

TRADE-REVEALED TFP*

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Abstract

This paper pursues a novel methodology, based on the trade model of Eaton and Kortum (2002), to estimate TFP levels, relative to the US, for the manufacturing sector of 18 OECD countries from 1985 to 2002. In the model, firms have technologies described by a probability distribution, with parameters related to absolute and comparative advantages. We show that manufacturing TFP is a function of these advantages, augmented by a measure of trade openness. Our results shed light on the role of international competition in selecting firms with higher productivity. In our sample, international competition raised manufacturing TFP by an average 7% — a contribution quite diversified across countries and with a common upward trend. Finally, we focus on Italy's relative TFP and compare it with one obtained from development accounting as well as with estimates available from national sources.

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1 Introduction

Estimating the level of a country Total Factor Productivity (TFP) is an extremely difficult task. The standard practice, commonly known as development accounting (King and Levine, 1994), consists in choosing a functional form for the production function, measuring output and inputs, and then obtaining the TFP as a residual. One of the hardest and most critical parts concerns the measurement of physical capital. The perpetual inventory method commonly adopted for this purpose suffers from a number of serious limitations. It is very demanding in terms of data, as it requires long time series on fixed investment and price deflators; it often entails heroic assumptions about the depreciation rate and the initial capital stock, whose importance is higher with shorter time series; it usually mixes up types of investment with very different efficiencies, such as public and private investment; it often ignores several other key aspects regarding the quality of capital (Caselli, 2005).

Difficulties in estimating TFP levels escalate if one needs homogeneous measures across several countries or sectoral measures. In fact, cross-country heterogeneities in the quality of capital are very large, especially when one considers samples including both industrial and developing countries. Despite the efforts in building a unified system of national accounts, some categories of expenditure still undergo diverse classifications in different countries. A similar difficulty arises with the deflators used to derive quantities from values, due to the enormous differences in the diffusion and cross-country consistency of hedonic prices. The lack of sectoral data on fixed investment is also stunning, since it is a problem that affects even some of the major economies.

Yet, the importance of measuring TFP levels is widely recognized. For instance, many development-accounting exercises find that most of the differences in income per capita across nations is due to cross-country differences in TFP. In addition, recent studies conjectured that those results might be due to sectoral differences in TFP — an hypothesis that, however, cannot be properly verified due to the lack of data.¹ All these arguments call for methodologies able to provide measures of TFP comparable across countries and available also at a sectoral level.

In this paper, we pursue a novel approach to measuring the TFP of tradeable goods.

¹For some different views about this hypothesis see Caselli (2005) and Herrendorf and Valentinyi (2006).

We take the Ricardian trade model of Eaton and Kortum (2002) (EK hereafter) seriously and use it in order to get country estimates of TFP levels, relative to the United States, for 18 OECD countries from 1985 to 2002. The main advantages of this exercise stem from the fact that our estimates require bilateral trade data instead of quantity data on physical capital. This ensures the availability of long time series, grants a relatively high degree of homogeneity and comparability of data across several countries, and makes it possible to compute sectoral estimates of TFP levels. Physical capital is not necessary because the model shows that it is the cost of inputs that matters for bilateral trade shares, and not their quantities. This feature makes of our methodology reminiscent of the dual method for computing TFP growth rates developed by Hsieh (2002). There are, however, many important differences. First and foremost, our TFP is not obtained as a residual, but is the productivity that better fits bilateral trade and cost data. Moreover, we can compute TFP levels and not just TFP growth rates.

In their model, EK consider countries endowed with different production technologies for each good, which mutually benefit from international trade by exploiting comparative advantages. Their key assumption — derived from an elegant theory about the arrival of ideas developed by Kortum (1997) — is that tradeable goods in each country are produced with technologies described by a Fréchet distribution. More specifically, the Fréchet distribution — whose two parameters are related to absolute and comparative advantages — describes the individual productivities of domestic firms for all existing tradeable goods. Its average, then, would represent the *potential productivity* of the tradeable sector of the country, i.e. the TFP of the tradeable sector *under autarky*. Our first contribution is to show that in an *open economy with perfectly competitive markets* the productivity of the firms surviving international competition is also described by a Fréchet distribution and that its mean — that is the TFP of the tradeable sector — is a function of absolute and comparative advantages, augmented by a measure of trade openness. This is what we dub *trade-revealed* TFP.

Our results provide several insights about the factors that influence the TFP of tradeable goods in an open economy. For instance, we show that an increase in TFP may occur without a "genuine" domestic technological progress. An increase may simply reflect factors such as improvements in the technology of competitor countries, loosening trade barriers (including entries of new competitor countries), and declining foreign input costs. These factors unwind their effects through *international competition*: some domestic firms

are crowd out by foreign firms, and the resulting domestic TFP increases.

These theoretical findings bring this paper close to the literature that emphasizes the role of institutions — or "social infrastructure", as Hall and Jones (1999) put it — in explaining TFP differences across countries. Examples include Conway and Nicoletti (2006) and Lagos (2007) who show that higher regulation in the non-manufacturing sector and in the labor market lowers manufacturing productivity. In our model one key factor reducing productivity is impediments to international trade. Countries with the same potential productivity may exhibit different TFP levels because of differences in trade barriers. However, regulation in the non-manufacturing sector and in the labor market has the opposite effect compared to Conway and Nicoletti and to Lagos. In addition, the effect of other factors, such as proximity to productive countries (or, in other words, *geography*), also emerges.

The functional form of the TFP that we get yields also important bearings for the literature on trade and productivity. Specifically, as a by-product of our analysis, we obtain a *Ricardian measure of trade openness*, which is defined as the ratio between the value of total absorption and that of the domestic production sold domestically. Interestingly, this ratio gathers all the factors related to domestic and foreign costs that are considered by Alcalá and Ciccone (2004), as well as the effects of foreign technologies and trade barriers.

Our second contribution is empirical and, as mentioned above, consists in quantifying our trade-revealed TFPs and the associated contribution of international competition. In doing so, we use a variant of the empirical methodology of EK, who estimate absolute and comparative advantages for the same set of 18 countries in one single year (1990). Here not only we extend their estimates to obtain TFP levels from the Ricardian advantages, but we also depart from their methodology in one main respect. We show that it is crucial to convert nominal variables (wages) into a common currency using purchasing-power-parity (PPP), instead of market-determined, exchange rates. This is also consistent with the standard practice in development-accounting, which will be the yardstick for our trade-revealed TFPs.

When we turn to the empirical estimates, the definition of tradeables that we adopt boils down to the manufacturing sector as a whole. However, one could easily exploit all the advantages of using trade data and extend the empirical methodology along two main dimensions. Building on Alvarez and Lucas (2007), one could generalize our estimates to

encompass the TFP of all tradeable goods and services. Most importantly, working along the lines of Shikher (2004), one could adopt a finer classification of industries and derive distinct measures of the TFP for several industries of the tradeable sector. The latter exercise would be virtually impossible whereas measures of physical capital are necessary.

Our third contribution is a zoom on the manufacturing TFP of Italy relative to the United States. For this pair of countries, we compare our trade-revealed TFP with one obtained using the development-accounting approach. On the one hand, this case study is particularly interesting as it is well known that standard methods often find that Italy is the most productive country in the world, a very surprising result given its weak "social infrastructure" relative to the other industrial countries (Hall and Jones, 1997). On the other hand, data limitations preventing the estimation of manufacturing TFP using development accounting would not allow to extend the methodological comparison to many other countries. However, by focusing on a specific pair of countries we are able to offer a very detailed analysis. We can consider data-enhanced variants of the original trade-revealed methodology as well as a comparison with the estimates of the growth rates of manufacturing TFP available from national sources.

The rest of the paper is organized as follows. Section 2 offers a brief outline of the Eaton-Kortum model (Section 2.1) and presents the main theoretical results about the TFP of tradeables (Section 2.2). In Section 3 we measure the trade-revealed TFPs. In the model, the export capacity of a country is represented by a competitiveness indicator that gathers the country's absolute and comparative advantages, and its labor costs. Hence, we first estimate this indicator (Section 3.1); then, we use it in order to extract absolute advantages, while we calibrate comparative advantages (Section 3.2); finally, we obtain manufacturing TFP levels and quantify the contribution of international competition to domestic TFP (Section 3.3). Section 4 illustrates our case study. Section 5 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 goods. As in Ricardo, the model assumes that countries produce goods with different constant-

returns-to-scale technologies. Denote with $z_i(j) > 0$ the efficiency of country i in producing good j , with $i \in \{1, \dots, N\}$ and $j \in [0, +\infty)$; namely:

$$q_i(j) = z_i(j) \cdot I_i(j) \quad , \quad (1)$$

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 of the model 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 :

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

with $T_i > 0$, $\theta > 1$, and Z_i independent from Z_n for any $i \neq n$. 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 below any real number z is simply the probability: $\Pr(Z_i < z) = F_i(z) = \exp(-T_i \cdot z^{-\theta})$, where F_i denotes the cumulative distribution function (c.d.f.) of Z_i . Therefore, this hypothesis allows to describe the technology of each country with the c.d.f. of Z_i that, in turn, is summarized by just two numbers, T_i and θ .²

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*, reflects country i 's absolute advantage; namely, 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 . The parameter θ is inversely related to the dispersion of Z_i .³ Its connection with the concept of comparative

²Kortum (1997) and Eaton and Kortum (2007) show that the Fréchet distribution emerges from a dynamic context in which, at each point in time: (i) the number of ideas about how to produce a good arrives randomly following a Poisson distribution; (ii) the efficiency conveyed by each idea is extracted by 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. The assumption of Pareto-distributed productivity shocks at the firm level is maintained by several recent models, including Melitz (2003) and Lagos (2007).

³Indeed, T_i and θ are both related to the mean and the variance of Z_i . In particular, denoting Euler's gamma function by Γ , it holds that if $\theta > 1$ then the mean of Z_i is $T_i^{1/\theta} \cdot \Gamma[(\theta - 1)/\theta]$, and if $\theta > 2$ then its variance is $T_i^{2/\theta} \cdot \{\Gamma[(\theta - 2)/\theta] - \Gamma^2[(\theta - 1)/\theta]\}$. The inverse link between the variance of Z_i and θ can be recognized considering also that the standard deviation of the log of Z_i is: $\pi / (\theta\sqrt{6})$.

advantage stems from the fact that in the Ricardian model gains from international 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 each country i is denoted with c_i ; later, it will be broken into costs of labour and intermediates and endogenized. Trade barriers are modeled as Samuelson's iceberg costs. Namely, delivering one unit of good from country i to country n requires producing d_{ni} units of the good, 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, this implies that the price of one unit of good j produced by country i and delivered to country n is:

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

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

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

Consumers of 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 are able to 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:

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

where

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

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 consumer price index of country n resulting from the CES aggregator and the prices $p_n(j)$ is:

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

where

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

with Γ denoting Euler's gamma function and where we need to assume $\sigma < \theta + 1$.

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

$$c_i = w_i^\beta p_i^{1-\beta}, \quad (8)$$

where w_i is the nominal wage in country i and p_i is defined by equation (7).⁴ The second hypothesis, added to enhance the realism of the model, 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*. Following EK, in the rest of this paper and, especially, in the estimates of the TFP and in our case studies, we identify tradeables with manufacturing goods.

With these further assumptions, EK are finally able 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 sector; in the

⁴Equation (8) implies that labor is the sole "non-produced" production factor, while physical capital is comprised into intermediate goods. It is worth noticing that the result that the quantity of physical capital is not necessary to estimate TFP levels is by no means dependent on this formulation of costs. In fact, labor appears as a distinct production factor but its quantity is not necessary as well, and only wages are.

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 .⁵ Because of non-linearities, there is no closed-form solution. Nonetheless, it is possible to rearrange the main equations in order to obtain some testable implications, as illustrated in Section 3. In the following, we keep on working with the theoretical model and show how we can use it in order to derive a theoretical expression for the TFP.⁶

2.2 States of technology and TFP

Reconsidering the assumptions about technology specified by equations (1) and (2), it should be clear that the mean of Z_i is linked, but not identical, to the TFP of the manufacturing sector of country i . In fact, the former is referred to the theoretical distribution of the productivity of *all manufacturing goods*, while the latter is the average productivity only of those goods that are *actually made* by country i . In other words, the mean of Z_i reflects the productivity of all potential producers, i.e. the average productivity under autarky. In an open economy, instead, manufacturing TFP includes only the average productivity 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 goods, because these goods are produced

⁵The system is made up by equations (5) and (7) (with equation (6) plugged into both of them), which specify, respectively, market shares and prices. If labor is mobile, then the system is completed by equations:

$$w_i L_i = \sum_{n=1}^N \frac{X_{ni}}{X_n} [(1 - \beta) w_n L_n + \alpha \beta Y_n] ,$$

with Y_n being the exogenous aggregate final expenditure and L_n the endogenous amount of labor in the tradeable sector; in this case, w_n is exogenous, as it is given by productivity in the non-tradeable sector. In the alternative case with immobile labor, the system is completed by equations:

$$w_i L_i = \sum_{n=1}^N \frac{X_{ni}}{X_n} [(1 - \beta + \alpha \beta) w_n L_n + \alpha \beta Y_n^0] ,$$

with Y_n^0 being the exogenous income from the non-tradeable sector; in this case, it is L_n that is exogenous, while w_n is endogenous.

⁶Alvarez and Lucas (2007) generalize the model by considering distinct final and intermediate goods, and distinguishing between tariffs and transport costs. For this more general model, they provide sufficient conditions for existence and uniqueness of the equilibrium. By the same token, they extend estimates and calibrations to encompass also non-manufacturing tradeable goods and tradeable services.

more efficiently in some other country.

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

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

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 some formal proof. First, if j is such that $p_{ii}(j) \leq p_{ik}(j)$, 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.⁷ Second, country i does not produce any other good; in other words, 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 but not at home. This is an immediate 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 (equation (2)) and markets for tradeable goods are perfectly competitive, so that prices are equal to marginal costs (equation (3)), then:*

$$\text{TFP}_i \sim \text{Fréchet}(\Lambda_i, \theta) ,$$

where

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

Proof. See Appendix A.1 ■

Thus, also TFP_i has a Fréchet distribution.⁸ Our empirical measure of the TFP will be based on the mean of this random variable:

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

⁷Given 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.

⁸Proposition 1 is an implicit consequence of a useful property of Fréchet distributions; namely, if $X \sim \text{Fréchet}(x, \theta)$, $Y \sim \text{Fréchet}(y, \theta)$, and $X \perp Y$, then: $\max(X, Y) \sim X \mid X \geq Y \sim \text{Fréchet}(x + y, \theta)$.

which is a monotone function in Λ_i .⁹ Equation (P1) shows that Λ_i depends not only on T_i , but also on the technologies, costs, and trade barriers of all the other countries. This result can be readily explained. Suppose that T_k increases for some $k \neq i$. Country k , then, will produce more goods than before (equation (5)), partly displacing the production of country i . The goods whose production remains in country i , however, will have on average a higher productivity, which is reflected in the increase in Λ_i . The effect of c_i is analogous: larger costs in country i crowd out its production in favor of other countries, but its average productivity increases;¹⁰ as well as that of d_{ik} : higher trade barriers between i and other countries diminish the range of goods exported by country i , letting survive only the firms with an higher 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 .

Despite its simplicity, equation (P1) provides many conceptual contributions. The first is that it may be important to distinguish between technology and TFP. In the Eaton-Kortum model, technology is a general concept that reflects the whole *potential productivity* of the country; TFP is the actual productivity resulting from international competition. The main reason to distinguish between technology and TFP is that, as just discussed, TFP in country i may improve without a "genuine" technological progress in this country. In an open economy, its improvement may simply reflect external developments, such as technological progress in other countries with no impact on the domestic technology, changing costs at home or abroad, or loosening trade barriers.¹¹

⁹ Clearly, the constant term $\Gamma[(\theta - 1)/\theta]$ will cancel out when we compute relative TFPs.

¹⁰ The positive relationship between aggregate productivity and domestic costs in equation (P1) contrasts with the results of Lagos (2007) and Conway and Nicoletti (2006). In the Eaton-Kortum model, if a country pays higher wages or incurs larger costs because of distorted labor or non-manufacturing product markets, then the selection effect operated by 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 (2007) and Conway and Nicoletti (2006) distorted markets operate an adverse selection of productive units, hampering their allocation in the economy and, in turn, reducing aggregate productivity. Assessing the net effect of distortions on TFP, then, remains essentially an empirical question.

¹¹ In its simple 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. However, the model could be extended to embed correlated Z_i 's (see Eaton and Kortum, 2002, footnote 14).

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 .

These effects of international competition on TFP emerge without the need of introducing market power (see, on the contrary, Melitz, 2003, and Del Gatto, Ottaviano, and Pagnini, 2007). The model preserves perfect competition — a feature that allows to derive a "pure" measure of TFP, not affected by fixed costs and monopolistic rents — embedding in the Ricardian model only firm heterogeneity.

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 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 to international trade.

Equation (P1) is theoretically appealing but also rather difficult to apply for empirical purposes, since it requires data on technologies, costs, and trade barriers for all countries. Interestingly, however, we can derive a nice alternative expression for Λ_i , by considering the fact that countries' technologies, costs, and trade barriers are partly gathered into their trade data; namely, we can prove that:

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

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

Proof. See Appendix A.2 ■

Equation (P2) shows that Λ_i is equal to T_i augmented by a "correction 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). Note, in particular, that the correction factor is a fraction, whose numerator is the total absorption (or total domestic demand) of country i and the denominator is the production sold domestically. This factor is a measure of *trade openness* for country i . Note that, consistently with equation (P1), as imports go to zero, then Λ_i tends to T_i .

Proposition 2 provides an interesting contribution to the literature concerning the measure for trade openness. Papers exploring the relationship between trade and productivity typically measure trade openness with nominal imports plus exports relative to nominal GDP (*nominal openness*). A recent exception is Alcalá and Ciccone (2004) who use imports plus exports in US dollars relative to GDP in PPP US dollars (*real openness*), arguing that, on theoretical grounds, this measure is preferable to the nominal one. Our analysis finds that the Ricardian trade theory (in its modern version represented by the Eaton-Kortum model) would suggest to measure trade openness with the ratio between the value of total absorption and the value of the domestic production sold domestically. Equation (P2) shows that this 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 this measure of trade openness takes into account the factors related to domestic and foreign costs (such as changes in productivity in the non-tradeable sector) and trade barriers, that are precisely those considered by Alcalá and Ciccone.

By substituting equation (P2) into equation (10), we can derive an expression for the manufacturing TFP which is rather easy to estimate — a task that we accomplish in the next sections. Before proceeding with the empirical analysis, however, we underscore one feature of the model that has a very important implication. Equations (5) and (7) show that market shares and relative prices are invariant with respect to linear transformations 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 *relative TFP levels*. For this reason, we will present results for T_i and $E(\text{TFP}_i)$ relative to a benchmark country, which is chosen to be the United States.

3 Empirical analysis

In order to measure manufacturing TFP, we proceed in three steps. 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 step 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 our results is then analyzed in Appendix A.3.

3.1 Competitiveness and trade barriers

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

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

where:

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

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, θ can be calibrated as explained in the next section; alternatively, it could be estimated on the basis of other testable implications of the model. Once that θ is obtained in either way, one can estimate the S_i 's 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 trade and production data.¹² For what concerns β , EK calibrate it as the cross-country average of labor share in gross manufacturing production. For the period 1985-2002, such calibration would provide 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 estimate, we adopt the latter type of calibration that, in the sample period, provides somewhat larger values of β (between 0.31 and 0.34). In Appendix A.3, however, we present also estimates obtained with the calibration of EK — together with other robustness tests — and show that they yield essentially the same results.

Turning to the right-hand side (RHS) of equation (11), trade barriers are modeled using the proxies suggested by the gravity literature. We select geographic distance, borders, language, trade agreements, and a destination effect; hence, we put:

$$\log d_{ni} = d_k + b + l + a + m_n , \quad (13)$$

where we have suppressed the dummy variables associated with each effect for notational simplicity. In equation (13), d_k ($k = 1, \dots, 6$) is the effect of the distance between n and i lying in the k th interval;¹³ b is the effect of n and i sharing a border; l is the effect of n and i sharing the language; a is the effect of n and i both belonging to the European Economic Community (EEC), from 1985 to 1992, and to the European Union (EU), from 1993 onwards;¹⁴ m_n ($n = 1, \dots, 19$) is an overall destination effect.

By imposing the specification (13) for trade barriers, equation (11) becomes:

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

¹²For a detailed description of the data used in this paper, see Appendix A.4.

¹³The intervals considered are specified in Table 1, with distance calculated in miles.

¹⁴Unlike Eaton and Kortum (2002), we have neglected the European Free Trade Agreement. The reason is that, at the beginning of the 1970s, after Denmark and the United Kingdom left it, all the remaining countries of this area started bilateral trade agreements with the EEC/EU. In general, we have decided to neglect bilateral agreements due to the difficulties in detecting them and tracking down their evolution.

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 θm_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 have to impose a restriction on the sets of dummy variables. To simplify the presentation of the results, we require that $\sum_n S_n = \sum_n S'_n = 0$. Therefore, the coefficients of these dummy variables measure the difference with respect to the average (equally-weighted) country.

We estimate equation (14) by OLS for each year of the period 1985-2002. Table 1 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.

Estimates of the source dummies S_i indicate that at the beginning of the sample period Japan was the most competitive country followed by the United States, while towards the end of the 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 since then, achieved a minimum in the year 2000, and showed 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 at home, 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.¹⁵

¹⁵Eaton and Kortum (2002) estimate equation (14) by GLS, using only 1990 data, obtaining similar results in terms of sign and significance of the coefficients and ranking of the countries. (See, in particular,

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

Variable	Coefficient	Year: 1985		Year: 1990		Year: 2002	
		Estimate	s.e.	Estimate	s.e.	Estimate	s.e.
Distance [0,375)	- θ d1	-3.33	(0.16)	-3.34	(0.16)	-2.98	(0.18)
Distance [375,750)	- θ d2	-3.85	(0.11)	-3.80	(0.11)	-3.44	(0.15)
Distance [750,1500)	- θ d3	-4.19	(0.08)	-4.04	(0.09)	-3.64	(0.14)
Distance [1500,3000)	- θ d4	-4.61	(0.16)	-4.24	(0.15)	-3.96	(0.19)
Distance [3000,6000)	- θ d5	-6.22	(0.09)	-6.10	(0.08)	-5.67	(0.08)
Distance [6000,maximum)	- θ d6	-6.72	(0.10)	-6.60	(0.10)	-6.12	(0.09)
Border	- θ b	0.62	(0.14)	0.61	(0.13)	0.67	(0.12)
Language	- θ l	0.49	(0.14)	0.57	(0.13)	0.46	(0.12)
EEC/European Union	- θ a	-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	- θ m1	-1.02	(0.15)	-0.86	(0.15)	-0.30	(0.14)
Austria	- θ m2	-1.11	(0.12)	-1.34	(0.12)	-2.24	(0.11)
Belgium	- θ m3	-4.88	(0.12)	-4.04	(0.12)	-7.24	(0.11)
Canada	- θ m4	-0.17	(0.15)	0.05	(0.14)	-0.33	(0.14)
Denmark	- θ m5	-2.28	(0.12)	-2.24	(0.12)	-3.36	(0.11)
Finland	- θ m6	-0.21	(0.13)	0.04	(0.13)	0.76	(0.11)
France	- θ m7	2.14	(0.12)	2.00	(0.12)	2.55	(0.11)
Germany	- θ m8	2.53	(0.12)	2.65	(0.12)	3.00	(0.11)
Greece	- θ m9	-2.11	(0.13)	-2.39	(0.12)	-1.75	(0.11)
Italy	- θ m10	2.38	(0.13)	2.65	(0.12)	3.01	(0.11)
Japan	- θ m11	5.18	(0.14)	5.11	(0.13)	5.55	(0.13)
Netherlands	- θ m12	-2.41	(0.12)	-2.81	(0.12)	-3.61	(0.11)
New Zealand	- θ m13	-2.51	(0.15)	-2.71	(0.15)	-2.00	(0.14)
Norway	- θ m14	-2.32	(0.13)	-1.93	(0.12)	-1.37	(0.15)
Portugal	- θ m15	-0.09	(0.13)	-1.05	(0.13)	-1.14	(0.12)
Spain	- θ m16	1.48	(0.13)	1.05	(0.12)	1.60	(0.11)
Sweden	- θ m17	0.05	(0.13)	0.22	(0.13)	0.54	(0.11)
United Kingdom	- θ m18	1.07	(0.13)	1.31	(0.12)	1.48	(0.12)
United States	- θ m19	4.30	(0.14)	4.31	(0.14)	4.86	(0.13)

(1) Estimates of equation (14) using OLS; standard errors in brackets.

3.2 States of technology

From the estimates of S_i derived above, we can extract the states of technology T_i by inverting equation (12); namely:

$$T_i = \left[\exp(S_i) \cdot w_i^\theta \right]^\beta . \quad (15)$$

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

For what concerns θ , Alvarez and Lucas (2007) calibrate it by exploiting a property of the theoretical model. EK show that the prediction about market shares expressed by equation (5) would also emerge 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 Armington and Eaton-Kortum models is: $\theta = \sigma_a - 1$, where σ_a is the Armington elasticity. Based on the empirical literature on import elasticities (see Broda and Weinstein, 2006, for recent estimates), Alvarez and Lucas (2007) consider a range of values of θ between 4 and 10, with 6.67 being their preferred estimate. EK, instead, estimate θ using other testable implications of the model and find values of θ between 3.6 and 12.9, with 8.28 being their preferred estimate. In line with our choice on β , we set $\theta = 6.67$ in our benchmark estimate and defer to the Appendix A.3 the proof that results are robust to this choice.

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:

$$w_i = comp_i \cdot \exp(-gh_i) , \quad (16)$$

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.¹⁶ Data on schooling come from the recent paper by de la Fuente and Doménech (2006), who

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 diverse values of β chosen and to the older update of the OECD data used in their paper, and not to the different estimation method.

¹⁶Setting $g = 0.06$ is a conservative calibration according to Bils and Klenow (2000). Therefore, in Appendix A.3 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).

have estimated 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 2 shows the states of technology, in selected years, derived from the methodology of EK, using wages converted in US dollars with market exchange rates. 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 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 meaning that a depreciation is associated with a decrease in the state of technology). These results remain the same with all the reasonable calibrations of β , θ , and g .¹⁷ For most countries, these correlations would not be significantly different from 1.

How can we explain the odd results obtained with the methodology of EK? 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 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 (i.e. in its productivity) in order to maintain its export shares almost unchanged.

¹⁷In a companion paper, Finicelli, Pagano, and Sbracia (2007) offer a detailed analysis of this question together with other issues concerning the empirical estimates of the Eaton-Kortum model.

Table 2: 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 (15).

These considerations raise two issues. First, the Eaton-Kortum 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,¹⁸ we address the former issue by converting input costs into a common currency using PPP exchange rates (calculated by the OECD), as a measure of equilibrium exchange rates. This is also consistent with the standard practice in development-accounting, which will be the yardstick for our trade-revealed TFPs.

¹⁸Important steps along this direction have been taken by Bernand, Eaton, Jensen, and Kortum (2003) and Eaton and Kortum (2007). 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 contribution provides an extension, still partly in progress, to market structures characterized by Cournot and monopolistic competition.

The right side of Table 2 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. Interestingly, we find that levels and first log-differences correlations of the new states of technology with PPP exchange rates are also very low (equal to -0.03 . and to -0.22 , respectively). These results suggest that market exchange rates dominate the estimates of the states of technology because of their very large volatility — a volatility that, however, does not have an empirical counterpart in production, price, and trade data (see, e.g., Tenreyro, 2007). Another important observation is 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, note that 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 this calculation is performed, we will see that low T_i 's are perfectly consistent with reasonable values of the TFPs.

3.3 Trade-revealed TFPs

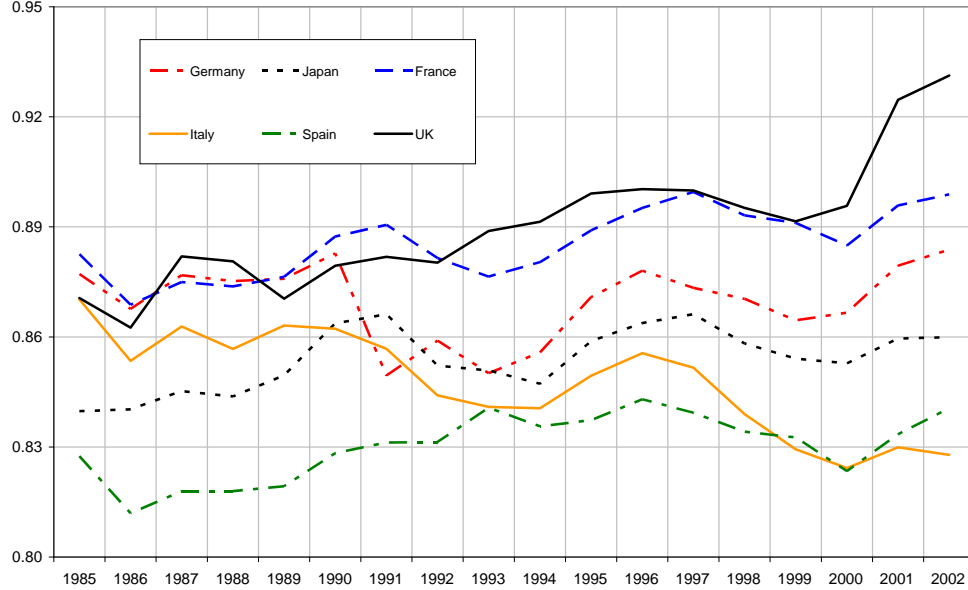
With the estimates of the states of technology derived above, we are now equipped to calculate TFP levels relative to a benchmark country. Recalling the meaning of the X_{ik} and using equations (10) and (P2), the relative TFP of country i with respect to the United States, denoted with λ_i , can be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

$$\lambda_i = \left(\frac{T_i}{T_{us}} \right)^{1/\theta} \cdot \left(1 + \frac{IMP_i}{PRO_i - EXP_i} \right)^{1/\theta} \cdot \left(1 + \frac{IMP_{us}}{PRO_{us} - EXP_{us}} \right)^{-1/\theta}, \quad (17)$$

where the subscript us stands for the United States.

Figure 1 presents our estimates of λ_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. The picture shows that up to the early 1990s, trade-revealed manufacturing TFPs are very 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 per cent of the level of the United States. The countries with the largest average TFP in

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



(1) Values of λ_i obtained from equation (17)

the sample period are Belgium, the United Kingdom and France; those with the lowest average TFP are Portugal, New Zealand, and Australia (results for all countries and years are in Appendix A.3).

The correction factor in equation (P2) (raised to the $1/\theta$ power) provides a synthetic measure of the "contribution" of international competition to the TFP. Table 3 shows that, on average across years and countries, international competition raises manufacturing TFP to 7.4 per cent above its autarky level. Over time, the average contribution of international competition exhibits a neat positive trend (from 5.8 per cent in 1985 to 9.4 per cent in 2002). The gain from international competition ranges from 0.6 per cent for Japan to 23 per cent for Belgium. Results for Belgium and the Netherlands (17 per cent), however, are likely to be overestimated, an artifact of their role as entrepôt countries.

With this further piece of information, let us return to Figure 1. The manufacturing TFP of Italy and, for opposite reasons, that of the United Kingdom display a very interesting behavior. Manufacturing TFP in these two countries is essentially identical in 1985 and, then, diverges. During the whole sample period, Italy loses ground with

Table 3: 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 $[IMP_i / (PRO_i - EXP_i)]^{1/\theta}$ (in percentage) for each country i .

respect to all the main industrial countries. In 2001-2002, its manufacturing-TFP level is the lowest, 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 that is consistent with the results of Propositions 1 and 2. Specifically, increasing international competition may have forced less efficient UK firms to exit the market, raising its average TFP. Indeed, during the sample period the manufacturing TFP of the United Kingdom is also the one that benefited, among the group of countries in Figure 1, of the largest increase in the contribution of international competition to productivity (from 4.9 in 1985 to 7.3 per cent in 2002; Table 3).

4 A case study: Italy relative to the US

In the development-accounting approach, TFP levels are backworked starting from the production function and measures of output and inputs. The measurement of physical

capital is the part of the job in which data limitations are binding. From the OECD STAN database, the most important source of cross-country data on production at the sectoral level, the *volume of net capital stock* — the most common proxy for capital as a provider of services in the production function — 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 "lower-quality" measure that neglects capital depreciation and does not make any attempt to use suitable weights to aggregate different capital assets — is available only for six additional countries (which do not include major countries such as the United States and Japan).¹⁹ Similar problems arise if one tries to calculate the stock of capital starting from data on 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 central issue of finding an appropriate price deflator.

Due to these difficulties in obtaining development-accounting measures of TFP levels for a sufficiently large set 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 and 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, sufficient data are available to allow us an extended analysis. We consider variants of the original empirical methodology to account for working hours (another time series that is rarely available at a sectoral level) and we compare our trade-revealed TFP growth rates with those provided by national sources.

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

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

where A_i is the TFP, K_i is the stock of physical capital, and H_i is the stock of human

¹⁹Very 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.

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:

$$H_i = L_i \cdot \exp(-gh_i), \quad (18)$$

where L_i is the total number of workers and $g = 0.06$ as in the previous section.

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

$$A_i = \left(\frac{Y_i}{L_i}\right)^{1-a} \left(\frac{K_i}{Y_i}\right)^{-a} \left(\frac{H_i}{L_i}\right)^{-(1-a)}. \quad (19)$$

Except for the years of schooling, which refer to the whole economy, all other data are referred to the manufacturing sector. In particular, we measure the capital stock with the perpetual inventory method as in Caselli (2005).²⁰ We calculate TFP levels for Italy and the United States separately and, then, we take the ratio.

Figure 2 shows the manufacturing TFP of Italy relative to that of the United States calculated with this methodology (which is 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. 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 0.96, meaning that manufacturing-sector productivity of Italy was 4 percentage points lower than that of the United States. Afterwards, the relative productivity of Italy records a gradual and steep decline and, in 2002, it is 20 percentage points lower than that of the United States. The trade-revealed relative TFP of Italy, instead, goes from 87 percent in 1985 to a level slightly below 83 percent in 2002. That is, given roughly similar initial levels, according to the development-accounting approach the manufacturing TFP of Italy relative to that of the United States shows a cumulative decline of 16 percentage points during the sample period, while the trade-revealed one falls by "just" 4.2 points.

²⁰ Appendix A.4 provides details on data sources and methodology of calculation.

Figure 2: Manufacturing TFP of Italy relative to the US

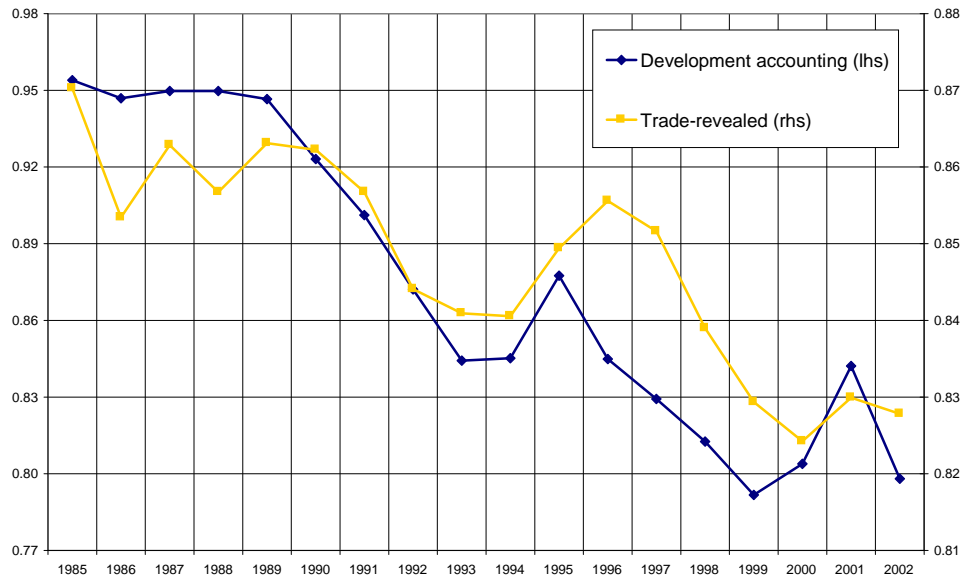
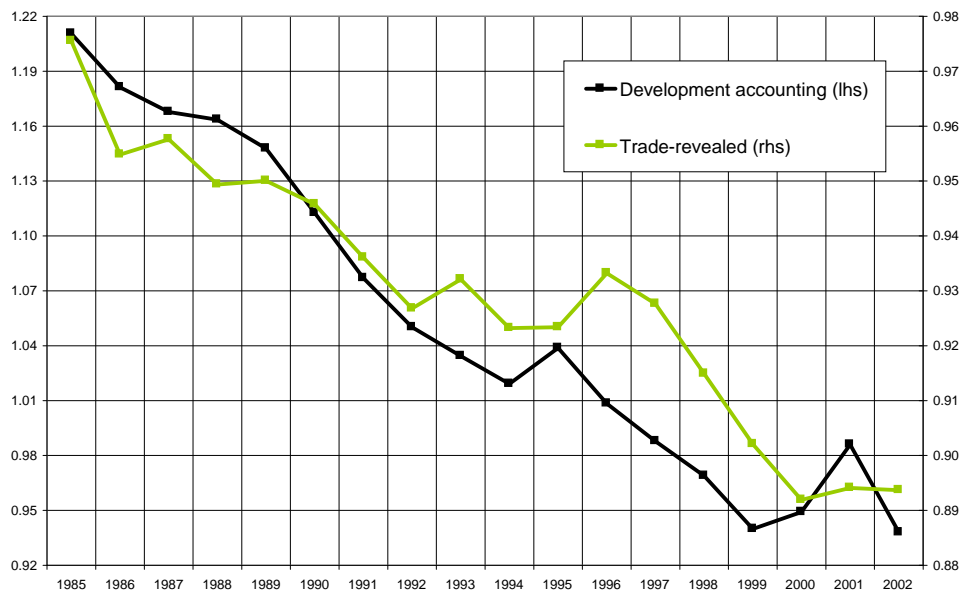


Figure 3: Manufacturing TFP of Italy relative to the US (including worked hours)



These measures of TFP use the number of workers as the labor input, neglecting the amount of worked hours, which is typically lower in Italy and has a cyclical component that might affect the dynamics shown in Figure 2. Therefore, in Figure 3 we present measures adjusted to take into account the number of worked hours, for both development-accounting and trade-revealed TFPs. The total amount of working hours per worker in the manufacturing sector can be obtained from the Bank of Italy for Italy and the US Bureau of Labor Statistics (BLS) for the United States. As expected, this modification raises the productivity of Italy for both methods. According to the development-accounting approach, however, in 1985 Italy is far more productive than the United States (by 21 percent); its manufacturing TFP declines sharply to 94 percent of the US level in 2002, with a cumulative loss of 27 percentage points. Trade-revealed TFP, instead, is lower than 100 per cent even in 1985 and records a much smaller decrease in the sample period (9 percentage points, to 89 percent in 2002). Hence, bringing into the picture the amount of working hours does not change the result that trade-revealed TFP exhibits less sharp movements than its development-accounting counterpart.

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 sources (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 and cumulating annual changes it turns out that in 2002 the Italian TFP was 11 percentage points lower than the US TFP, a number not far from the one we have obtained with our trade-revealed TFP which included working hours and significantly lower than the one arising 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 relatively small. The latter result is interesting if compared with what would emerge from the development-accounting and the growth-accounting methodologies. Recall that results from these standard methodologies are mere residuals and, then, can be regarded as "measures of our ignorance". Hence, the overwhelmingly large differences in cross-country TFP levels and growth rates coming from these methodologies may be just the outcome of excessively large errors in the measurement of production factors.

5 Conclusion

Measuring productivity is a crucial issue in the analysis of economic performances. In this paper, this task is accomplished using a novel methodology grounded on the Ricardian model of international trade, as formulated by Eaton and Kortum (2002). We show that manufacturing TFP is a function of the Ricardian absolute and comparative advantages, augmented by a measure of trade openness. A decomposition of this expression sheds lights on the role of international competition in selecting firms with higher efficiencies as well as on the relationship between trade and productivity. When we turn to the estimates, we show that the main advantage of our empirical methodology is that TFP levels can be retrieved using data on bilateral trade flows and input costs. Therefore, we overcome the data limitations, due to the difficulties in measuring the stock of physical capital, that hamper standard development-accounting exercises. In addition, TFP levels are no longer obtained as a residual, but come from a combination of estimation and calibration.

The analysis presented in this paper can be extended along several dimensions. First of all, the wide availability of data on bilateral trade flows allows to enlarge the sample of countries, encompassing many developing economies. For instance, Alvarez and Lucas (2007) calibrate a version of the Eaton-Kortum model that includes 60 countries, albeit they do not compute TFP levels. Such an extension would make it possible to study the evolution of TFP levels and income per capita, with special reference to dynamic emerging economies such as China and India. In this way, it could provide another perspective on the results of the development-accounting literature.

A related question concerns the conjecture that the large differences in aggregate TFP levels across advanced and developing countries are due to a combination of heterogeneities in the sectoral composition of production and different TFP levels across sectors, with possibly identical sectoral productivities across countries. If this conjecture were true, it would yield very important consequences about the best policies to raise TFP and, ultimately, output per worker in developing economies. For instance, it would suggest that authorities in those countries should focus on removing domestic barriers to the mobility of factors across sectors, while barriers to the mobility of technology across countries would be less influent. As shown by Shikher (2004), the Eaton-Kortum model can be generalized to incorporate a finer classification of industries. Therefore, it can potentially be used to provide some evidence about this conjecture.

Finally, the potential reversal of the globalization process brought about by a resurgence of protectionism in the face of widening global imbalances makes it interesting to perform, in a larger cross-section of countries, several counterfactual experiments. Starting from our finding that international competition raises TFP above its autarky level, these experiments would allow to quantify the effects of, say, rising tariffs on productivity.

A Appendix

A.1 Proof of Proposition 1

Before computing $G_i(z)$ from equation (9), we show 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 , as assumed by that equation. Of course, if $p_{ii}(j) \leq p_{ik}(j)$ for any k , then good j is produced by country i . 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 probability density function (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:

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

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

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

The numerator is:

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

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, $\text{TFP}_i \sim \text{Fréchet}(\Lambda_i, \theta)$.

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 Λ_i we find:

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

A.3 Results and sensitivity analysis

The empirical analysis in Section 3 has lead to a measure of relative TFP levels for the manufacturing sector of the main industrial countries, which are shown in Table 4. It is worth recalling that these results have been obtained following three main steps: from "normalized" bilateral trade shares and gravity data we estimated the competitiveness indicators S_i ; from S_i and data on wages we extracted the states of technology T_i ; the T_i are then augmented to obtain the Λ_i necessary to complete our knowledge of the distribution of TFP_i and finally calculate TFPs (as mean of the random variables TFP_i).

We now turn to examine the sensitivity of our main *intermediate result*, the states of technology, to alternative values of the parameters θ , β , and g — i.e. the 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 3.2 for a brief discussion). β , measured by 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

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	67.9	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	theta=4	0.95
		theta=6.67	0.93	theta=6.67	1.00
		theta=8.3	0.95	theta=8.3	0.99
		theta=10	0.96	theta=10	0.98
	non-linear g	theta=4	0.72	theta=4	0.85
		theta=6.67	0.83	theta=6.67	0.90
		theta=8.3	0.85	theta=8.3	0.89
		theta=10	0.86	theta=10	0.88

(1) Values obtained by computing, for each country, the time-series correlation between the T_i 's resulting from an alternative calibration and the corresponding benchmark estimates and, then averaging across countries.

estimates, we consider also the non-linear calibration used by Hall and Jones (1999) and Caselli (2005) and 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 the sensitivity of the results by computing, for each country, the time-series correlation between the T_i 's obtained with an alternative calibration and the corresponding benchmark estimates.²¹ Table 5 summarizes the results of this analysis by presenting the cross-country average correlation.

The north-east panel of Table 5 shows that changing θ 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 correlation remains as high as 0.95. Measuring β with the ratio between labor compensation and production has a somewhat larger impact, even though

²¹By the relationship between T_i 's and TFPs, the correlation analysis on the TFPs would give similar results.

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 θ and β) rises to 0.99 (instead of 0.90) and when we change also θ correlation rises to around 0.93 (instead of being lower than 0.90). Similarly, when we change both g and β (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 θ . 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 θ . Overall, the results of this analysis confirm that our estimates of the are broadly robust to the calibration adopted in the benchmark estimates.

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 2.

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, described by Borde (2004). The reconciliation between ISIC and SITC codes is done according to Eurostat-RAMON (see <http://europa.eu.int/comm/eurostat/ramon/index.cfm>) and Maskus (1991).

Gravity data: Geographic distances and the border dummy are taken from Jon Havenman'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 (16) 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 δ 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 $\text{RGDPL} \cdot \text{POP} \cdot \text{KI} \cdot \text{IM}$, 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 standard practice, initial capital stock is computed as $K_0 = I_0 / (g + \delta)$, where I_0 is the first available value in the investment series (1970) and g is the geometric growth rate of investment over the first decade.

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

The number of employees in manufacturing (L_t), which we used to compute series shown in Figure 2, is from OECD STAN. The total amount of working hours per worker in the manufacturing sector, used to compute series reported in Figure 3, are from the Bank of Italy for Italy and the Bureau of Labor Statistics (BLS) for the United States.

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