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Abstract

We introduce a novel methodology to measure the relative TFP of the tradeable sector across countries, based on the relationship between trade and TFP in the model of Eaton and Kortum (2002). The logic of our approach is to measure TFP not from its "primitive" (the production function) but from its observed implications. In particular, we estimate TFPs as the productivities that best fit data on trade, production, and wages. Applying this methodology to a sample of 19 OECD countries, we estimate the TFP of each country's manufacturing sector from 1985 to 2002. Our measures are easy to compute and, with respect to the standard development-accounting approach, are no longer mere residuals. Moreover, they do not yield common "anomalies", such as the higher TFP of Italy relative to the US.

JEL classification: F10, D24, O40

Keywords: Multi-factor productivity, TFP measurement, Eaton-Kortum model

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1 Introduction

Estimating the level of a country's Total Factor Productivity (TFP) is a very difficult task. The standard development-accounting (or "level-accounting") methodology consists in choosing a functional form for the aggregate production function, measuring output and inputs, and then obtaining TFP as a residual (see King and Levine, 1994, or Caselli, 2005). One of the hardest and most critical parts of this approach 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, since it requires long time series on fixed investments and price deflators, as well as a guess at the initial level of the capital stock, whose importance is higher the more recent is such initial date. It often entails heroic assumptions about the depreciation rate. It usually mixes up types of capital with very different efficiencies, such as public and private investments. It also ignores key issues regarding the quality of capital (Caselli, 2008).

Difficulties in estimating TFP levels escalate if one needs homogeneous measures across several countries or sectors. In fact, the cross-country heterogeneity in the quality of capital becomes especially large when one considers samples including both industrial and developing countries. Despite the efforts in building an international system of national accounts, some categories of expenditure still undergo diverse classifications in different countries. Similar difficulties arise with respect to the deflators used to obtain quantities from values, given the cross-country differences in the diffusion of hedonic prices and in the methodologies used to estimate them. The lack of sectoral data on fixed investment, which affects also some industrial economies, is also stunning.

The need to refine the existing methodologies and to complement them with new ones is warranted by the importance of TFP for understanding the distribution and growth of wealth across countries. In particular, studies based on development accounting find that cross-country differences in TFP account for a big chunk of differentials in per capita income (e.g. Hall and Jones, 1999). In addition, recent research has conjectured that such results might be due to sectoral differences in TFP levels — an hypothesis that, however, cannot be properly verified due to the lack of data.[1] Factor-augmenting productivity differences across countries have also proven important to narrow the gap between the predictions of the Hecksher-Ohlin-Vaneck theory and the empirical evidence on the factor content of trade and the cross-country variation in factor prices.[2]

In this paper, we pursue a novel approach that essentially maps international trade flows, domestic production, and wages into the TFP of the tradeable sector. We build on the Ricardian trade model developed by Eaton and Kortum (2002) (EK hereafter) and the

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

[2]See Trefler (1993 and 1995) and the references therein.

theoretical results obtained in a companion paper by Finicelli, Pagano, and Sbracia (2009a). In the EK model, industry productivities in the tradeable sector of each country are described by a Fréchet distribution, whose scale parameter represents the country's technological endowment. This parameter can be estimated relative to a benchmark country using nominal data on bilateral trade flows, production, and wages. The tradeable-TFP in the open economy, however, is not equivalent to the average productivity of *all* tradeable goods (which corresponds to the TFP *under autarky*). Rather, it must be computed as the average across *only* the tradeable industries that, having survived international competition, are actually engaged in production. Finicelli, Pagano, and Sbracia (2009a) show that in the EK model the productivities of surviving industries are also distributed as a Fréchet, and that the mean of this distribution — which we dub *trade-revealed* TFP — is equal to the TFP under autarky augmented by an easy-to-quantify measure of trade openness. In this paper, we exploit these results to estimate the relative levels of the tradeable-TFP for 19 OECD countries, with annual data from 1985 to 2002.

With respect to development accounting, our TFP estimates have two main advantages. First, they are no longer mere residuals, but the productivities that best fit data on trade, production, and wages. Therefore, the estimation process that is involved potentially allows to reduce the measurement error implicit in the standard methodology. Second, they are obtained from value data about those variables and do not require hard-to-get quantity data on the stock of physical capital. This feature ensures a wider availability of long time series and a higher degree of homogeneity and comparability of data across several countries, making it possible also to compute sectoral estimates of TFP levels.[3] Physical capital is not necessary because in the model it is the cost of inputs that matters for bilateral trade shares, not their quantities. On the other hand, two limitations of our methodology are that it is restricted to the universe of tradeable industries, rather than embracing the whole economy, and that it provides a measure of *relative* levels of the TFP across countries, instead of their *absolute* values.

The TFP rankings and relative values delivered by our analysis appear more plausible than those delivered by the standard development-accounting approach. One noticeable difference with respect to development-accounting studies, most notably Hall and Jones (1999), is that while in their samples Italy is usually found to have the highest TFP, a surprising result given the relative weakness of institutions and government policies ("social infrastructure") in this country, according to our analysis Italy ranks only 6th or 7th over the whole sample period, and the most productive country is invariably the United States.[4] Interest-

[3]In this paper we only consider the aggregate tradeable-goods sector, which we identify as the manufacturing sector, and do not pursue any finer classification. Shikher (2004), however, extends the EK model to many sectors and estimates sectoral states of technology. From his estimates, then, one could retrieve sectoral TFPs following our methodology.

[4]For a brief discussion of this point, see Hall and Jones (1999) and Lagos (2006).

ingly, in our sample of countries the correlation between TFP and Hall and Jones' social infrastructure index is higher if TFP is measured using our methodology than with their TFP data.

We then provide a zoom shot of the manufacturing TFP of Italy relative to the United States, comparing the dynamics of our measure with one obtained from development accounting. We view this case study as especially intriguing because of the just mentioned anomaly of development-accounting results. The focus on this country pair also allows us to offer a more detailed and data-enhanced analysis. We find that our measure yields a sharp difference in levels with respect to development accounting, while preserving a very similar time pattern.

The focus on input costs (instead of quantities) to measure TFP makes our methodology reminiscent of the dual method for computing TFP growth rates developed by Hsieh (2002). However, we do not obtain our TFP as a residual, and we compute TFP (relative) levels instead of growth rates. Another closely related method for comparing TFP across countries is the "revealed-superiority" approach of Bar-Shira, Finkelshtain, and Simhon (2003), which in turn is inspired by Samuelson's principle of revealed preferences. With this paper, our methodology shares the idea of measuring TFP not from its "primitive" (the production function) but from its observed implications. Our approach distinguishes from Bar-Shira, Finkelshtain, and Simhon's in that they extract information about the TFP for the whole economy from observed aggregate profits, while we focus on the TFP of the tradeable sector and derive it from countries' shares in international trade. In addition, we quantify relative TFPs, while their methodology only delivers a ranking.

Traces of the idea of exploiting the effects of TFP on trade flows to retrieve a measure of the TFP itself appear, in different forms, also in other papers. Trefler (1995) obtains Hicks-neutral factor-augmenting productivities for several countries (relative to the US) as the productivities that minimize the gap between observed trade data and the trade pattern implied by factor intensities according to the Hecksher-Ohlin-Vaneck theory. Waugh (2008) obtains a relationship between model parameters and TFP using a variant of the EK model with traded intermediate goods and a non-traded final good; then, he quantifies the contribution of international trade to the TFP without estimating the latter. Fadinger and Fleiss (2008) develop a model with monopolistic competition and homogeneous firms (whereby we assume perfect competition and heterogeneous industries), but end up with an empirical framework to measure TFP that turns out to be similar to ours, in that it requires only data on trade flows, production and input costs. These authors measure the TFP of several countries and industries in one single year, while we consider a smaller set of developed countries, but provide a time-series dimension that spans 18 years.

Here is a roadmap of the paper. Section 2 briefly summarizes the EK model and the main results that provide the theoretical ground from which the empirical methodology presented in Section 3 takes off. Section 4 computes and describes the trade-revealed TFPs, comparing them with results from a sample of previous studies. Section 5 analyzes more closely the case of Italy versus the United States. Section 6 concludes, with some suggestions for future research.

2 Theoretical background

The EK model considers a framework with many countries and a continuum of tradeable goods produced by industries operating under perfect competition. The production of tradeable goods requires the combination of labour and intermediate goods, with shares β and $1-\beta$, in a constant-returns-to-scale technology. In the production function, the bundle of inputs is scaled by an efficiency parameter which varies across countries and industries. Denoting with $z_i(j)$ the efficiency of industry j in country i, a key hypothesis in EK is that each $z_i(j)$ is described by a country-specific random variable Z_i, with $Z_i \sim \textit{Fréchet}\,(T_i, \theta)$, where $T_i > 0$, $\theta > 1$, and the Z_i are mutually independent across countries.

The two parameters of the distribution are the theoretical counterparts of the Ricardian concepts of absolute and comparative advantage. The former, T_i (the *state of technology*), captures country i's absolute advantage: an increase in T_i, relative to T_n, implies a higher share of goods that country i produces more efficiently than country n. The latter, θ (the *precision of the distribution*), which is assumed identical across countries, is inversely related to the dispersion of Z_i and its connection with the concept of comparative advantage stems from the fact that Ricardian gains from trade depend on cross-country heterogeneities in technologies.[5] In this perspective, EK demonstrate that a decrease in θ (higher heterogeneity) generates larger gains from trade for all countries.

Another relevant assumption concerns trade barriers, which are modeled as 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 $d_{ii} = 1$). Trade barriers lift the price at which countries can sell their products in foreign markets above the one at which they sell the same goods at home.

If representative consumers in all countries have identical CES preferences across tradeable goods, the solution of the model is given by a system of non-linear equations in relative wages, relative prices, and trade flows, where d_{ni}, T_i, θ, and β (the elasticity of labour in the production function) are the main parameters.[6] Although the model does not yield a closed-

[5] Denoting Euler's gamma function by Γ, the moment of order k of Z_i is given by $T_i^{k/\theta} \cdot \Gamma\left[(\theta-k)/\theta\right]$ if $\theta > k$. The connection between θ and the dispersion of Z_i can be appreciated by considering that the standard deviation of $\log Z_i$ is $\pi/(\theta\sqrt{6})$.

[6] There is also a non-tradeable sector in the economy, and a constant fraction $1-\alpha$ of the aggregate final expenditure is spent on non-tradeable goods. For the whole solution of the model see EK, pp. 1756-1758.

form solution, by manipulating the main equations EK obtain the following key relationship:

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

where

$$S_i \equiv \frac{1}{\beta}\log\left(T_i\right) - \theta\log\left(w_i\right) \ , \tag{2}$$

and X_{ni} is the value of imports of country n from country i, X_n the value of the total expenditure (or total absorption) of country n, X_{nn} the value of expenditure on domestically produced goods, w_i the nominal wage in country i. The parameter S_i, given by the state of technology adjusted for labor costs, is a measure of the competitiveness of country i. The left-hand side of equation (1) is a "normalized" share of the imports of country n from country i. This equation shows that the ability of country i to sell its own products in country n is increasing in the relative competitiveness of country i vis-à-vis n and decreasing in the iceberg cost of exporting from i to n.[7]

Equation (1) can be used, as in EK, to obtain estimates of the *relative states of technology* in a cross section of countries (i.e. the ratios T_i/T_n). However, we are interested in estimating TFPs, which are related but far from identical to the states of technology. In fact, while the mean of Z_i is the average productivity in country i across *all* existing tradeable goods, with open markets there exist some industries in country i that cease to produce because they eventually succumb to foreign competition. The latter happens, precisely, to the industries that make their goods less efficiently than their foreign competitors, so that these goods are cheaper to import than to produce at home, despite the advantage provided by trade barriers. Therefore, $E\left(Z_i\right)$ corresponds to the TFP of country i only under autarky, while if markets are open then the TFP must be calculated over the subset of tradeable goods that are *actually made* by country i.

This issue is addressed from a theoretical standpoint in Finicelli, Pagano, and Sbracia (2009a), who derive, within the EK model, the productivity distribution of the industries that survive international competition, also a Frechét. The mean of this distribution calculated for country i, that is the TFP of the tradeable sector of this country, denoted with TFP_i, can be expressed as follows:

$$\text{TFP}_i = E\left(Z_i\right)\cdot\Omega_i^{1/\theta} = T_i^{1/\theta}\cdot\Gamma\left(\frac{\theta-1}{\theta}\right)\cdot\Omega_i^{1/\theta} \ , \tag{3}$$

where

$$\Omega_i \equiv 1 + \frac{IMP_i}{PRO_i - EXP_i} \ . \tag{4}$$

[7] The fact that quantity-data on physical capital are not needed in our methodology is by no means driven by the omission of this factor from the production function. As equations (1) and (2) show, in fact, although labor is included in the production function, its cost, and not its quantity, is relevant for bilateral trade shares.

The factor $\Omega_i^{1/\theta}$ is a measure of trade openness that captures the effect of international competition in selecting industries that have a competitive advantage.[8] Equation (3) forms the basis of our estimates of cross-country relative TFPs: once the relative states of technology are estimated, measuring relative TFPs requires only widely available data on trade and production.

3 Empirical methodology

In this section, we illustrate the methodology to estimate the manufacturing TFPs, and apply it to a sample of 19 OECD countries for each year between 1985 and 2002. The methodology follows three main steps. First, equation (1) is used to estimate the competitiveness indexes S_i. Second, the states of technology T_i are derived from the estimated S_i, using equation (2). In applying these two steps, we provide an extension of the cross-section analysis performed by EK with 1990 data, to a sample period spanning 18 years. In addition, we update the original EK methodology in that we convert nominal wages into US dollars using PPP instead of market exchange rates, as suggested by Finicelli, Pagano, and Sbracia (2009b). Once states of technology are obtained, it is immediate to compute our trade revealed TFPs from equations (3) and (4), a step that we finalize in Section 4.[9]

Let us consider equation (1). The left-hand side can be measured with production and trade data, and a calibration for β. For β, we follow Alvarez and Lucas (2007) who define it as the cross-country average of manufacturing value added over gross manufacturing production. By doing so, they consider labor and capital goods as part of a single production factor, which they label as "equipped labor". Over the period 1985-2002 this calibration delivers annual values of β between 0.31 and 0.34.[10] On the right-hand side, trade barriers can be modeled using the proxies suggested by the gravity literature. Following EK, we proxy

[8] Notice that the selection effect is always positive ($\text{TFP}_i > E(Z_i)$). In other words, industries that survive international competition are *on average* more productive than those that are crowded out, implying that the TFP of the open economy is above the autarky level. Finicelli, Pagano, and Sbracia (2009a) focus on this result and show that it holds under very general assumptions about the distribution of productivities. In particular, it holds irrespectively of the correlation among country technologies, if the assumed joint distribution is multivariate Fréchet, Pareto, normal, and lognormal; with independent technologies the result always holds, irrespectively of their joint distribution.

[9] Appendix A.1 describes our dataset.

[10] EK use an alternative calibration, setting β equal to the cross-country average of the labor share in gross manufacturing production. This calibration implies that labor is the sole production factor and that capital goods are comprised into intermediate goods. Over our sample period this approach returns annual values of β between 0.19 and 0.22. Section 4 provides a battery of robustness tests, in which we analyze the sensitivity of our results to this as well as other calibrations.

trade barriers between i and n with a set of standard dummy variables, namely:

$$\log d_{ni} = d_k + b + l + e + m_n \ , \tag{5}$$

where the dummy variables associated with each effect are suppressed for notational simplicity. In equation (5), d_k is the effect of the distance between i and n lying in the k-th interval ($k = 1, ..., 6$);[11] b is the effect of i and n sharing a border; l is the effect of i and n sharing the language; e is the effect of both i and n 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 a destination effect.

With (5), equation (1) becomes

$$\log \left[\left(\frac{X_{ni}}{X_{nn}} \right) \left(\frac{X_{ii}/X_i}{X_{nn}/X_n} \right)^{\frac{1-\beta}{\beta}} \right] = S_i - S'_n - \theta d_k - \theta b - \theta l - \theta e \ , \tag{6}$$

where $S'_n = S_n + \theta m_n$. The competitiveness of country i is estimated as the source country effect (S_i), while the destination dummies (S'_n) are the sum of country n's competitiveness (S_n) and destination effect (θm_n). To avoid perfect multicollinearity, we impose the same restriction as EK that $\sum_n S_n = \sum_n S'_n = 0$; therefore, the estimated coefficients of these dummy variables measure the differential competitiveness effect with respect to the average (equally-weighted) country.

We estimate equation (6) by ordinary least squares for each year in the period 1985-2002. With 19 countries, we have 342 informative observations for each regression (the equation is vacuous when $n = i$). Table 1 reports the results of the regressions for the first and last year of our sample, and for 1990 (the benchmark year in EK). The coefficients of the distance dummies indicate, as expected, that geographic distance inhibits trade. However, the size of this effect tends to decline over time, perhaps suggesting an increasing degree of integration not captured by other effects. In addition, the decline appears to be sharper for the biggest distances. The dumping effect of distance is mitigated by positive border and language effects. Belonging to the EEC/EU also tends to foster trade, although this effect is not statistically significant, which comes as no surprise given that most countries in the sample are European.

Estimates of the source dummies S_i indicate that in 1985 Japan is the most competitive country, followed by the United States, while the ranking between these two countries inverts towards the end of the sample period. On the other hand, Greece and Belgium stand out as the least competitive countries throughout the whole period. Relative to the United States, competitiveness of most countries in the sample peaks towards the end of the 1980s, then declines until 2000, and recovers somewhat in 2001-02.

[11] Intervals are specified in Table 1, with distance calculated in miles.

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

		Year: 1985		Year: 1990		Year: 2002	
Variable	Coefficient	Estimate	s.e.	Estimate	s.e.	Estimate	s.e.
Distance [0,375)	-θd1	-3.33	(0.16)	-3.34	(0.16)	-2.98	(0.18)
Distance [375,750)	-θd2	-3.85	(0.11)	-3.80	(0.11)	-3.44	(0.15)
Distance [750,1500)	-θd3	-4.19	(0.08)	-4.04	(0.09)	-3.64	(0.14)
Distance [1500,3000)	-θd4	-4.61	(0.16)	-4.24	(0.15)	-3.96	(0.19)
Distance [3000,6000)	-θd5	-6.22	(0.09)	-6.10	(0.08)	-5.67	(0.08)
Distance [6000,maximum)	-θd6	-6.72	(0.10)	-6.60	(0.10)	-6.12	(0.09)
Border	-θb	0.62	(0.14)	0.61	(0.13)	0.67	(0.12)
Language	-θl	0.49	(0.14)	0.57	(0.13)	0.46	(0.12)
EEC/European Union	-θe	-0.22	(0.13)	0.11	(0.12)	0.12	(0.17)
Source country effect (S_i):							
Australia	S1	-0.35	(0.15)	-0.43	(0.15)	0.21	(0.14)
Austria	S2	-1.30	(0.12)	-1.20	(0.12)	-1.58	(0.11)
Belgium	S3	-1.89	(0.12)	-1.61	(0.12)	-2.66	(0.11)
Canada	S4	0.16	(0.15)	0.30	(0.14)	-0.01	(0.14)
Denmark	S5	-1.28	(0.12)	-1.34	(0.12)	-1.72	(0.11)
Finland	S6	-0.76	(0.13)	-0.57	(0.13)	-0.28	(0.11)
France	S7	1.01	(0.12)	0.98	(0.12)	1.22	(0.11)
Germany	S8	1.92	(0.12)	1.91	(0.12)	2.00	(0.11)
Greece	S9	-2.24	(0.13)	-2.49	(0.12)	-2.36	(0.11)
Italy	S10	1.29	(0.13)	1.33	(0.12)	1.52	(0.11)
Japan	S11	3.49	(0.14)	3.51	(0.13)	3.50	(0.13)
Netherlands	S12	-0.61	(0.12)	-0.92	(0.12)	-1.19	(0.11)
New Zealand	S13	-1.08	(0.15)	-1.27	(0.15)	-1.03	(0.14)
Norway	S14	-1.72	(0.13)	-1.45	(0.12)	-1.52	(0.15)
Portugal	S15	-1.11	(0.13)	-1.30	(0.13)	-1.42	(0.12)
Spain	S16	-0.08	(0.13)	-0.13	(0.12)	0.41	(0.11)
Sweden	S17	0.04	(0.13)	0.15	(0.13)	0.10	(0.11)
United Kingdom	S18	1.11	(0.13)	1.10	(0.12)	1.14	(0.12)
United States	S19	3.42	(0.14)	3.43	(0.14)	3.67	(0.13)
Destination country effect ($-\theta m_i$):							
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 (6) using OLS; standard errors in brackets.

Estimates of $-\theta m_n$ provide a measure of how cheap it is to export manufacturing goods to country n, compared to the average. 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. Over the entire sample period, the country ranking of $-\theta m_n$ is similar to that S_n; for instance, Japan is the cheapest destination, while Belgium stands out as the most expensive one.[12]

From S_i, we can now extract the states of technology T_i simply by inverting equation (2), i.e. $T_i = \exp(\beta S_i) \cdot w_i^{\beta\theta}$. This step requires data on nominal wages and a calibration for θ.

Following EK, nominal wages are adjusted for education to account for the different degrees of "worker quality" among the countries in our sample. We set $w_i = comp_i \cdot \exp(-g \cdot h_i)$, where $comp_i$ is the nominal compensation per worker, g the return on education (which we set to 0.06 as in EK), h_i the average years of schooling.[13] Wages are converted into a common currency using PPP exchange rates, as suggested by Finicelli, Pagano, and Sbracia (2009b).[14] This approach is also consistent with the standard practice in development accounting, which is the yardstick for our trade-revealed TFPs.

The parameter θ is set equal to 6.67 as in Alvarez and Lucas (2007), who exploit the fact that the expression for market shares derived in EK is identical to one obtained in a model à la Armington (1969), with θ replacing Armington's $\sigma_a - 1$, where σ_a is the Armington elasticity. Based on Anderson and van Wincoop (2004), Alvarez and Lucas pick their preferred calibration from a range of values between 4 and 10.[15]

Table 2 shows the values of the resulting states of technology, at the $1/\theta$ power, relative

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[12] Eaton and Kortum (2002) estimate equation (6) by generalized least squares, using only 1990 data, obtaining similar results in terms of sign and significance of the coefficients and of country ranking. (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.

[13] Setting $g = 0.06$ is a conservative calibration according to Bils and Klenow (2000). See Section 4 for results with the somewhat larger (and non-linear) values of the return on education used by Hall and Jones (1999) and Caselli (2005).

[14] Finicelli, Pagano, and Sbracia (2009b) document that, by converting wages into a common currency using market exchange rates, as originally suggested by EK, the resulting estimates of relative technologies show implausible swings for several countries. In addition, the time-series of these estimates exhibit a correlation with nominal exchange rates vis-à-vis the US dollar that, for most countries, is not significantly different from -1 (a negative correlation means that a depreciation of a country's currency vis-à-vis the US dollar is associated with a decrease in its relative state of technology).

[15] Following a different approach, EK estimate θ using other testable implications of the model and find values between 3 and 13 (their benchmark is 8.28). Notice that both Alvarez and Lucas (2007) and EK consider cross-sectional data. In our empirical analysis spanning 18 years, we take θ time-invariant. Finicelli, Pagano, and Sbracia (2009b) provide some evidence supporting this assumption.

Table 2: States of technology in selected years (1)

	1985	1990	1995	2002
Australia	0.698	0.668	0.698	0.698
Austria	0.721	0.730	0.731	0.713
Belgium	0.770	0.796	0.787	0.761
Canada	0.804	0.796	0.789	0.777
Denmark	0.678	0.678	0.686	0.695
Finland	0.716	0.736	0.748	0.761
France	0.865	0.863	0.864	0.868
Germany	0.855	0.860	0.852	0.854
Greece	0.716	0.736	0.748	0.761
Italy	0.860	0.852	0.836	0.812
Japan	0.847	0.872	0.869	0.872
Netherlands	0.760	0.746	0.751	0.730
New Zealand	0.708	0.654	0.653	0.649
Norway	0.664	0.693	0.691	0.722
Portugal	0.632	0.628	0.622	0.646
Spain	0.821	0.813	0.818	0.814
Sweden	0.781	0.784	0.770	0.803
United Kingdom	0.841	0.849	0.863	0.887
United States	1.000	1.000	1.000	1.000

(1) Values of $(T_i/T_{us})^{1/6.67}$.

to those of the United States in selected years. We report the values of $(T_i/T_{us})^{1/\theta}$, where the subscript us stands for the United States, because this ratio is equal to $E(Z_i)/E(Z_{us})$ (see footnote 4 for the mean of the Fréchet), that is, as discussed in Section 2, the TFP of the manufacturing sector of country i, relative to the United States, under an autarky regime.

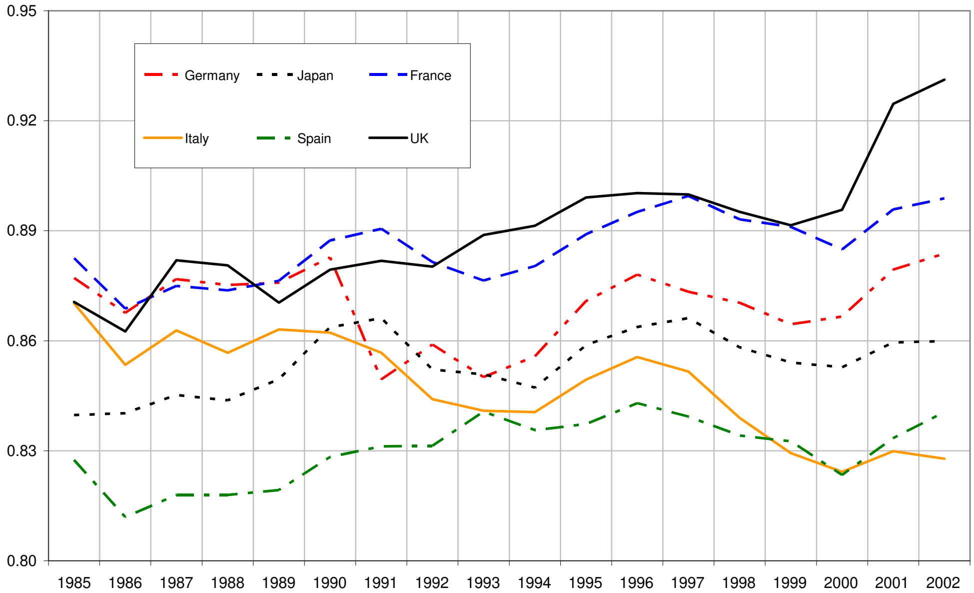
Over the whole sample period, the United States stands out as the country with the highest state of technology, followed by the other major industrial countries (the second place is taken by France, Japan, or the United Kingdom, depending on the sample year). On average, the state of technology of the United States is about 15% above that of the rest of the sample. Portugal occupies invariably the bottom place of our sample, with a state of technology that is 35% lower than that of the United States. In the next section, we transform these estimates into reasonable values of relative TFPs.

4 Trade-revealed TFPs

We are now equipped to calculate TFP levels relative to a benchmark country. Denoting with λ_i the TFP of country i relative to the United States, from equations (3) and (4) one obtains

$$\lambda_i = \left(\frac{T_i}{T_{us}} \frac{\Omega_i}{\Omega_{us}} \right)^{1/\theta} . \quad (7)$$

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



(1) Values of λ_i obtained from equation (7)

By construction, then, the TFP in the United States is normalized to 1 in every year.

Table 3 shows that, over the whole sample period, the manufacturing TFP of the United States is the highest among the 19 OECD countries considered, followed by Belgium, the United Kingdom and France. Portugal, New Zealand, and Australia have the lowest average TFPs. Over time, the average relative TFP across all countries (excluding the United States) exhibits tiny fluctuations around 0.8.[16]

In Figure 1, we focus on the relative TFPs of Japan, the United Kingdom, and the four largest euro area countries. In the early 1990s, the TFPs of these countries are close to each other and become more dispersed thereafter. The divergent path of the TFPs of Italy and the United Kingdom, in particular, is noteworthy. In 1985 they are not dissimilar. Afterwards, Italy looses ground with respect to the other countries, while the United Kingdom's relative TFP grows rapidly. In 2001-2002, Italy's TFP is the lowest among the group of countries in the figure, also surpassed by Spain, while the United Kingdom ranks first, not too distant from the United States. Finicelli, Pagano, and Sbracia (2009a) show that an important driver of the UK's TFP has been the selection effect of international competition (according to their estimates, the contribution of trade openness to the UK's TFP has grown from 4.9% in 1985 to 7.3% in 2002, the largest increase among the countries in Figure 1).

[16]Our results are robust to alternative calibrations of the main parameters in the model, i.e. β, θ, and g (see Appendix A.2 for details).

Table 3: Trade-revealed TFPs (relative to the United States)

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

The finding that the United States' TFP is the highest throughout the two-decade period is worth stressing. According to a number of studies based on development accounting, in fact, in the mid-1980s to early-1990s it was Italy's TFP that ranked first among the 19 countries in our sample.[17] These findings appear rather odd given the well known relative weakness of Italy's institutions. For example, Lagos (2006) is puzzled by the result that TFP is higher in Italy than in the US, which is at odd with the observation that Italy has a more distorted labour market vis-à-vis the US. Similarly, Hall and Jones (1999) underscore that hours per worker "are higher in the United States than in France and Italy, making their [high] productivity levels more surprising." Our methodology returns a more plausible assessment, whereby in our sample of high-income countries Italy ranks 6th or 7th, with a manufacturing TFP that is 13% to 17% lower than that of the United States.

Besides the specific result for Italy, which is analyzed with greater detail in the next section, our findings are broadly in line with those from a sample of other studies that use different methodologies. The rank correlation of our 1990 results with the TFP ranking estimated by Bar-Shira, Finkelshtain, and Simhon (2003) is above 0.8. The (linear) correlation of our 1985 results with the 1983 "trade-revealed type" of TFP provided by Trefler (1995) is about 0.7.[18] The broad picture delivered by our methodology is also not too different from that in Klenow and Rodriguez-Claire (1997) and Hall and Jones (1999): the correlation between their relative TFPs and ours are fairly high, equal to about 0.65 in both cases.[19]

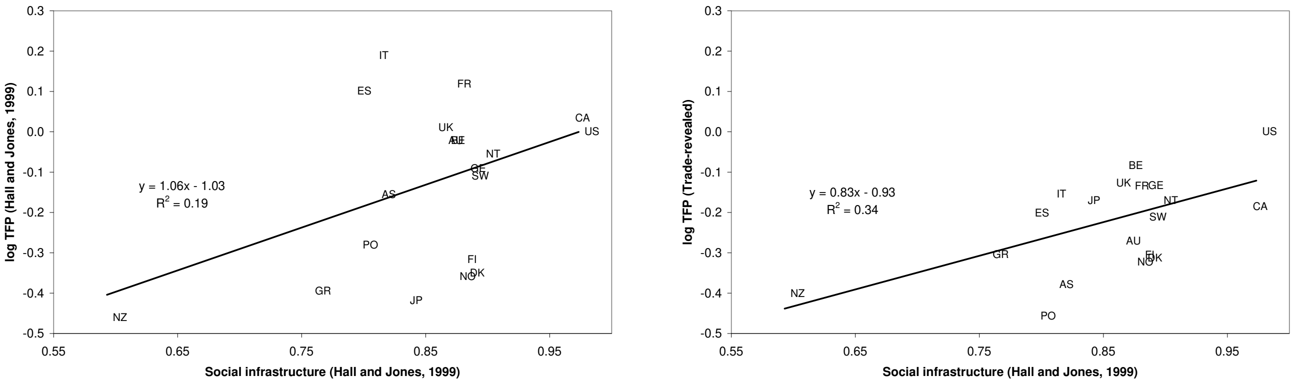
It is worth recalling the result documented by Hall and Jones (1999) who find that, in a sample of 127 countries, differences in social infrastructure drive differences in capital accumulation, productivity, and output per worker. The positive correlation between their measure of TFP and their index for social infrastructure remains also if one narrows the analysis to the 19 advanced economies of our sample (left panel of Figure 2). Yet, in that scatter plot some countries — notably Italy, but also France and Spain — display very large residuals from a simple OLS regression, featuring a much higher TFP than the predicted one. Interestingly, using our trade-revealed TFPs (right panel of Figure 2) delivers a stronger correlation and a better fit of the data (R^2 climbs from 19 to 34 percent), while solving the TFP "anomalies" of Italy, France, and Spain, that present a much smaller residual in the new regression.

[17] See, for example, Hall and Jones (1999), Chari, Restuccia, and Urrutia (2005), or the development-accounting excercise performed by Fadinger and Fleiss (2008). In Klenow and Rodríguez-Clare (1997), the TFP of Italy is third, but it is still higher than that of the US.

[18] Trefler (1995) obtains the Hicks-neutral factor-augmenting productivities of several countries (relative to the US) that provide the smallest gap between observed trade data and the trade pattern implied by factor intensities. While the purpose of his study was not that of measuring TFP (but, rather, that of vindicating the predictions of the Hecksher-Ohlin-Vaneck theory), his results can be considered as the first example of a trade-revealed TFP.

[19] The estimates in Kleenow and Rodriguez-Claire refer to year 1985, those in Hall and Jones to 1988. The correlations are obviously calculated with respect to our estimates for the corresponding years.

Figure 2: TFP and social infrastructure



(1) Data refer to 1988 in both pictures. TFP is relative to the US.

5 A case study: Italy versus the United States

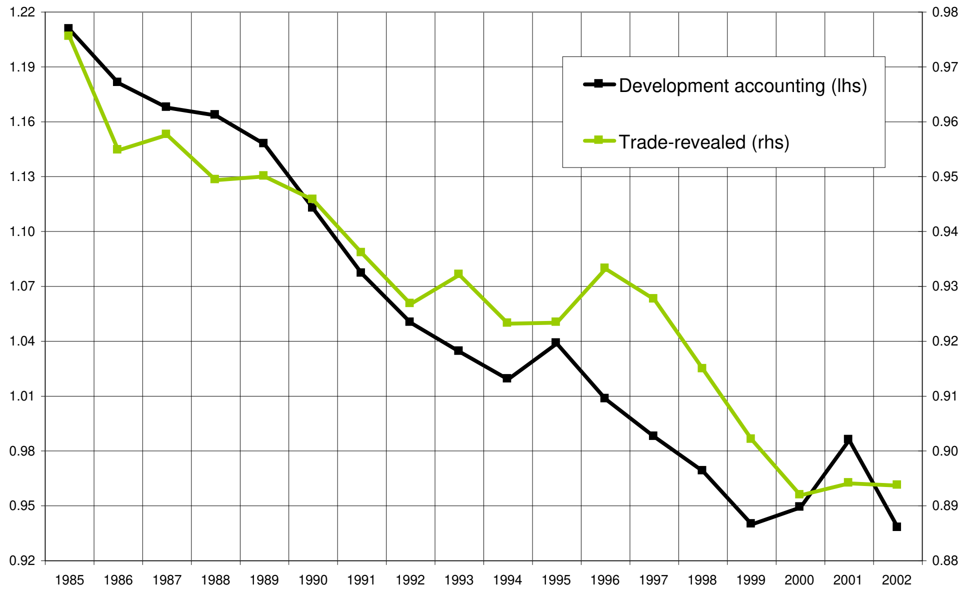
The methodology that we propose to evaluate countries' tradeable TFP marks a neat departure from the standard approach. It is therefore interesting to compare our results with those from a development-accounting procedure. We perform this exercise for Italy versus the United States, which is a particularly interesting case given the aforementioned "Italian anomaly" from development-accounting studies. This case also allows us to refine the measurement of labor inputs by adjusting wages for working hours, which are available for both countries at the sectoral level.[20] The limited availability of the necessary data to implement the development-accounting methodology prevents us from extending the comparison to all the countries in the sample.[21]

As is standard in development accounting, we assume 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 the stock of physical capital with share η, and H_i the stock of human-capital augmented labor.

[20] Recall that Hall and Jones (1999) were especially concerned by the high TFP of Italy because of the lower number of hours worked in this country vis-à-vis the US. Therefore, accounting for working hours also allows us to explicitly address their concern.

[21] The measurement of physical capital is the step in which data limitations are stronger. 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 3: Manufacturing TFP of Italy relative to the US (including worked hours)



Assuming that each worker in country i has been trained with h_i years of schooling, 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 and $g = 0.06$ as in the previous section.

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

$$A_i = \left(\frac{Y_i}{L_i}\right)^{1-\eta} \left(\frac{K_i}{Y_i}\right)^{-\eta} \left(\frac{H_i}{L_i}\right)^{-(1-\eta)} . \tag{8}$$

Except for the years of schooling, which are not sector specific, all data refer to the manufacturing sector. In particular, we measure the capital stock with the perpetual inventory method as in Caselli (2005).[22]

Figure 3 shows the TFP of Italy relative to the United States obtained with this methodology, and compares it with the one that results from the trade-revealed approach. Note that the two series are measured on different axes and scales. The similar time pattern exhibited by the two TFPs, evident at first sight, is quite remarkable given that they are derived from unrelated methodologies and completely different data series (quantity data on production and inputs on the one hand, value data on trade flows, production and wages on the other). According to our development accounting calculations, at the beginning of the sample period Italy's TFP is 21% higher than that of the United States; afterwards it falls by as much as 27 percentage points. When measured on the basis of our trade-revealed approach, instead, in

[22] Appendix A.1 provides all the details on the methodology, as well as on data sources.

1985 Italy's TFP lies below that of the United States and records a much smaller cumulative loss, falling by 9 percentage points (to 0.89).[23]

Our TFP measures seem to provide a more reasonable picture of the productivity divide between Italy and the United States. In fact, on the one hand, our trade-revealed TFP is not blurred by the surprising result that in the mid-1980s to the early-1990s Italy's TFP was higher than that of the United States. On the other hand, this improvement is obtained while preserving a very similar time pattern.

6 Conclusion

We have proposed a new methodology to measure the relative TFP of the tradeable sector across countries, based on the relationship between trade and TFP in the state-of-the-art model of Eaton and Kortum (2002). With respect to the standard development-accounting approach, our methodology has two main advantages. First, it is based on easy-to-get value data on trade, production, and wages. Second, our TFPs are no longer a mere residuals, but are the productivities that best fit those data.

Applying this methodology to estimate the TFPs of the manufacturing sector of 19 OECD countries (with respect to the US) from 1985 to 2002 provides promising results. Our findings, while being broadly in line with those of many previous studies, including the standard development accounting approach, appear more reasonable. In particular, they fix the "anomaly" produced by the standard method that Italy's TFP is the highest among a large pool of developed countries in the mid-1980s to the early-1990s. Similarly to other "alternative" methodologies existing in the literature (such as the "revealed superiority" approach of Bar-Shira, Finkelshtain, and Simhon, 2003, and the measures based on the Hecksher-Ohlin-Vaneck theory provided by Trefler, 1995), we obtain that the TFP of the US ranked first throughout our two-decade sample period. Interestingly, the case study about the TFP of Italy versus the US shows that our measure yields a difference in levels with respect to development accounting, while preserving a very similar time pattern.

These results suggest that it is worth exploring alternative methods to measure TFP, that are not based solely on its "primitive" (the production function) but, rather, take its observed implications (on trade data or profits) as the starting point of the analysis. For what concerns our methodology, in particular, future research is needed to enhance it along two main dimensions. The Ricardian framework of EK needs to be generalized into a truly dynamic model, in order to meaningfully include physical capital among the production factors. Second, the model requires a better treatment of the non-tradeable sector, in order

[23] By comparing the results of Figure 3 with those from Table 3, note that accounting for working hours raises the TFP of Italy versus the US by 11 percentage points in 1985, and then delivers a richer dynamics.

to extend the methodology to estimate the TFP of the whole economy.

A Appendix

A.1 Data

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) are from the Statistics Canada's World Trade Analyzer. The reconciliation between the ISIC and SITC codes follows Eurostat-RAMON (http://europa.eu.int/comm/eurostat/ramon/index.cfm).

Gravity data. Geographic distances and border dummies are from Jon Haveman's International Trade Data (http://www.macalester.edu/research/economics/page/Haveman/Trade.Resources/TradeData.html). Countries are grouped by language as in EK: (*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 from OECD-STAN. Values are converted into a common currency using the PPP exchange rates available from the OECD. Wages are then adjusted for education, as explained in Section 3. Years of schooling are obtained from de la Fuente and Doménech (2006). We deal with missing data by interpolation and extrapolation using the most recent update of the dataset first presented in Barro and Lee (2000).

Development-accounting methodology and data. Capital stock data are obtained from real investment using the perpetual inventory method, according to the following relationship:

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

where I_t is real investment and δ 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 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 the standard practice, initial capital stock is computed as $K_0 = I_0 / (\delta + \kappa)$, where I_0 is the oldest 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 ten years of data.

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.

A.2 Sensitivity analysis

This section provides a brief analysis about the sensitivity of the estimates of the states of technology to alternative calibrations of θ, β, and g. Recall that states of technology represent an essential intermediate step for the quantification of countries' relative TFP.[24] In our empirical analysis we have chosen as benchmarks $\theta = 6.67$, annual values of β set equal to the ratio between manufacturing value added and production, and $g = 0.06$. As alternative values for θ, we set $\theta = 4$ and $\theta = 10$, which are the lower and upper bounds in the range that Alvarez and Lucas (2007) consider reasonable, and $\theta = 8.3$ (EK's preferred calibration). The alternative calibration for β is given by the ratio between labor compensation and production (see footnote 9), as in EK. Finally, for the return on education g we adopt a non-linear function as in Hall and Jones (1999) and Caselli (2005), setting $g = 0.13$ for $h_i \leq 4$, $g = 0.10$ for $4 < h_i \leq 8$, and $g = 0.07$ for $h_i > 8$.

Combining the above set of parameter values results in 16 alternative estimates of the states of technology, including our benchmark. Since states of technology vary both across countries and over time, we analyze the sensitivity of the results by computing, in turn, the time series and cross-country correlations between our benchmark estimates and those obtained with each alternative calibration. A high correlation suggests that the results are little changed by the alternative assumptions. In Table 4, we report the average correlations computed for each calibration. The number on the left side of each cell is the average (computed across countries) of the time series correlations calculated for each country; specularly, the number on the right of each cell is the average (computed along the time series dimension) of the cross-country correlations calculated for each year.

The values of correlations shown in the table reveal, at a glance, that results are robust to the alternative calibrations. Cross country correlations (right-hand values in each panel) are in most cases very close to one, and never below 0.9. As far as time-series correlations are concerned, results are also quite comforting. We never get a value below 0.8, except in the case in which we change all the parameters and set β equal the ratio between labor compensation and production, $\theta = 4$, and the non-linear specification for returns on education, which nonetheless results in an average time-series correlation of about 0.7, still within an acceptable range of values. A deeper analysis of time-series for individual countries reveals that the

[24] Given the relationship between the two parameters, the sensitivity evidence provided for the relative states of technology can be safely applied to the relative TFPs.

Table 4: Correlation of alternative calibrations with benchmark estimates (1)

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

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

largest impact on our estimates comes from the influence of the non-linearity assumption on Greece, the only case in which we get a negative correlation. Once this country is excluded, there is a significant improvement, with the lowest correlation now close to 0.8.

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