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More evidence on technological catching-up in the manufacturing sector

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Abstract

Production frontiers for the manufacturing sector are estimated to determine a "country specific" catching-up process of Total Factor Productivity (TFP).TFP gains were aimed at assessing the manufacturing industry's productive performances for 14 OECD countries over the period between 1970-2001. Our TFP measure does not assume technical or allocative efficiency which are inherent drawbacks of usual TFP indices. We show that catching-up processes can be very different between sub-periods and across countries. A significant catching-up process was in progress in the manufacturing sector between 1970 and 1986 then it overturned over the period 1987-2001. During the first sub-period, the speed of technological catching-up of the euro-zone countries was definitely higher than those of the other European or OECD nations whereas the divergence noted in second sub-period had the same order of magnitude amongst the three groups.

JEL classification: O33; O40; O47
Keywords: Catching-up; TFP change index; Technology adoption; Production Frontier

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1. Introduction

The productivity catching-up hypothesis put forth by Abramovitz (1986) has recently been investigated at the disaggregated level of industries by testing for convergence in Total Factor Productivity (TFP) within sectors across countries[2]. These studies lead to the same major finding that services are driving the aggregate convergence result while tradable sectors as manufacturing showed non significant catching-up process (see for instance Bernard and Jones, 1996a, 1996b; Hansson and Henrekson, 1997).

While these studies take clearly into account the potential differences between industries in the technological catching-up process, they suffer from one main drawback. The technology level is either computed as a Solow-residual indicator of technology or as a traditional Törnquist index. These choices may then alter or bias the subsequent evaluation of the catching-up mechanism because they assume technical as well as allocative efficiencies for each country.

A detailed analysis of the comparative productivity performance at sectoral level, and more precisely in the manufacturing sector, is a good way to better understand the mechanism behind the catch-up and convergence process for the economy as a whole. The manufacturing sector plays an important role in the earlier stages of economic growth due to its increasing share of the sector in total production and employment, and its rapid increase in productivity. But it also plays an important role in the later stages when manufacturing becomes less important in relative terms, as is presently true for most OECD countries, due to its role of new technology generator and to the associated spill-over effects to other sectors.

Moreover, the industrial manufacturing sector is vast and many of its companies are highly diversified and so less exposed to falling consumer confidence than companies in other sectors during low phases of the business cycle. Finally, the manufacturing sector still has a large positive effect on available income of consumers due to the decreasing price of manufacturing goods induced by rapid productivity growth in this sector.

Due to the major impact of the manufacturing sector on growth, we propose a re-examination of the productivity catching-up mechanism across the leading industrial countries in this sector by using an empirical strategy which avoids the above-mentioned drawback. The central point of this methodology consists in using a TFP index to determine a parametric-stochastic world production frontier for OECD countries with data spanning the period 1970-

[2] In this study, we follow Abramowitz's distinction between catch-up and convergence. Catch-up is defined as the narrowing of the productivity gap compared to the leading country, whereas the convergence hypothesis supposes that the productivity gaps narrow among the follower countries as well.

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2001. We then evaluate the convergence of the estimated technical levels by testing whether countries with technological delays start a catching-up process by adopting more advanced production technology from more efficient countries[3].

Compared to usual researches on technological adoption, one main methodological contribution of our research is to develop a panel data procedure that enables us to estimate individual specific processes concerning direction and magnitude of TFP convergence within a set or a sub-set of countries.

Empirical results partly confirm previous findings that no (or even a slow) catching-up effect was in progress in the manufacturing sector. However, our results strongly mitigate this finding by showing that the catching-up process is not uniform over time and among different groups of countries. More precisely, while there is strong evidence of the spread of technology across OECD and other European nations over the period 1970-1986, this process of technological adoption appears to have been be reversed over the fifteen years following 1986. While within the euro-zone, it was more significant and spread out over a longer period of time (1970-1997).

The paper is organised as follows. Section 2 lays out the basic framework by providing the catching-up model and the measures of TFP gaps between countries. Section 3 reports the empirical results and Section 4 is the conclusion.

2. Production Frontier and Total Factor Productivity Convergence

Since the latter part of the eighties, many empirical studies focusing on international comparison of Total Factor Productivity (TFP) have shown that differences in technology may contribute to gaps in TFP levels[4]. By evaluating the dynamic properties of TFP we can investigate whether countries are able to catch-up in terms of the highest observed TFP levels and how income convergence depends on both TFP growth rates and initial TFP levels. In the same way, we develop a catching-up model based on TFP gaps measured as distances between national production plans to a production frontier constructed for the OECD countries.

[3] As the analysis is restricted to the case of the main OECD countries, the assumption of technological diffusion appears to be valid since each country in the data set is characterised by rather similar level of "social capabilities" and catch-up potential.

[4] See Islam (2001) for a review on different approaches to international comparisons of TFP and the issue of convergence

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2.1. TFP catching-up model

Our catching-up model supposes that relative growth rates of productivity in an industry are determined by specific country catching-up factors. The TFP growth rate of country *i* at time *t* is supposed to be generated by both the lagged technology gap between the desired and observed level of productivity and the common rate of technical change that shifts the production frontier simultaneously for all countries:

$$\ln(q_{it}) - \ln(q_{it-1}) = \lambda_i . \ln\left(\frac{q^d_{it-1}}{q_{it-1}}\right) + g_t \qquad (1)$$

where q^d_{it} is the desired level of TFP for country *i* and g_t the technical progress at time t. We can consider that this desired level of TFP may be considered as the leader's productivity $q_{L,t.}$ located on the production frontier

According to Abramovitz's (1986) concept of «social capabilities», countries may differ in their ability to recognise, incorporate and use available technology. In an attempt to incorporate this concept in the model at hand, we assume that the speed of the catching-up process λ_i is specific to each country[5]. Obviously, the concept of «social capabilities» may encompass many economic factors such as the institutional framework, the level of education, the organisation of firms, international openness, and adjustment costs, so that no single economic variable may adequately measure countries' ability to adopt the technology gap. As suggested by Hultberg et al. (1999), country-specific effects from the production frontier equation should take into account country heterogeneity due to social capabilities of adopting available technology.

Equation (1) is rewritten as:

$$\ln(q_{it}) - \ln(q_{it-1}) = -\lambda_i . \ln\left(\frac{q_{it-1}}{q_{Lt-1}}\right) + g_t \qquad (2)$$

Finally subtracting equation (2) from equation of productivity dynamics for leading country *L*, we obtain:

$$\ln(\tilde{q}_{it}) - \ln(\tilde{q}_{it-1}) = -\lambda_i . \ln\left(\tilde{q}_{it-1}\right) \qquad (3)$$

where the notation "tilde" indicates a ratio of TFP level in country *i* to the same variable in the leading country.

Considering the relationship between long term growth-rates across countries, equation (3) can be solved to give:

[5] In that way, productive inefficiency for each country can be incorporated in our catching-up model (cf. point 2.2).

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$$\frac{\ln(\tilde{q}_{iT}) - \ln(\tilde{q}_{i0})}{\ln(\tilde{q}_{i0})} = \delta_i \qquad (4)$$

with $\delta_i = -[1-(1-\lambda_i)^T]$.

2.2. TFP growth decomposition

Total Factor Productivity indices are usually used to compare production technologies at the aggregate level as well as the sector levels. However, these indices measure both technical and efficiency changes. While technical change shifts the production frontier, the latter measures the movement of production towards the efficient frontier that can be constructed as the benchmark for all countries in the sample.

The frontier nature of the production function establishes a link between maximal potential output quantities and input quantities. This link is able to capture any productive inefficiency and offers a "benchmarking" perspective. For instance, an economy's performance can be evaluated with respect to both its past experience and by the best practice of other countries[6].

The production technology of a given sector (manufacturing in this study) is represented by the production frontier:

$$y_{i,t}^F = g(x_{i,t}, t) \qquad (5)$$

where $y_{i,t}^F$ is potential output of this sector in country *i* at time *t* ($i = 1 \cdots I$, $t = 1 \cdots T$), x_{it} is the *k*-dimension vector of inputs and *t* is time.

The effective level of output of country *i* at time *t* ($y_{i,t}$) is then supposed to be given by:

$$y_{it} = y_{it}^F \cdot e^{u_{i,t}} = g(x_{it}, t) \cdot e^{u_{it}} \qquad (6)$$

where $e^{u_{i,t}}$ lies in the interval [0 , 1] and measures the efficiency score associated with the effective level of output y_{it} produced with inputs x_{it}.

Differentiating equation 6 with respect to time then leads to

$$\frac{dy_{it}}{y_{it}} = g_x \frac{dx_{it}}{x_{it}} + g_t + \frac{du_{it}}{dt} \qquad (7)$$

[6] For a unified discussion of efficiency and productivity from a production frontier approach and its methodological advantages, the reader can consult Fried, Lovell and Schmidt (2008). See also Barros (2008) for advances and applications in this field.

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where g_x is the elasticity of output with respect to input and g_t is the elasticity of output with respect to time which we assume to be common to all countries.

According to equation (7) production growth includes three distinct components: changes in input quantities weighted by their respective elasticity ($g_x(dx_{it}/x_{it})$), the shift of the production frontier over time due to the effect of technical change (g_t) and changes in productive efficiency (du_{it}/dt).

Total factor productivity gains (dq/q) are then defined as the amount of output growth not attributed to the input quantity variations and can be evaluated as the sum of the technical change effect and of the efficiency change effect:

$$\left(\frac{dq}{q}\right)_{it} = g_t + \frac{du_{it}}{dt} \qquad (8)$$

With a Cobb-Douglas production frontier specification, equation (6) can be rewritten as:

$$\ln(y_{it}) = \alpha + \sum_{k=1}^{K} \beta_k \ln\left(x_{it}^{(k)}\right) + \gamma t + \varepsilon_{it} \qquad (9)$$

where $x_{it} = \left(x_{it}^{(1)}, \cdots, x_{it}^{(K)}\right)'$ and $\varepsilon_{it} = u_{it} + v_{it}$ where $u_{i,t}$ is the efficiency effect and $v_{i,t}$ an usual iid noise process with zero mean and constant variance.

The Time Varying Effect method proposed by Cornwell, Schmidt and Sickles (1990) is then used to estimate the two components of ε_{it} separately. This method allows the inefficiency component to vary over time by assuming that the efficiency effect u_{it} can be expressed as a quadratic function of time with country-fixed effects:

$$u_{it} = \theta_i^{(0)} + \theta_i^{(1)} t + \theta_i^{(2)} t^2 \qquad (10)$$

where $\theta_i^{(0)}$ is a country-fixed effect, $\theta_i^{(1)}$ and $\theta_i^{(2)}$ are the country-specific parameters measuring efficiency change over time.

Equation (9) added to equation (10) can then be estimated thanks to a generalised within procedure under the two following constraints $\sum_i \theta_i^{(0)} = 0$ and $\sum_i \theta_i^{(1)} = 0$ so as to avoid perfect multi-co-linearity.

Under such a specification, the initial TFP level and its growth rate are estimated as a panel data model including both a set of national dummies (to control for the inevitable country heterogeneity due to political and social institutions and to take into account some of

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Abramovitz's ideas of social capabilities) and a set of temporal variables (to control for technology adoption fluctuations that are specific to each country).

Productive efficiency levels can be computed as

$$\mu_{it} = \mathrm{e}^{\hat{u}_{it} - u_t^{\max}} \quad (11)$$

where $\hat{u}_{it} = \hat{\theta}_i^{(0)} + \hat{\theta}_i^{(1)} t + \hat{\theta}_i^{(2)} t^2$ and $u_t^{\max}$ is the value of the efficiency effect in the leader country that is located on the production frontier at time *t*.

By differentiating equation (10) with respect to time, total factor productivity growth may be rewritten as a linear function of time adding up technical change and efficiency change components:

$$\left(\frac{dq}{q}\right)_{it} = \gamma + \theta_i^{(1)} + 2\,\theta_i^{(2)} t \qquad (12)$$

The log of Total Factor Productivity can then be written as:

$$\ln\left(q_{it}\right) = \alpha + \theta_i^{(0)} + \left(\gamma + \theta_i^{(1)}\right) t + \theta_i^{(2)} t^2 + v_{it} \quad (13)$$

from equation (10), the technological gaps in terms of TFP levels between country *i* and the leading country at time *T* and *0* are measured as follows:

$$\ln(\tilde{q}_{iT}) = (\hat{\theta}_i^{(0)} - \hat{\theta}_{L_T}^{(0)}) + (\hat{\theta}_i^{(1)} - \hat{\theta}_{L_T}^{(1)})T + (\hat{\theta}_i^{(2)} - \hat{\theta}_{L_T}^{(2)})T^2 \qquad \text{at time } T \qquad (14a)$$

and

$$\ln(\tilde{q}_{i0}) = (\hat{\theta}_i^{(0)} - \hat{\theta}_{L_0}^{(0)}) \qquad \text{at time } 0 \qquad (14b)$$

where $\hat{\theta}_{L_T}^{(0)}, \hat{\theta}_{L_T}^{(1)}, \hat{\theta}_{L_T}^{(2)}$ are estimated coefficients for the leader at time *T* and $\hat{\theta}_{L_0}^{(0)}$ the logarithmic of the leader's estimated TFP at time 0.

From equations 4, 14a and 14b, we get δ_i and finally an indirect estimate of λ_i as:

$$\hat{\lambda}_i = 1 - \left[1 + \frac{\left(\hat{\theta}_{L_0}^{(0)} - \hat{\theta}_{L_T}^{(0)}\right) + \left(\hat{\theta}_i^{(1)} - \hat{\theta}_{L_T}^{(1)}\right)T + \left(\hat{\theta}_i^{(2)} - \hat{\theta}_{L_T}^{(2)}\right)T^2}{\left(\hat{\theta}_i^{(0)} - \hat{\theta}_{L_T}^{(0)}\right)}\right]^{1/T} \quad (15)$$

A positive speed ($\hat{\lambda}_i > 0$) is consistent with the catching-up hypothesis while negative speed reveals productivity divergence.

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3. Empirical results

The sample used in this study consists of annual data from fourteen OECD countries : Australia (1), Belgium (2), Canada (3), Denmark (4), Finland (5), France (6), Germany (7), Italy (8), Japan (9), the Netherlands (10), Norway (11), Sweden (12), the United Kingdom (13) and the United States (14). The data span between 1970-2001 interval was obtained from the International Sectoral Data Bank (ISDB) and the OECD STAN database for Industrial Analysis. It comprises added value expressed in international prices (base year 1990) as the usual proxy for output, labour input measured by total employment and capital stock, expressed in international prices (base year 1990). We focus on the total manufacturing sector. Added value is calculated as the difference between production and intermediate inputs and encompasses labour costs (compensation of employees), consumption of fixed capital, taxes less subsidies and net operating surplus and mixed income. Labour includes all people involved in production: entrepreneurs, unpaid family workers of unincorporated units and home based workers, as well as employees. To gauge productivity levels, labour input for an industry should be more appropriately measured as the number of hours actually worked weighted by the relative quality of the various categories of people employed. Unfortunately, such detailed series are not available at this sector level. Although our reductive measure of labour does not reflect changes in the quality nor in the average work time per employee, these effects are implicitly considered in our TFP measures with the country's specific effects. In ISDB, capital stock data are used as measures of capital input in the production process, merging the volume of physical capital assets available in the respective countries. But where data is missing, estimates have been made using a perpetual inventory model.

3.1. Production frontier regression and TFP growth

The Time Varying Effect method consists in estimating Equation (9) and the two components of ε_{it} thanks to a one step generalised within procedure (cf. 2.2). The results of production frontier regression under constant returns to scale hypothesis are reported in Table 1. Only seven out of the thirty six coefficients are non significant at the 5% confidence level. The output/input elasticities β_L for labour and β_K for capital are respectively 0.83 and 0.17. Thanks to a GMM panel procedure, Hultberg and al. (2004) get an output/capital elasticity of approximately 0.22, their period being between 1973-1990. Using STAN data base, Harringan (1999) estimates β_K over the 1980-1990 period for several detailed manufacturing sectors. His

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results vary from 0.71 for the motor vehicles industry to 0.26 for the non electrical machinery sector. While Harrigan recommends that output elasticities should be estimated econometrically, Frantzen (2004) prefers to compute TFP levels by imposing an exogenous given value of these parameters which are approximated by the average revenue shares of labour and capital across countries. He retains different simulations of β_L in the interval [0.65, 0.72] on disaggregate manufacturing panel data from STAN over the period 1970-1995. More recently, using data from STAN on France, the United Kingdom and the United States and using the same approach as Bernard and Jones (1996a) Khan (2006) computes β_L as the time-averaged labour share across all countries rather than using actual labour. Focusing on the total manufacturing sector, he respectively retained 68% for France and the USA and 76% for the UK. In the three latter studies implicit assumptions of perfect competition with no technical as well no allocative inefficiencies are presupposed. Differences between our output/input elasticity levels and all of these previous results are mainly explained at the same time by our econometrical panel data procedure allowing productive inefficiency, the number of countries, the period of observation under study and the degree of details of sector classification.

Averages of TFP growth rates estimated with equation (12) for each country and for several groups of countries are presented in Table 2. On average, TFP growth rates are mainly explained by the common technical progress component (2.4%). Applying the DEA methodology and standard Malmquist indices on the same data but covering a shorter period (1970-1990), Shestalova (2003) found a similar result. She set up that the contribution of technical progress to TFP growth was about 1.5-2% while the contribution of efficiency change was modest and even negative in some particular sectors such as the basic metal industry. Khan (2006) detected quite comparable TFP growth rates for the total manufacturing industry. Between 1980-2002, time-averaged TFP growth rates were 2.1% for France, 2.7% for the UK and the USA. Finally, Frantzen (2004) obtained an average annual growth rate of TFP of approximately around 2.3%.

Finland has the highest growth rate of TFP with an efficiency change close to 1.7% per year. Within the euro currency zone, five out of six countries (Belgium, Finland, France, Italy and the Netherlands) achieve a growth rate of TFP exceeding the overall sample average. Based on the average of individual un-weighted TFPs, this group obtains the best progression. However, this result is mainly driven by small countries of the overall Euro zone such as Finland and Belgium. When countries' TFP average is respectively weighted by size of GDP,

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this conclusion is reversed, for example Germany, as the biggest economy of this group, performs relatively poorly compared to the USA, Japan or the United Kingdom. With similar data from ISDB based on a shorter period of time (1970-1987), Bernard and Jones (1996a) also found that Finland and Belgium had a high rate of TFP growth: 3.7% and 5.1% respectively while West Germany and Norway only achieved 2.4% and 1.7% which are amongst the smallest performances of the European countries.

With regard to efficiency levels, the euro zone gets the highest average score compared to the European countries and the OECD group when excluding the USA who are the leader. We would like to highlight the fact that the United States are the leading country throughout this period as a number of previous studies concerning cross-country comparisons of TFP levels for manufacturing in the OECD show. Hultberg and al. (2004) estimate negative efficiencies (inefficiencies) relative to the United States for all countries and confirm the hypothesis of the USA as leaders. Harrigan (1997) makes it clear that the USA was either the leader or joint leader in TFP during the 1980's in six out of eight manufacturing sectors. Dollar and Wolff (1993) report TFP for total manufacturing in 1985 using constant wage shares and find that the USA is the technical leader. From Malmquist indexes using a non parametric approach, Shestolova (2003) as well Boussemart et al. (2006) conclude that the USA exhibits the highest level of efficiency in most industries while this country cannot systematically be considered as the leader.

Table 1: Production Frontier Regressions

	Estimated values of the coefficients					
Country *i*	$\alpha+\theta_i^{(0)}$	*(t-stat)*	$\gamma+\theta_i^{(1)}$	*(t-stat)*	$\theta_i^{(2)}$	*(t-stat)*
1	8.24	*(19.07)*	1.95E-02	*(6.21)*	-5.40E-05	*(-0.62)*
2	7.99	*(18.62)*	5.71E-02	*(16.13)*	-7.82E-04	*(-9.00)*
3	8.43	*(19.20)*	4.25E-03	*(1.35)*	3.82E-04	*(4.29)*
4	8.03	*(18.71)*	2.75E-02	*(8.73)*	-4.08E-04	*(-4.68)*
5	7.88	*(17.86)*	1.45E-02	*(4.19)*	8.66E-04	*(9.75)*
6	8.38	*(19.22)*	2.02E-02	*(6.10)*	1.25E-04	*(1.43)*
7	8.41	*(19.51)*	2.13E-02	*(6.89)*	-1.99E-04	*(-2.27)*
8	7.95	*(18.27)*	4.82E-02	*(15.06)*	-5.39E-04	*(-6.21)*
9	8.09	*(19.73)*	3.64E-02	*(8.83)*	-3.47E-04	*(-3.75)*
10	8.27	*(18.83)*	3.61E-02	*(10.55)*	-3.70E-04	*(-4.23)*
11	8.16	*(18.80)*	6.65E-03	*(1.73)*	8.30E-05	*(0.86)*
12	8.15	*(18.86)*	-2.88E-03	*(-0.98)*	1.06E-03	*(11.99)*
13	8.09	*(19.17)*	1.63E-02	*(4.39)*	2.69E-04	*(2.91)*
14	8.73	*(19.57)*	-5.10E-03	*(-1.59)*	9.50E-04	*(10.85)*
	Estimated values of the output/input elasticity					
$\overline{\beta}$	0.83	(20.59)				

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Table 2: TFP growth rates and Efficiency Levels (%)

Country I	TFP	Efficiency Change	Technical Progress	Efficiency levels
AUS	1.78	-0.66	2.44	64.95
BEL	3.28	0.85	2.44	71.97
CAN	1.61	-0.82	2.44	71.58
DNK	1.49	-0.95	2.44	53.59
FIN	4.13	1.70	2.44	57.45
FRA	2.40	-0.03	2.44	80.16
WGR	1.51	-0.92	2.44	75.86
ITA	3.15	0.71	2.44	64.98
JPN	2.56	0.12	2.44	66.38
NLD	2.46	0.03	2.44	78.99
NOR	0.92	-1.51	2.44	52.00
SWE	3.00	0.56	2.44	60.12
GBR	2.46	0.03	2.44	59.32
USA	2.44	0.00	2.44	100.00
Un-weighted Average				
Euro zone	2.82	0.39	2.44	70.53
European countries	2.48	0.05	2.44	64.23
Total OECD including USA	2.37	-0.06	2.44	66.96
Total OECD excluding USA	2.37	-0.07	2.44	64.93
Weighted Average				
Euro zone	2.21	-0.22	2.44	73.86
European countries	2.29	-0.15	2.44	70.15
Total OECD including USA	2.43	-0.01	2.44	79.74
Total OECD excluding USA	2.30	-0.14	2.44	68.89

3.2. TFP Convergence Process and Technological catching-up

In order to evaluate the stability of the TFP convergence process over time and amongst countries, Figure 1 plots the coefficient of variation of Total Factor Productivity for three groups of countries: OECD, other European countries and the euro-zone.

When considering the first and the last year of the sample, no significant phenomenon of TFP convergence seems to appear. The standard deviation of TFP is even higher at the end of the sample than during the 70's. At first sight, this result appears to be consistent with the finding by Bernard and Jones (1996 a,b), Gouyette and Perelman (1997) and Hansson and Henrekson (1997) that there is no TFP convergence in the manufacturing sector.

However, by considering more detailed sub-periods, contrasting conclusions can be set up. Figure 1 shows significan different patterns of the convergence process: the σ-convergence indicator decreases until 1986, and then increases. On the one hand, this movement shows that TFP levels converge over this first sub-period, and on the other hand, TFP gaps amongst countries gradually increase over the period 1986-2001. Frantzen (2004) sets up similar conclusions. When looking at the evolution of σ-convergence concerning TFP levels, year by year, he clearly reveals that this convergence occurred mainly between 1970 to 1985 and disappeared after 1985. Relying on comparisons concerning labour productivity, Galli(1997)

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also finds that from the 1960's until the 1970's the European countries were strongly converging while in the 1990's they diverged in all sectors. Notice that the patterns of our σ-convergence indicators are rather similar for the first two country groups, i.e. OECD countries and other European countries although the TFP levels within the latter group seem to be slightly more homogenous. However, a particular process can be seen for the countries in the the euro zone. The differentials of productivity between the latter nations strongly decreased until 1997 although since 1998, a phenomenon of divergence has reappeared without however finding standard deviations as high as those noted for the two previous groups. On the whole, these results lead us to conclude that TFP convergence is rather a cyclical process requiring recurrent re-assessment.

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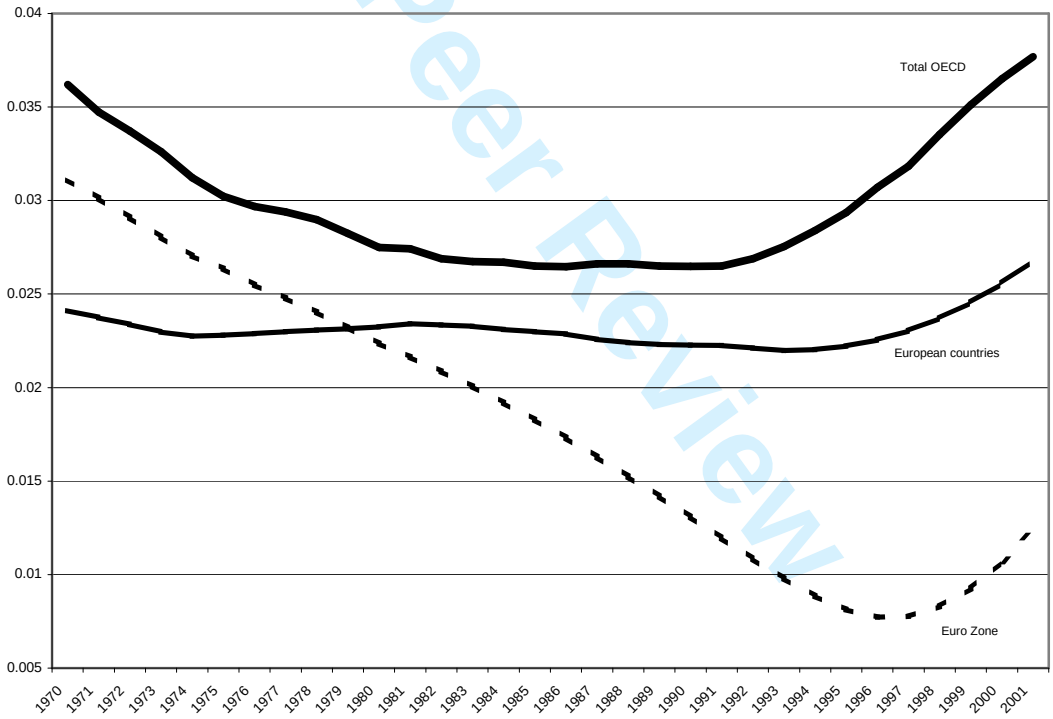
Figure 1: Coefficient of variation of Total Factor Productivity (standard deviation/average, Levels of TFP in logarithm)



Due to the changing patterns in the TFP convergence process observed on Figure 1, the speed parameter of catching-up towards the technical benchmark given by the performance of the American leader is calculated with equation (15) for the sub-periods between 1970-1986 and 1986-2001 As the United-States appears to be the leader over the whole period, the coefficients $\hat{\theta}_{L_t}^{(k)}$ in equation (15) are such that $\hat{\theta}_{L_t}^{(k)} = \hat{\theta}_{USA}^{(k)}$ $\forall k = 0,1,2$ and $\forall t = 0,T$.

Empirical results concerning the catching-up parameters are reported in Table 3 and add support to the σ-convergence indicator analysis. During the period 1970-1986, positive and significant speed is estimated for nearly all countries, suggesting that a catching-up process was in progress and that technical diffusion was taking place across countries over this period. The highest speeds were obtained for Belgium, the Netherlands and Italy. All things being equal, the greater the gap in levels of technical efficiency between the USA and several other countries in the manufacturing industry, the faster the rate of TFP growth in this country. As our model does not incorporate any exogenous variables such as measure of R&D or measure of international trade openness, it is not possible to conclude that this finding is consistent with both the endogenous growth literature and the micro-econometric literature on R&D and productivity. However, consistent with the predictions of the theory and empirical results presented by authors such as Cameron et al. (2005), the further an industry lies behind the technological frontier, the higher its rate of TFP growth.

Table 3: Average Speed of catching-up by period and by country (annual rate)

	1970-1986		1986-2001		1970-2001	
Countries	λ^*	t value*	λ^*	t value*	λ^*	t value*
AUS	0.020	4.267	-0.043	-10.024	-0.011	-6.076
BEL	0.082	15.515	-0.054	-6.783	0.014	6.404
CAN	0.001	0.129	-0.042	-8.496	-0.020	-7.008
DNK	0.018	5.403	-0.041	-13.790	-0.011	-8.800
FIN	0.026	9.201	0.040	6.925	0.031	12.171
FRA	0.050	6.127	-0.053	-5.689	-0.001	-0.306
WGR	0.032	3.830	-0.077	-9.923	-0.021	-7.753
ITA	0.056	14.451	-0.033	-6.469	0.011	6.732
JPN	0.045	10.617	-0.041	-7.278	0.002	0.965
NLD	0.075	9.320	-0.078	-8.127	0.001	0.259
NOR	-0.004	-0.955	-0.036	-14.469	-0.020	-12.335
SWE	0.007	1.939	0.016	3.376	0.011	5.196
GBR	0.019	5.286	-0.017	-4.675	0.000	0.260
USA	Leader		Leader		Leader	
Average Speed calculated from un-weighted TFPs						
Euro Zone	0.053		-0.042		0.006	
European countries	0.036		-0.033		0.002	
Total OECD including USA	0.033		-0.035		-0.001	
Average Speed calculated from weighted TFPs						
Euro Zone	0.047		-0.056		-0.006	
European countries	0.039		-0.044		-0.002	
Total OECD excluding USA	0.037		-0.036		0.000	

* We computed the values and estimated covariance matrix for a non linear function of the parameters (cf. equation 15) estimated by the generalised within procedure mentioned in page 6. This delta method linearizes the nonlinear functions around the estimated parameter values and then uses the standard formulas for the variance and covariance of linear functions of random variables.

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This supports the studies by Dollar and Wolff (1988), Miller-Upadhyay (2002) or Hulberg and al. (2004) that the manufacturing industry shows strong catch-up rates of TFP levels. Comparing France and the UK to the USA for 14 manufacturing industries, Khan (2006) also finds that sectors further behind the production frontier exhibit higher productivity growth.

As total factor productivity is the closest measure of technology, TFP convergence during the period 1970-1986 gives some clues about the characteristics of the technological catching-up process. Moreover, as income convergence can be the joint outcome of the twin processes of capital deepening and technological catch-up (Islam, 2003), our previous result suggests that the income convergence result frequently reported in the literature may be partly explained by the narrowing of TFP gaps until the mid eighties.

In contrast, the estimated speed turns out to be negative and significant during the period 1986-2001, for all countries with the exception of Sweden and Finland. This result is also largely consistent with the pattern of the σ-convergence indicator over this period. The same results are obtained with average speed for both OECD, European and euro-zone country groups The evidence showing that TFP catching-up in the manufacturing sector was in progress throughout the period 1970-1986 while TFP divergence occured during the period 1987-2001 is clearly in opposition with the finding by Bernard and Jones (1996 a) and Dowrick and Duc-Tho Nguyen (1989) that there is no catching-up effect in the manufacturing sector during the sub-period studied. Decomposing the initial period and evaluating the catching-up by using a parametric stochastic production frontier allows us to show that a catching-up reversal appears in the manufacturing sector in the midst 1980s. Moreover while simple labour productivity indicators (such as added value per hour worked) reveal that all countries caught up with the USA in terms of labour productivity up to the mid 1970s, our TFP measure shows that the catching-up process worked until the mid 1980s.

It is difficult to provide an explanation as to why manufacturing industries have behaved so differently with respect to patterns of productivity catching-up. This result may be partly due to the rise of manufacturing GDP growth in the United-States, which was substantially higher between 1987 and 2001 than it was in the previous sub-period between 1970-1986. In contrast to the rapid growth in the United-States, GDP increased at a slower rate than it had done previously in other OECD countries (cf. table 4). Further possible explanations of this TFP catching-up reversal are linked to processes that would contribute to (or abstract from) any tendency towards convergence if for example, capital or labour mobility was particularly high in the United-States and not in other countries. Other factors that are likely to have an impact on convergence include the use of the 'best practice' technology. Following Galli (1997), one

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can interpret the switch from convergence to divergence as a consequence of a deep-seated technological change driven by information technology affecting all industrial sectors and services over the last two decades. It is well known that the Unites States has consistently had an above average propensity to innovate in the past and especially since the eighties. Thus it is probable that the United-States has raised and maintained its technological lead irrespective of any impact that diffusion may have had, and this would alter the process of the TFP gap narrowing. As a result, divergence began to occur when the USA started to implement this new technical paradigm while the other OECD countries still using the previous technology were not able to adopt it at the same time.

Table 4: Annual GDP growth rate for manufacturing industry (%)

	1970-1986	1987-2001
Euro zone	2.07	1.33
European countries	1.58	1.38
Total OECD excluding USA	2.27	1.55
USA	1.75	4.43

4. Conclusion

This paper has used an original testing procedure to re-examine the stability of the TFP catching-up hypothesis in the manufacturing sector across OECD, European and euro-zone countries over a period of thirty years. Empirical results suggest that contrary to previous conclusions put forth by authors such as Bernard and Jones (1996), Gouyette and Perelman (1997) and Hansson and Henrekson (1997), there was a significant movement towards TFP catching-up during the period 1970-1986 for OECD and European countries. These catching-up patterns were reversed during the period 1987-2001. This result may indicate that while structural factors such as the capability to use the "best-practice technology" certainly constitute one of the main determinants of productivity growth, the characteristics of the technological catching-up process may be unstable over time.

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