ratio between Italy and the United States obtained with this methodology and compares it with our trade-revealed TFP. Visual inspection reveals that the time pattern of the two curves is remarkably similar. However, the curves are measured on different axes and on quite different scales. 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 cumulative loss of 27 percentage points. On the other hand, the trade-revealed TFP in 1985 is below 1 and records a gradual, but much smaller decrease subsequently (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

[29] Appendix A.4 provides details on data sources and methodology.

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, our relative TFPs 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) puts 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

In this paper we unravel the probabilistic foundations of the relationship between trade and TFP in the general version of the Ricardian model developed by Eaton and Kortum. The model yields a remarkable implication: trade openness raises TFP. Counterexamples in which this result does not hold are limited to specific highly correlated country technologies and, irrespectively of the degree of correlation, cannot be constructed for large families of joint distributions of country technologies, such as the multivariate Fréchet and the multivariate normal.

While our main 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 in TFP occurs. In Melitz all and only the firms whose TFP is higher than a certain threshold will export; in the Ricardian model, the law of comparative advantage implies that few "bad" exporters and "good" non-exporters coexist with many "good" exporters and "bad" non-exporters. These differences could be exploited by future empirical studies to discriminate between the two theories.

Since our results link model parameters to the TFP of the tradeable sector of a country relative to that of another country, by estimating model parameters we obtain estimates of relative TFPs. The comparison between this method and the development-accounting methodology, which we have performed for the TFP of Italy relative to the United States, seems promising. In particular, the dynamics of the two variables turn out to be very similar, but our method 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 (although very indirect) validation of the EK model.

A Appendix

A.1 Proof of Proposition 1

Before computing $G_i(z)$ from equation (4), 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:

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

The numerator is:

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

where Λ_i is given by equation (P1).

By using the expressions found for the numerator and the denominator of $G_i(z)$, 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, $\mathrm{TFP}_i\sim \textit{Fréchet}\,(\Lambda_i,\theta)$.

A.2 Proof of Proposition 2

Plugging the expression of costs (equation (3)) 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 (1), 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 Λ_i we find:

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

A.3 TFP gains with normal technologies

If (Z_1,Z_2) has a bivariate normal distribution, a useful property holds: 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 write $Z_1 = (U+V)/2$, while $Z_1 \geq Z_2$ is equivalent to $V \geq 0$; then:

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

where the last step follows from the properties of normal and truncated normal random variables. Equation (10) immediately obtains after simplifying and dividing by μ_1.

A.4 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 source for production, total imports, and total exports of manufacturing goods in local currency is OECD-STAN. Bilateral manufacturing imports from each of the other 18 countries, as a fraction of total manufacturing imports, come 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 dummies are taken from Jon Haveman's International Trade Data (http://www.macalester.edu/research/economics/PAGE/HAVEMAN/Trade.F Language groups are the same as in EK, 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 OECD-STAN. 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 adjusted for education, as explained in Section 5.2.

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 δ is the depreciation rate, which we set equal to 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 $K_0 = I_0/\left(\delta+\kappa\right)$, where I_0 is the first available value in the investment series (which start in 1970 for both Italy and the Unites States) and κ 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, are from the Bank of Italy for Italy and the Bureau of Labor Statistics for the United States.

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