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Abstract

A method for analyzing productivity convergence based on frontier production functions is proposed. It is examined whether departures from the frontier—country–level inefficiencies—exhibit long–run relationships and convergence. The method is applied to 1-digit industries of 14 OECD countries from 1970–90. Results suggests that comovements in efficiency are concentrated between the EU–countries. Catch–up is found in all but one sector. Even manufacturing, which previous studies have found not to display convergence, shows signs of catch–up.

Key Words: cointegration, convergence, economic growth, efficiency, productivity, technological diffusion, unit root
JEL Classification: C2, O47, O57

1 Introduction

The group of industrialized countries is generally thought to belong to a "convergence club," a term coined by Baumol (1986). That is, they form a group in which countries with initially low levels of per capita output have grown faster in subsequent periods than countries with initially high per capita output levels. Baumol, Nelson, and Wolff (1994) have recently argued that the forces of convergence among the OECD countries may have been exhausted by now because of the relatively strong convergence in the post-war decades.

The latter observation represents the point of departure for our paper. We want to shed more light on the presumption that the forces of convergence have exhausted themselves. It is conceivable that there are different levels and thus sources of convergence. We know of no reason for per capita output to be the only economic variable displaying convergence. Dowrick and Nguyen (1989), for example, claim that convergence in total factor productivity (TFP) in the OECD has been a steady trend during a period of generally weak income convergence. Thus, we are investigating whether OECD countries converge in more than one sense.

This paper is also motivated by the limited number of empirical studies paying attention to developments on a more disaggregated level. We investigate 1-digit industry productivity using a methodology that distinguishes catch–up, which will be interpreted as technological diffusion, from shifts in best–practice. The question of whether certain industries are displaying stronger tendencies in catch–up than others is of particular interest to us.

In addition, we are interested in another connection between the productivity leader and laggards. Not much is known about the relation between the rate of convergence and the growth of productivity in the leading economy. The rate of productivity growth in the leading economy is generally interpreted as a outward shift in the frontier, i.e., technical change. Laggards can converge to the leader by adopting best–practice technology. Thus, according to our connotation, they are catching up.

We address these issues by employing a methodology consisting of three interrelated steps. First, we construct an empirical representation of the technology for a given set of countries. The approach is based on a *frontier production function.* Traditional regression approaches to estimating production functions give *mean* output for a given set of inputs. The definition of a production function, however, is that of *maximum* output for a given set of inputs. The production frontier mimics the theoretical construct of the production function as the outer boundary of the production set. Departures from the constructed frontier can be translated into a measure of a country's efficiency, which we interpret as a country's ability to absorb technological innovations. This interpretation has been adopted previously in Färe, Grosskopf, Norris, and Zhang (1994).

Second, we determine whether departures from the frontier, i.e., country–sector efficiencies, are cointegrated. Failure to reject the cointegration null for a set of countries would indicate a long–run relationship in the diffusion of technology within that set. Similar strategies have been applied to international output series by Bernard and Durlauf (1995). Third, we estimate convergence regressions to determine the degree of productivity convergence or catch–up in the cointegrated set. We apply this methodology to nine 1-digit ISIC industries of 14 OECD countries observed over the period 1970–90.

The results suggest that comovements in efficiency–levels are concentrated among the countries of the EU but not among the G–7. It is further found that catch–up occurs in all but two sectors. Even the manufacturing sector displays catch–up despite opposite findings by other recent studies.

Our conclusions can be summarized as follows. First, the forces of convergence have not exhausted themselves and catch–up is an important contributor to this ongoing phenomenon. Second, catch–up does not occur uniformly across sectors, thereby masking specific convergence trends at the aggregate–economy level. Third, we have taken account for the moving–target nature of the production frontier and thus shown that laggards are catching up, despite the leaders' continuous efforts to push the frontier outward.

This paper proceeds as follows. Section 2 discusses the evidence on sectoral productivity convergence. The data of this study are described in section 3. Section 4 addresses the issues involved in dealing with different measures of productivity. In section 5, we develop our methodology for examining productivity convergence. Section 6 contains empirical results and section 7 concludes.

2 Evidence on Sectoral Productivity

In this section, we will take a look at the extant literature devoted to the analysis of sectoral productivity. What can be found in the sectoral data regarding the behavior of productivity estimates? Do these sectors under consideration show similar trends in the development of their productivities?

According to Dowrick's (1989) model, the rate of output growth is a linear function of the change in aggregate capital stock relative to output, the growth of aggregate employment, sectoral changes in employment, sectoral shares in output, the technological gap and the exogenous rate of technological change in the reference sector. For his sample of 23 OECD countries he finds that the movement of labor out of agriculture increases the growth of GDP because the marginal productivity of labor is higher in the industrial and the services sectors. However, the reallocation of labor out of the agricultural sector does not explain the convergence of productivity. Rather, his results suggest that this catch–up is driven by technology transfers.

An extensive study by Dollar and Wolff (1993) examines the productivity of OECD countries at various levels of aggregation: country–level, sectoral–level, and two–digit industries within the manufacturing sector. They confirm the evidence of productivity convergence for the total economy. At the sectoral level, though, the dispersion of labor productivity is found to decline, while no clear trend of convergence in total factor productivity emerges. Intercountry productivity differences are smallest among sectors that produced internationally tradable goods and where technology transfers occurred with relative ease. The two–digit industries of the manufacturing sector show greater dispersion in productivity than has been found at the more aggregated levels. Dollar and Wolff attribute this result to the countries' increased specialization in different industries and the fact that these countries have developed technological leads.

Perelman (1995) investigates productivity growth across eight 2-digit manufacturing industries in a sample of eleven OECD countries, using data drawn from the OECD's International Sectoral Data Base (ISDB). Although productivity convergence is not the main focus of his paper, his results indicate catch–up in only a few of the manufacturing industries in selected countries over the sample period 1970–87.

The study of productivity convergence by Bernard and Jones (1996a,b) results in the finding that the behavior of aggregate and sectoral productivity is rather different. Using the ISDB data set and employing time–series as well as cross–sectional tests, they find, in particular, no evidence of convergence and even some evidence for divergence in the manufacturing sector. Other sectors, like agriculture, services, and utilities, display strong convergence. They conclude that the strong force of convergence in the services sector together with its increasing output share dominates the tendency of divergence in manufacturing and contributes significantly to the convergence of *aggregate* output.

3 Data

The data for this study are taken from the OECD–ISDB, a detailed description of which can be found in Meyer-zu-Schlochtern (1988) and OECD (1995). The 14 countries included in this data set are Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden, the United Kingdom, and the United States. For each country, the ISDB provides complete production data, each 1-digit ISIC industry for the period 1970–90. The nine sectors are agriculture, construction, finance, manufacturing, mining, retail, services, transportation, and utilities (electricity/gas/water). [1]

Output is measured by valued added at constant 1985 prices and purchasing power adjustments. Capital is measured by gross capital stock data for each country and sector. When official capital stock data are not available, estimates have been made using the perpetual inventory method. Labor input is represented by total employment (including self–employment) with no adjustment for quality or hours worked.

4 Sectoral Productivity

The ISDB provides estimates of an index of total factor productivity (TFP), which is constructed in the standard growth accounting tradition. According to this approach, TFP growth is the difference between output growth and the weighted growth of factor inputs. To eliminate a number of problems associated with the use of aggregate factor shares for different industries, labor shares w are computed by country and sector with adjustments made to include self–employment.[2] Using these weights, TFP growth is calculated as

$$\dot{\mathrm{TFP}}/\mathrm{TFP} = \dot{\mathrm{Y}}/\mathrm{Y} - w\,\dot{\mathrm{L}}/\mathrm{L} - (1-w)\,\dot{\mathrm{K}}/\mathrm{K}, \tag{1}$$

with Y referring to value added, L denoting total employment, and K being the gross stock of capital.

The Törnqvist approximation to the Divisia index in equation (1) is constructed with factor shares that are computed under the assumptions of constant returns to scale and perfect competition. Thus, the observed value added is the maximum producible output for the given input

[1] In some sectors the entire sample of countries is not available because of missing data. Thus, some countries have to be deleted from the sectoral analysis. These sectors and countries are finance – Belgium, Germany, Italy, and the Netherlands; mining – Belgium and Italy; retail – Australia, Japan, and the USA; services – the Netherlands; transportation – the Netherlands.

[2] For further discussion, cf. Meyer-zu-Schlochtern (1988).

quantities. This implies that all countries have access to and employ best practice technology. Changes in productivity are then entirely due to technology shifts. The assumption of perfect competition rules out the existence of technical inefficiency, i.e., the possibility that some country–sectors produce value added which is not maximal for the given input quantities. Allowing for the presence of technical inefficiency necessarily introduces the concept of a production frontier. The traditional measure of productivity cannot distinguish between movements of the frontier and movements toward the frontier.

A productivity measure that is capable of making this distinction is the Malmquist index of productivity change. It is constructed in a way that specifically allows for technical inefficiency. Färe et al. (1994) have shown that this index can be decomposed into a measure of technical change and a measure of efficiency change. In this paper, a movement toward or away from the frontier, will be called catch–up and interpreted as technological diffusion.

Caves, Christensen, and Diewert (CCD) (1982) define Malmquist productivity indexes as the ratio of two distance functions. Avoiding the problem of choosing an arbitrary base year, Färe et al. (1994) suggest to construct the Malmquist index of productivity change as the geometric mean of two of these CCD–type indexes. Dropping country–sector subscripts to reduce clutter, this can be written as

$$M(x_{t+1}, y_{t+1}, x_t, y_t) \quad = \quad \left[\left(\frac{D_t(x_{t+1}, y_{t+1})}{D_t(x_t, y_t)} \right) \left(\frac{D_{t+1}(x_{t+1}, y_{t+1})}{D_{t+1}(x_t, y_t)} \right) \right]^{1/2}, \tag{2}$$

where $D_t(\cdot, \cdot)$ is an output distance function and y and x are output and input vectors, respectively. In case of improvements in productivity, the Malmquist index exceeds unity. Deteriorations in productivity translate into Malmquist indexes of less than unity. Note that every sector's distance function is computed relative to the technology of that particular sector, i.e., Germany's manufacturing sector is evaluated relative to the manufacturing sectors of all other countries but not relative to the agricultural sector. To construct the Malmquist index, distance functions have to be computed that compare data across different time periods.

We compare the empirical estimates from these two productivity growth indexes. Panels A and B of table 1 contain the average annual growth rates of TFP for each of the nine sectors over the sample period.[3] Given the absence of inefficiency, one would expect that both measures reach comparable findings. However, if technical efficiency is prevalent, then estimates of TFP growth should be different. A priori, it is not obvious in which direction the Malmquist TFP growth estimates should vary from the Törnqvist estimates.

[3]The index of agricultural productivity is missing from the ISDB.

According to the Törnqvist index, most country–sectors experienced an increase in productivity over the period 1970–90. Every country had positive productivity growth in manufacturing and in transportation; the majority showed increases in productivity in utilities and retail. In contrast to this, most countries showed declining productivity in construction. About half the countries had increasing productivity in finance, mining, and services. An interesting case is the utilities sector in Great Britain. The explanation of the strong productivity growth most certainly lies in the privatization efforts of the conservative government during the 1980s. Other notables are the manufacturing sectors in France and Italy.[4]

Results from the Malmquist index show that there is not a single sector in which average productivity growth has been positive across all countries. Productivity growth rates for the agricultural sector are computed with this approach, and they are mostly positive. With the exception of one country, the utilities and transportation sectors experienced increases in productivity throughout the sample. Services and mining are the sectors that which display mostly decreases in productivity.

Judging from the mean sectoral growth rates of productivity, the results of these two approaches differ in the utilities, manufacturing and services sectors. However, no pattern seems to emerge: the Törnqvist index is mostly larger than the Malmquist index for the manufacturing sector but smaller for the utilities sector. Closer matches are found in mining and transportation, where the majority of TFP growth rates deviate from each other by less than one–third of a percentage point.

Table 2 contains the correlations between the average TFP growth rates of the Malmquist and the Törnqvist indexes. It was to be expected that the correlations are fairly high. Recall that, in the absence of inefficiency, the TFP estimates from the two methods should be very close, with correlations almost unity. The correlations between utilities, manufacturing, and services sectors are 0.78, 0.68, and 0.80, respectively. Compared to other correlations, in particular, mining and transportation, these values seem a little bit too low to justify the argument that there is no real distinction between these productivity growth measures.

It has been mentioned above that the bias introduced into the productivity growth index by neglecting inefficiency cannot be signed ex ante. And the results suggest that this cannot even be done ex post. Apart from the different treatment of efficiency, Färe et al. (1994) point to two other sources of disturbance between the two productivity indexes. Calculation of the Törnqvist index requires the use of factor shares. In case these shares are not the cost–minimizing ones, as assumed by the growth accounting method, its productivity measure is biased. The second difference arises

[4] The result for the mining sector in Denmark appears to be an outlier. However, such a high growth rate of TFP is confirmed by the Malmquist index as well as findings by Bernard and Jones (1996b).

from the concept of multilateral comparisons. In the growth accounting approach, each country is compared to itself in an earlier period, but no common reference point exists for all countries. The Malmquist index explicitly models the common benchmark (cf. Färe et al. (1994), p. 81).

5 Testing for Productivity Convergence

Our approach to productivity convergence is based on the idea that country–sector–level efficiencies exhibit a long–run relationship. If so, measured efficiencies should be cointegrated. Then, among countries with cointegrated efficiency series, laggards may catch up or converge to the frontier, ostensibly through technological diffusion.

The analysis proceeds in three stages.[5] First, we compute country–sector efficiency series using data envelopment analysis (DEA), which involves solving linear programs corresponding to the underlying distance functions. Second, we conduct unit–root tests on each efficiency series for the purpose of identifying candidates for long–run comovements. Then, we examine whether long–run relationships exist between the integrated efficiency series by applying standard cointegration tests. Finally, we estimate convergence regressions and examine coefficients of variation to determine if cointegrated country–sectors are becoming more similar in terms of efficiency.

5.1 Construction of Efficiency Series

To compute country–sector efficiencies using DEA, we solve linear programs for a constant returns to scale technology of the following variety

$$\begin{aligned} (D_t(x_{it}, y_{it}))^{-1} &= \max_{\lambda, z} \lambda \\ \text{s.t.} \quad \lambda y_{it}^k &\leq \sum_{i=1}^{N} z_i y_{it}^k, \qquad k = 1, 2, \ldots, K, \\ \sum_{i=1}^{N} z_i x_{it}^l &\leq x_{it}^l, \qquad l = 1, 2, \ldots, L, \\ z_i &\geq 0, \qquad i = 1, 2, \ldots, N, \end{aligned} \tag{3}$$

where y_{it}^k denotes output k of country–sector i in period t, x_{it}^l, denotes input l of country–sector i in period t, and the vector z contains intensity variables. As pointed out in Färe et al. (1994), the inverse of the Farrell (1957) output measure of technical efficiency is the output distance function.

[5] A similar approach was employed by Alam and Sickles (1995) to examine productivity convergence in the US airline industry.

5.2 Unit–Root Tests

After having constructed the technical efficiency series for each country–sector, the second step of our analysis consists of conducting unit–root tests. The unit–root inference is the basis for subsequent cointegration tests of long–run relationships between integrated series.

The interpretation of unit–root tests in this context is somewhat problematic. Recall that the efficiency levels are bounded by zero and unity. Hence, they can never diverge to infinity, which is what the presence of a unit root would suggest. In addition, unit roots represent a "razor's edge" problem. Nevertheless, failure to reject the unit–root null hypothesis can be interpreted as an indication of "persistence." From this point of view, a stochastic trend can be followed as an "as if" proposition.

The simplest and most widely used test for unit–root nonstationarity is the Dickey–Fuller (DF) (1979) test. Depending on the assumptions about the data–generating process of the efficiency levels, several different test regressions are available. In section 6.2, we report results from the regression

$$\Delta \mathrm{TE}_{it} \quad = \quad (\alpha - 1)\mathrm{TE}_{i,t-1} + \omega_{it}, \qquad (4)$$

where TE denotes the efficiency level series and ω_{it} is white noise. The usual DF test statistic is just the t–ratio corresponding to the coefficient of $\mathrm{TE}_{i,t-1}$.[6]

Since DF tests are characterized by low power in distinguishing root that are close (and even not so close) to unity from ones that are exactly unity, we also perform the unit–root test proposed by Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) (1992), which contrasts the stationarity null with a unit–root alternative. Stationarity means either level or trend stationarity, which can be tested for separately. Testing for level stationarity requires the residuals from a regression of the efficiency levels on a constant. Testing for trend stationarity requires the residuals from a regression of the efficiency levels on a constant and a time trend. Assuming that the errors in these auxiliary regressions are iid,[7] the test statistic is constructed as

$$\mathrm{LM} \quad = \quad \frac{1}{T^2}\sum_{t=1}^{T} S_t^2/\hat{\sigma}_\epsilon^2 \qquad (5)$$

where $S_t = \sum_{t=1}^{T} e_t, t = 1, \ldots, T$ and $\hat{\sigma}_\epsilon^2 = \frac{1}{T}\sum_{t=1}^{T}(e_t - \bar{e})^2$.

[6] Test outcomes from regressions including drift only and drift and time trend are consistent with findings from equation (4).

[7] If the iid assumption about the errors is relaxed, the estimator of the variance is replaced by a consistent estimator of the long–run variance. This is the version of the test we employ.

5.3 Cointegration Tests

If a linear combination of two or more nonstationary series is stationary, then these series are said to be cointegrated. This means that even though each series diverges from its mean as time passes, the series move together in the long run. Therefore, cointegration between economic time series is often interpreted as indicating a long–run equilibrium relationship.

We conduct two distinct cointegration tests: the Engle–Granger (1987) test and the Johansen (1991) test. We employ the former because its simplicity permits straightforward tests for cointegrating relationships between all country pairs. The latter has the advantage of being invariant to normalization and can reveal cointegrating relationships between more than two variables. However, because of data limitations, we opted to apply the Johansen test to two subsets of countries: the G–7 and European Union.

To implement the Engle–Granger test, we first regress, for each individual sector, the efficiency series of country i on that of country j:[8]

$$\mathrm{TE}_{it} = \beta_0 + \eta \mathrm{TE}_{jt} + v_t, \tag{6}$$

where v_t is a random disturbance. These two efficiency series can be regarded as cointegrated if the residuals from (6) are stationary. Thus, the null of no cointegration is tested by determining whether the $\hat{v}_t$ have a unit root, which involves estimating the test regression,

$$\Delta \hat{v}_t = (\alpha - 1)\hat{v}_{t-1} + \epsilon_t, \tag{7}$$

and applying a residual–based unit–root test.

In contrast, Johansen's test takes a full-information maximum likelihood (FIML) approach to the problem. Following Johansen, we specify a VAR in the country-sector efficiency series (either G–7 or EU as noted earlier), which we express in levels as

$$\mathbf{TE}_t = \boldsymbol{\pi}_0 + \boldsymbol{\pi}_1 \mathbf{TE}_{t-1} + \boldsymbol{\pi}_2 \mathbf{TE}_{t-2} + \boldsymbol{\epsilon}_t, \tag{8}$$

where $\mathbf{TE}_t$ is a vector containing the period t efficiency level for each country–sector and $\boldsymbol{\epsilon}_t$ is a zero-mean random vector with $E(\boldsymbol{\epsilon}_t\ \boldsymbol{\epsilon}_s') = \boldsymbol{\Omega}$, $\forall t = s$ and zero, otherwise.[9] More convenient is the formulation in differences:

$$\boldsymbol{\Delta}\mathbf{TE}_t = \boldsymbol{\pi}_0 + \boldsymbol{\xi}_1 \boldsymbol{\Delta}\mathbf{TE}_{t-1} + \boldsymbol{\xi}_0 \mathbf{TE}_{t-1} + \boldsymbol{\epsilon}_t \tag{9}$$

[8] Including a time trend had no impact on the results.

[9] We found a lag length of 2 was sufficient to capture the system dynamics.

where $\boldsymbol{\xi}_1 = -\,\boldsymbol{\pi}_2$ and $\boldsymbol{\xi}_0 = \boldsymbol{\pi}_1 + \boldsymbol{\pi}_2 - \boldsymbol{I}$ determines the extent to which the system is cointegrated.

To construct the test statistic, we estimate two sets of auxiliary regressions,

$$\Delta \mathrm{TE}_{it} = \Pi_0 + \boldsymbol{\Pi}_1 \boldsymbol{\Delta}\mathbf{TE}_{t-1} + u_{it}, \tag{10}$$

$$\mathrm{TE}_{i,t-1} = \Theta_0 + \boldsymbol{\Theta}_1 \boldsymbol{\Delta}\mathbf{TE}_{t-1} + v_{it}, \tag{11}$$

for each country–sector separately by OLS. These regressions serve to concentrate the likelihood function about $\boldsymbol{\xi}_0$ and $\boldsymbol{\Omega}$. The concentrated likelihood depends on the canonical correlations between u_t and v_t, which we calculate from the eigenvalues $(\hat{\lambda}_1 > \hat{\lambda}_2 > \cdots > \hat{\lambda}_n)$ of

$$\hat{\boldsymbol{\Sigma}}_{vv}^{-1} \hat{\boldsymbol{\Sigma}}_{vu} \hat{\boldsymbol{\Sigma}}_{uu}^{-1} \hat{\boldsymbol{\Sigma}}_{uv}, \tag{12}$$

where

$$\hat{\boldsymbol{\Sigma}}_{vv} = \frac{1}{T}\sum_{t=1}^{T} \hat{\boldsymbol{v}}_t \hat{\boldsymbol{v}}_t', \qquad \hat{\boldsymbol{\Sigma}}_{uu} = \frac{1}{T}\sum_{t=1}^{T} \hat{\boldsymbol{u}}_t \hat{\boldsymbol{u}}_t',$$
$$\hat{\boldsymbol{\Sigma}}_{uv} = \frac{1}{T}\sum_{t=1}^{T} \hat{\boldsymbol{u}}_t \hat{\boldsymbol{v}}_t', \qquad \hat{\boldsymbol{\Sigma}}_{vu} = \frac{1}{T}\sum_{t=1}^{T} \hat{\boldsymbol{v}}_t \hat{\boldsymbol{u}}_t'$$

and the $\hat{\boldsymbol{u}}_t$ and $\hat{\boldsymbol{v}}_t$ are the residual vectors from the auxiliary regressions. This yields two likelihood–ratio test statistics:

$$\text{trace} = -T \sum_{i=r+1}^{n} \ln(1-\hat{\lambda}_i)$$
$$\text{maximum eigenvalue} = -T \ln(1-\hat{\lambda}_{r+1}).$$

The former is referred to as the trace test and contrasts the null of exactly r cointegrating relations with an alternative of n (i.e., that $\boldsymbol{\xi}_0$ is of full rank, if n is the number of elements in $\mathbf{TE}_t$). The latter is called the maximum eigenvalue test since it compares the r cointegrating relations null with an $r+1$ alternative. We report the outcomes of both tests.

5.4 Convergence Regressions

The presence of cointegration indicates a long–run relationship between the efficiency series. However, this does not necessarily imply *convergence* of efficiency levels. To investigate the convergence aspect, we run simple cross–section regressions of time–averaged efficiency growth rates on the initial level of efficiency:

$$\mathrm{GRTE7090}_i = \alpha + \beta\, \mathrm{TE}_{i,1970} + \epsilon_i \tag{13}$$

where GRTE7090_i denotes the average growth rate of the efficiency level of each individual sector in country i between 1970 and 1990; and $\text{TE}_{i,1970}$ is the level of efficiency of country i in the same sector in 1970. In the tradition of Baumol and Barro (1991), a negative and statistically significant coefficient on the initial level of efficiency can be interpreted as indicating convergence of efficiency levels.

However, Quah (1993, 1996), among others, criticizes such regressions on the grounds that they are plagued by Galton's "regression-to-the-mean" fallacy. We address this criticism by calculating coefficients of variation in the efficiency series along with the regression coefficients.

6 Application to Industry Data

In this section, the methodology outlined above is applied to the nine 1-digit ISIC industries of 14 OECD countries observed from 1970–90.

6.1 Computation of Efficiency Series

In the first step of our analysis, we construct efficiency series for each country and every sector by solving the linear program in equation (3). We chose to use a constant returns to scale model, because it appeared reasonable to us to assume that, in this sample of OECD countries, industries are matured and thus have exhausted all available scale economies. The country–sector efficiencies are constrained to the unit interval. A value of unity implies that a country–sector is on the frontier in that particular year, i.e., output cannot be increased any further with the existing amount of inputs. Table 3 indicates which country represents best–practice in any given year and sector. In most years, more than one country represents best–practice. However, there appears to be a rather stable group of countries that defines the technology–frontier in each sector, e.g., Italy in utilities and France and the Netherlands in mining.

6.2 Unit–Root Tests

The results of the DF tests indicate that in the vast majority of cases we cannot reject the null hypothesis of a unit–root. Minor exceptions are found in the agriculture, manufacturing, mining, and transportation sectors. Serial correlation in the error terms of the test regressions would render this form of the test invalid. Thus, we test for nonspherical disturbances employing the Box–Pierce test.

We fail to find any sign of autocorrelation in the efficiency series of construction, retail, and utilities sector. France, Germany, and Great Britain exhibit some autocorrelation in agriculture; Belgium and Great Britain in manufacturing; the USA in mining; Japan and Sweden in services; and Great Britain in transportation. Despite these occurrences of serial correlation, application of the augmented Dickey–Fuller (ADF) tests to these sectors with autocorrelated residuals does not change the conclusions based on DF tests.

Serial dependence appears to be more of a problem in the financial sector. The countries showing signs of serial correlation are Australia, France, Finland, Sweden, and the USA. But, similar to other sectors, estimation of ADF test regressions does not lead to rejection of the null hypothesis of a unit root.

As discussed previously, these tests suffer from lack of power. Thus, it might not be the presence of unit roots but rather the problem of the tests distinguishing between unit and stable roots that brings about these results. Thus, we decided not to rely too heavily on the results obtained using these tests. Instead, we will mainly rely on the results from the KPSS test, which puts the stationarity assumption into the null hypothesis.

To account for weak evidence of autocorrelation, we employ the KPSS test using the consistent estimator of the long–run variance with one lag. We test the null hypothesis of level stationarity against the alternative of a unit root. Results from the KPSS test present a more differentiated picture in that there is more evidence against the presence of unit roots than has been found in the DF and ADF tests. Table 4 contains, as a summary statement, the countries that have been found to exhibit unit roots in their efficiency series of particular sectors. These conclusions are based on findings of the DF (or ADF) and the KPSS tests, with more emphasis being given to results of the latter.

6.3 Cointegration Tests

Our cointegration empirics are focused on those country–sectors for which the DF and KPSS tests reinforce each other. For the EG test, the basic model of equation (6) is estimated. This model is estimated twice, once with every efficiency series as the regressor and once as the regressand. Using the residuals from these regressions, we construct the test regressions given in equation (7).

The evidence for cointegration varies dramatically from sector to sector.[10] Tables 5 and 6 summarize our findings for the two subsets of countries.[11] In agriculture, the null hypothesis of no cointegration can be rejected for the vast majority of country pairs. This is true not only for EU countries but also for G–7 members. Support for the cointegration alternative is much weaker in all other sectors. In the construction sector, we find relationships between the USA and Germany, Germany and Belgium, and Italy and Belgium.[12] In finance, manufacturing, and services, evidence of cointegration is either completely absent or very weak. In the mining sector, there is no sign of cointegration among the countries of either subset. However, the USA and Finland as well as Australia and Denmark seem to exhibit a long–run relationship. Compared to these sectors, evidence in the retail sector for EU countries is rather plentiful. Belgium seems to be cointegrated with France, the UK, the Netherlands, Denmark, Sweden, and Finland. In addition, the same seems to hold for the Netherlands and Denmark. In the transportation sector, we can reject the no cointegration null hypothesis for Canada and Japan and Canada and Australia.

To create a benchmark against which to gauge the findings from the bivariate Engle–Granger test, we apply to the data the FIML approach introduced by Johansen. Tables 7 and 8 contain the test statistics for trace and maximum eigenvalue tests. Results for G–7 countries are discussed first. In construction, services, and utilities, there is ample support for the cointegration hypothesis. Contrary to that, the manufacturing sector shows virtually no sign of a long–run relationship. In the other sectors, there seems to be a small number of cointegrating relationships between the countries' efficiency levels.

While the assessment for the G–7 countries is rather cautious, results for the various combinations of EU countries emphatically indicate the presence of strong long–run relationships. Our results show that agriculture, construction, retail, services, and utilities exhibit the maximum number of cointegrating relationships, a result not found for the G–7. Even the manufacturing sector displays two long–run relationships according to the two test statistics. The results suggest that there is a great deal of long–run comovement among the efficiencies of the EU member countries. However, this cannot be concluded for the G–7 group, indicating that catch–up is

[10] There is almost no evidence of serial dependence in the residuals of the Engle–Granger test regressions. Thus, we decided to rely on the simple specification of these regressions and not include any further lagged differences in the residuals.

[11] Detailed results are available upon request.

[12] The results discussed here only refer to countries that exhibit cointegration in "both directions." By this, we mean that the regression of country i on country j indicates cointegration, as does the regression of country j on country i.

more prevalent in the European Union. These results confirm our previous findings regarding the behavior of efficiency estimates on the aggregate level (see Cornwell and Wächter (1998a)).

Since two different cointegration tests have been employed, a brief comparison of their respective results seems in order. Across most sectors in either subset of countries, the Johansen test yields stronger evidence of cointegration than the Engle–Granger test. The major discrepancies for both subsamples are in construction, services, and utilities, where the EG test indicates very little or no cointegration and the Johansen test suggests just the opposite. It appears that the full information approach picks up relationships between the efficiencies of several countries that the bivariate approach cannot. Despite these discrepancies, closer matches are to be found in agriculture (for G–7 and EU), manufacturing (G–7), mining (G–7), retail (G–7 and EU), and transportation (G–7). In agriculture, both tests suggest the presence of several long–run relationships. In the other four sectors, it is the absence of such a relationship that is responsible for the congruent result.

6.4 Convergence Regressions

The emphasis in the previous subsection has been on the comovement between the efficiency series of different country–sectors. Now, we will turn our attention to the question of convergence. Do the country–sector efficiency series that have been found to be I(1) display signs of convergence over the 21 years of the sample? To answer this question, we estimate cross–section convergence regressions for each individual sector and examine coefficients of variation.[13] Results of the full sample regressions for the nine sectors can be found in table 9. In addition, coefficients of variation are displayed in figures 1 and 2.

Every sector except finance and services displays strong evidence of convergence for the entire sample of countries. All slope coefficients have the negative sign. The time-series graphs of the coefficients of variation lead to similar conclusions. Despite the fairly small sample sizes, the fit of these models is remarkable. The speed of catch–up for converging industries ranges between 2 and 5 per cent.

Our finding of catch–up in agriculture and utilities corroborates the results of Bernard and Jones. Regarding services, we have chosen to deviate from their treatment of this sector by not aggregating the sectors finance, retail, transportation, and other services into overall services. As it turns out, this aggregation hides the lack of catch–up in finance and other services. One explanation

[13] The regressions are also estimated for the G–7 and EU subsamples, which are restricted to the countries whose efficiency series are I(1). Because the already small sample sizes are reduced even further in these regressions, we decided not to include the results here.

for the lack of catch–up in these 1-digit industries might be the introduction of new technologies and subsequent adoption cost. Especially financial services have experienced a dramatic change in how it conducts its business nowadays. Another explanation, suggested by Baily and Gordon (1988), are measurement problems, a phenomenon particularly prevalent in the service sector.

Our result of catch–up in manufacturing represents an interesting deviation from the results of Bernard and Jones, who fail to find evidence for productivity convergence. Additional evidence (e.g., Cornwell and Wächter (1998b)) in conjunction with this finding suggests that increased specialization on a more disaggregated level within manufacturing is the most promising explanation.

7 Conclusions

The purpose of this paper was to contribute to the debate on the convergence hypothesis by moving the discussion away from the aggregate level and toward the sectoral level. We developed a methodology to investigate sectoral productivity that distinguishes catch–up, interpreted as technological diffusion, from shifts in best-practice.

The results suggest that comovements in efficiency–levels are concentrated among the countries of the EU but not among the G–7. It is further found that catch–up occurs in all sectors except finance and services. Even the manufacturing sector displays catch–up despite opposite findings by Bernard and Jones.

Returning to the questions in the Introduction, we reach several conclusions. First, the forces of convergence have not exhausted themselves and catch–up is an important contributor to this ongoing phenomenon. Second, catch–up does not occur uniformly across sectors, thereby masking specific convergence trends at the aggregate–economy level. Third, we have taken account for the moving–target nature of the production frontier and thus shown that laggards are catching up, despite the leaders' continuous efforts to push the frontier outward.

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Figure 1: CVs of Efficiency Levels of Sectors: CST, FIN, MAN, RET, TRS

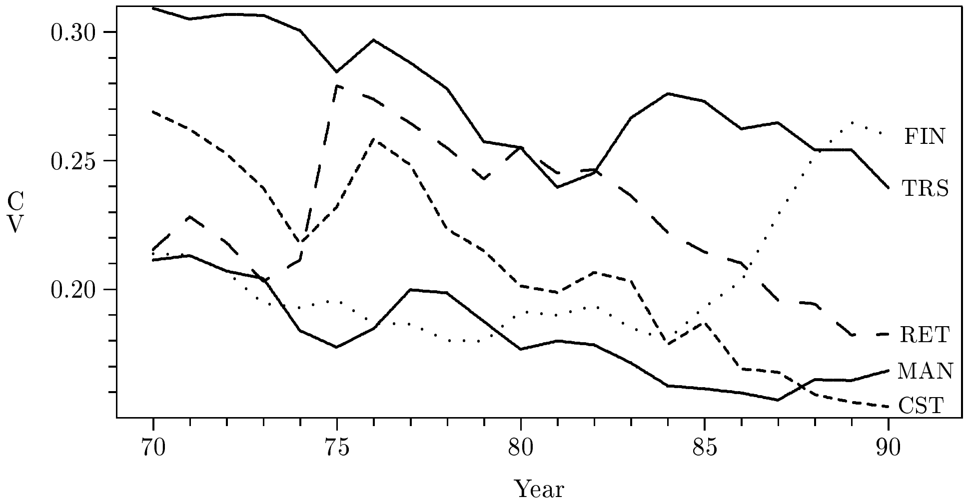
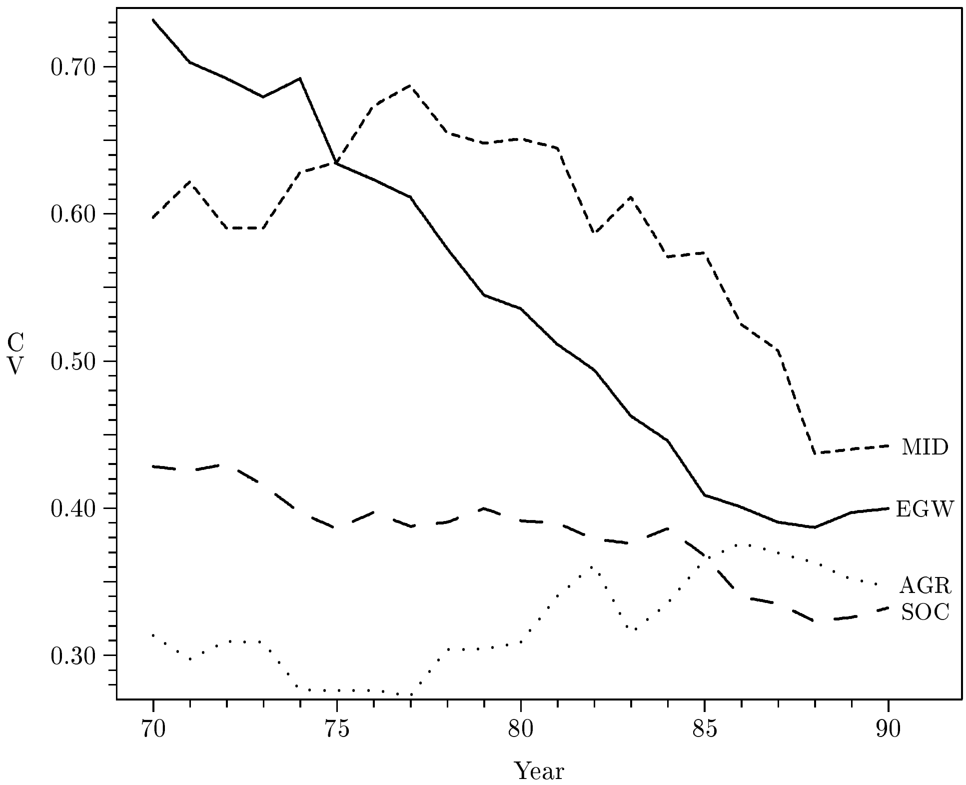


Figure 2: CVs of Efficiency Levels of Sectors: AGR, EGW, MID, SOC



Note: Sectors: AGR – Agriculture, CST – Construction, EGW – Utilities, FNI – Finance, MAN – Manufacturing, MID – Mining, RET – Retail, SOC – Services, TRS – Transportation.

Table 1: Average Annual Productivity Growth

Panel A: Productivity Growth Computed by Törnqvist Index

	Sector								
Country	AGR	CST	EGW	FNI	MAN	MID	RET	SOC	TRS
USA	n.a.	−1.4	−0.1	0.0	1.4	−1.7	n.a.	−0.7	2.4
CAN	n.a.	0.1	−0.1	0.2	1.0	−3.1	0.3	0.3	2.7
JPN	n.a.	−0.7	−0.7	−0.1	2.3	−0.2	n.a.	−1.8	1.1
DEU	n.a.	1.0	0.9	n.a.	1.4	−3.6	0.8	0.1	2.1
FRA	n.a.	0.8	3.4	1.0	1.9	−2.0	0.2	1.7	2.8
ITA	n.a.	−0.2	−1.8	n.a.	3.0	n.a.	0.6	−1.0	1.5
GBR	n.a.	−0.1	4.2	−0.4	1.7	0.9	−0.2	−0.1	2.5
AUS	n.a.	−0.4	2.5	−0.5	1.3	0.2	n.a.	−0.1	2.6
NLD	n.a.	−0.4	1.2	n.a.	2.4	0.1	1.8	n.a.	n.a.
BEL	n.a.	1.2	3.0	n.a.	4.1	n.a.	1.3	0.6	1.3
DNK	n.a.	−1.2	1.9	0.5	1.4	12.5	1.6	−0.1	0.9
NOR	n.a.	−1.6	1.0	−1.4	0.6	5.5	−0.3	−1.1	3.5
SWE	n.a.	1.3	3.1	−0.3	1.4	−1.2	0.5	0.5	2.8
FIN	n.a.	1.3	1.2	0.3	2.4	3.1	2.0	1.2	2.3
Avg	n.a.	−0.0	1.4	−0.1	1.9	0.9	0.8	−0.0	2.2

Note: All growth rates are expressed in per cent. Sectors: AGR – Agriculture, CST – Construction, EGW – Utilities, FNI – Finance, MAN – Manufacturing, MID – Mining, RET – Retail, SOC – Services, TRS – Transportation. Agriculture productivity index is missing from ISDB. Countries: AUS – Australia, BEL – Belgium, CAN – Canada, DEU – Germany, DNK – Denmark, FIN – Finland, FRA – France, GBR – Great Britain, ITA – Italy, JPN – Japan, NLD – Netherlands, NOR – Norway, SWE – Sweden, USA – USA.

Panel A: All growth rates are expressed in per cent. The average productivity growth is computed as the arithmetic mean of annual growth rates of the Törnqvist productivity index.

Table 2: Correlations between Average Annual Productivity Growth Rates of Törnqvist and Malmquist Indexes

	Sector								
	AGR	CST	EGW	FNI	MAN	MID	RET	SOC	TRS
Correlation	n.a.	0.79	0.78	0.81	0.68	0.98	0.91	0.80	0.93

Note: Own computations. Sectors: AGR – Agriculture, CST – Construction, EGW – Utilities, FNI – Finance, MAN – Manufacturing, MID – Mining, RET – Retail, SOC – Services, TRS – Transportation.

Table 1: continued

Panel B: Productivity Growth Computed by Malmquist Index

	Sector								
Country	AGR	CST	EGW	FNI	MAN	MID	RET	SOC	TRS
USA	2.3	−1.7	0.9	−0.4	1.4	−2.0	n.a.	−1.6	2.6
CAN	1.4	−0.5	2.1	0.1	0.2	−4.0	0.1	0.2	2.8
JPN	−5.4	−3.9	0.2	0.0	−1.2	0.1	n.a.	−6.5	−0.2
DEU	5.1	0.7	3.2	n.a.	0.1	−3.9	1.3	1.3	2.3
FRA	−0.1	1.1	4.9	0.5	0.6	−2.1	1.0	0.2	3.0
ITA	−1.6	0.0	−1.3	n.a.	2.2	n.a.	0.2	−1.2	1.6
GBR	2.7	0.1	3.3	0.0	−0.1	−0.3	−1.1	−0.9	1.9
AUS	2.2	0.1	4.5	−0.1	0.2	−1.0	n.a.	−0.9	2.9
NLD	4.4	0.1	0.3	n.a.	3.7	1.2	2.5	n.a.	n.a.
BEL	1.5	1.6	1.8	n.a.	2.8	n.a.	1.3	0.6	1.1
DNK	5.6	−1.1	3.8	−0.3	−0.1	10.9	2.8	−1.9	0.9
NOR	3.4	−1.6	2.2	−1.6	−1.2	3.5	−1.8	−4.6	3.8
SWE	3.0	1.5	4.7	−0.5	0.1	−1.6	−1.1	−1.3	2.9
FIN	3.2	1.4	2.7	0.3	2.0	2.8	3.0	2.1	2.6
Avg	1.9	−0.2	2.4	−0.2	0.8	0.2	0.7	−1.1	2.2

Note: All growth rates are expressed in per cent. Sectors: AGR – Agriculture, CST – Construction, EGW – Utilities, FNI – Finance, MAN – Manufacturing, MID – Mining, RET – Retail, SOC – Services, TRS – Transportation. Agriculture productivity index is missing from ISDB.
Countries: AUS – Australia, BEL – Belgium, CAN – Canada, DEU – Germany, DNK – Denmark, FIN – Finland, FRA – France, GBR – Great Britain, ITA – Italy, JPN – Japan, NLD – Netherlands, NOR – Norway, SWE – Sweden, USA – USA.
Panel B: The average productivity growth over the entire sample period is computed as the geometric mean of the year-by-year Malmquist productivity growth indexes in equation (2).

Table 3: Annual Best-Practice Country-Sector

	Sector			
Year	AGR	CST	FNI	MAN
1970	BEL JPN USA	JPN USA	JPN USA	DEU JPN USA
1971	BEL USA	JPN USA	JPN USA	DEU JPN USA
1972	BEL USA	JPN USA	JPN USA	JPN USA
1973	BEL USA	JPN USA	JPN USA	JPN USA
1974	BEL USA	CAN JPN USA	JPN USA	DEU JPN USA
1975	BEL USA	CAN JPN USA	JPN USA	DEU USA
1976	BEL USA	CAN JPN USA	JPN USA	DEU USA
1977	BEL USA	CAN USA	JPN USA	DEU USA
1978	BEL USA	CAN JPN USA	JPN USA	DEU USA
1979	BEL FRA NLD USA	CAN JPN USA	JPN USA	DEU USA
1980	BEL	CAN USA	JPN USA	DEU FRA USA
1981	BEL NLD USA	CAN	JPN USA	DEU FRA USA
1982	BEL FRA NLD	CAN	JPN USA	DEU FRA USA
1983	BEL FRA NLD	CAN	JPN USA	DEU FRA USA
1984	BEL NLD	CAN	JPN	DEU USA
1985	BEL USA	CAN	JPN	DEU USA
1985	BEL USA	CAN	JPN	DEU USA
1987	BEL FRA USA	CAN	JPN	DEU USA
1988	BEL FRA	CAN	JPN	DEU USA
1989	BEL FRA USA	CAN	JPN	DEU USA
1990	BEL FRA NLD USA	CAN GBR	JPN	DEU USA

Note: Sectors: AGR – Agriculture, CST – Construction, FNI – Finance, MAN – Manufacturing. Countries: BEL – Belgium, CAN – Canada, DEU – Germany, FRA – France, GBR – Great Britain, JPN – Japan, NLD – Netherlands, USA – USA.

Table 3: continued

	Sector				
Year	MID	RET	SOC	TRS	EGW
1970	FRA NLD	CAN FRA	ITA JPN	BEL JPN USA	ITA
1971	FRA NLD	CAN FRA	ITA JPN	BEL JPN USA	ITA
1972	FRA NLD	CAN FRA	ITA JPN	BEL JPN USA	ITA
1973	FRA NLD	CAN FRA	ITA JPN	BEL GBR USA	ITA
1974	FRA NLD	CAN FRA	ITA JPN	BEL GBR JPN USA	ITA
1975	FRA NLD	BEL CAN	ITA JPN	BEL JPN USA	ITA
1976	FRA NLD	BEL CAN	ITA JPN	BEL GBR JPN USA	ITA
1977	FRA NLD	BEL CAN	ITA JPN	BEL GBR USA	ITA
1978	FRA NLD	BEL CAN	ITA JPN	BEL GBR USA	ITA
1979	FRA NLD	BEL CAN	ITA JPN	BEL GBR USA	ITA
1980	FRA NLD	BEL CAN	ITA JPN	BEL GBR USA	ITA
1981	FRA NLD	BEL CAN	ITA JPN	BEL GBR USA	ITA
1982	FRA NLD	BEL CAN	ITA JPN	BEL GBR USA	ITA
1983	FRA NLD	BEL CAN	ITA JPN	GBR USA	ITA
1984	FRA NLD	BEL CAN	ITA JPN	GBR USA	ITA
1985	FRA NLD	BEL CAN	ITA JPN	GBR USA	ITA
1985	FRA NLD	BEL CAN	ITA	GBR USA	ITA
1987	FRA NLD	BEL CAN	ITA	GBR USA	ITA
1988	FRA NLD	BEL CAN	ITA	GBR USA	ITA
1989	FRA NLD	BEL CAN	ITA	GBR USA	ITA
1990	FRA NLD	BEL CAN	ITA	GBR USA	ITA

Note: Sectors: MID – Mining, RET – Retail, SOC – Services, TRS – Transportation, EGW – Utilities.
Countries: BEL – Belgium, CAN – Canada, FRA – France, GBR – Great Britain, ITA – Italy, JPN – Japan, NLD – Netherlands, USA – USA.

Table 4: Sectors and Countries with Unit Roots in the Efficiency Series

	Sector								
Country	AGR	CST	EGW	FNI	MAN	MID	RET	SOC	TRS
USA		x	x	x		x		x	
CAN	x	x	x	x	x	x			x
JPN	x	x	x		x	x		x	x
DEU	x	x	x				x	x	x
FRA	x	x	x				x	x	x
ITA	x	x			x		x		x
GBR	x	x	x	x	x	x	x	x	
AUS	x	x	x			x		x	x
NLD	x	x	x		x		x		
BEL		x	x		x		x	x	x
DNK	x	x	x	x		x	x	x	x
NOR	x	x	x	x	x	x	x	x	x
SWE	x	x	x			x	x	x	x
FIN	x	x	x	x	x	x	x	x	
Number	12	14	13	6	8	9	10	11	10

Note: The significance level for Dickey-Fuller and Kwiatkowski et al. tests is 5%.
Sectors: AGR – Agriculture, CST – Construction, EGW – Utilities, FNI – Finance, MAN – Manufacturing, MID – Mining, RET – Retail, SOC – Services, TRS – Transportation.
Countries: AUS – Australia, BEL – Belgium, CAN – Canada, DEU – Germany, DNK – Denmark, FIN – Finland, FRA – France, GBR – Great Britain, ITA – Italy, JPN – Japan, NLD – Netherlands, NOR – Norway, SWE – Sweden, USA – USA.

Table 5: Results from Engle-Granger Cointegration Tests; Countries: G-7

Sector: Agriculture

G-7

Dependent Variable	Independent Variable CAN	JPN	DEU	FRA	ITA	GBR
Canada				**	**	
Japan				**		
Germany	*				**	
France	**	**	**		**	**
Italy	**		**	**		
Great Britain	**	**	**	**	**	

Sector: Construction

G-7

Dependent Variable	Independent Variable USA	CAN	JPN	DEU	FRA	ITA	GBR
USA			*	*			
Canada	**		**	**	**	**	**
Japan							
Germany	*		**			*	
France							
Italy							
Great Britain							

Sector: Finance

G-7

Dependent Variable	Independent Variable USA	CAN	GBR
USA			
Canada			
Great Britain	**	**	

Note: ** denotes significance at 5% level, * at 10% level. Entries in each panel refer to country-pairs that exhibit cointegration. For further details, refer to the text.

Table 5: continued

Sector: Manufacturing				
G-7				
Dependent	Independent Variable			
Variable	CAN	JPN	ITA	GBR
Canada		*		
Japan				
Italy				
Great Britain				

Sector: Mining				
G-7				
Dependent	Independent Variable			
Variable	USA	CAN	JPN	GBR
USA		**	**	**
Canada				
Japan				
Great Britain				

Sector: Retail				
G-7				
Dependent	Independent Variable			
Variable	DEU	FRA	ITA	GBR
Germany				
France				*
Italy				
Great Britain				

Note: ** denotes significance at 5% level, * at 10% level. Entries in each panel refer to country-pairs that exhibit cointegration. For further details, refer to the text.

Table 5: continued

Sector: Services

G-7

Dependent Variable	Independent Variable USA	JPN	DEU	FRA	GBR
USA					
Japan					
Germany					
France					
Great Britain					

Sector: Transportation

G-7

Dependent Variable	Independent Variable CAN	JPN	DEU	FRA	ITA
Canada		**			*
Japan	**				
Germany					
France					
Italy					

Sector: Utilities

G-7

Dependent Variable	Independent Variable USA	CAN	JPN	DEU	FRA	GBR
USA						
Canada						
Japan						
Germany						
France		*				*
Great Britain		*			*	

Note: ** denotes significance at 5% level, * at 10% level. Entries in each panel refer to country-pairs that exhibit cointegration. For further details, refer to the text.

Table 6: Results from Engle-Granger Cointegration Tests; Countries: EU

Sector: Agriculture

EU

Dependent Variable	Independent Variable DEU	FRA	ITA	GBR	NLD	DNK	SWE	FIN
Germany			**		**			*
France	**		**	**	**	**	**	**
Italy	**	**			**			*
Great Britain	**	**	**		**	**	**	**
Netherlands	*							
Denmark	**	**	**	**	**		**	**
Sweden								
Finland								

Sector: Construction

EU

Dependent Variable	Independent Variable DEU	FRA	ITA	GBR	NLD	BEL	DNK	SWE	FIN
Germany			*			**			**
France									
Italy						*			
Great Britain									
Netherlands									
Belgium	**		**						**
Denmark									
Sweden									
Finland			*			**			

Sector: Finance

EU

Dependent Variable	Independent Variable GBR	DNK	FIN
Great Britain			**
Denmark			
Finland			

Note: ** denotes significance at 5% level, * at 10% level. Entries in each panel refer to country-pairs that exhibit cointegration. For further details, refer to the text.

Table 6: continued

Sector: Manufacturing

EU

Dependent Variable	Independent Variable ITA	GBR	NLD	BEL	FIN
Italy		*			
Great Britain					
Netherlands					
Belgium					
Finland					

Sector: Mining

EU

Dependent Variable	Independent Variable GBR	DNK	SWE	FIN
Great Britain				
Denmark				
Sweden				
Finland				

Sector: Retail

EU

Dependent Variable	Independent Variable DEU	FRA	ITA	GBR	NLD	BEL	DNK	SWE	FIN
Germany									
France				*		**			
Italy									
Great Britain						*			
Netherlands						**	**		
Belgium		**		**	*		**	**	**
Denmark		**			**	**			
Sweden				*		**			**
Finland						**			

Note: ** denotes significance at 5% level, * at 10% level. Entries in each panel refer to country-pairs that exhibit cointegration. For further details, refer to the text.

Table 6: continued

Sector: Services

EU

Dependent Variable	Independent Variable: DEU	FRA	GBR	BEL	DNK	SWE	FIN
Germany							
France				**			
Great Britain							
Belgium					*		
Denmark							
Sweden				**			
Finland							

Sector: Transportation

EU

Dependent Variable	Independent Variable: DEU	FRA	ITA	BEL	DNK	SWE
Germany						
France						
Italy						
Belgium						
Denmark				*		
Sweden						

Sector: Utilities

EU

Dependent Variable	Independent Variable: DEU	FRA	GBR	NLD	BEL	DNK	SWE	FIN
Germany								
France			*			*		
Great Britain		*						
Netherlands						*		
Belgium	*			*				
Denmark		**	*					
Sweden								
Finland								

Note: ** denotes significance at 5% level, * at 10% level. Entries in each panel refer to country-pairs that exhibit cointegration. For further details, refer to the text.

Table 7: Results from Johansen Cointegration Tests; Countries: G-7

Sector: Agriculture

G-7: CAN, JPN, DEU, FRA, ITA, GBR

Eigen-values	Trace Test H_0 vs. H_1	Statistic	Max. EV Test H_0 vs. H_1	Statistic
0.9866	$r = 0$ vs. $r = 6$	169.03**	$r = 0$ vs. $r = 1$	81.98**
0.8771	$r \leq 1$ vs. $r = 6$	87.05**	$r = 1$ vs. $r = 2$	39.82**
0.7541	$r \leq 2$ vs. $r = 6$	47.23**	$r = 2$ vs. $r = 3$	26.65*
0.4233	$r \leq 3$ vs. $r = 6$	20.58	$r = 3$ vs. $r = 4$	10.46
0.2689	$r \leq 4$ vs. $r = 6$	10.12	$r = 4$ vs. $r = 5$	5.95
0.1970	$r \leq 5$ vs. $r = 6$	4.17		

Sector: Construction

G-7: USA, CAN, JPN, DEU, FRA, ITA, GBR

Eigen-values	Trace Test H_0 vs. H_1	Statistic	Max. EV Test H_0 vs. H_1	Statistic
1.0000	$r = 0$ vs. $r = 7$	1919.45**	$r = 0$ vs. $r = 1$	593.39**
1.0000	$r \leq 1$ vs. $r = 7$	1326.06**	$r = 1$ vs. $r = 2$	593.39**
1.0000	$r \leq 2$ vs. $r = 7$	732.67**	$r = 2$ vs. $r = 3$	635.38**
0.9407	$r \leq 3$ vs. $r = 7$	97.30**	$r = 3$ vs. $r = 4$	53.67**
0.8159	$r \leq 4$ vs. $r = 7$	43.63**	$r = 4$ vs. $r = 5$	32.15**
0.4191	$r \leq 5$ vs. $r = 7$	11.48	$r = 5$ vs. $r = 6$	10.32
0.0592	$r \leq 6$ vs. $r = 7$	1.16		

Sector: Finance

G-7: USA, CAN, GBR

Eigen-values	Trace Test H_0 vs. H_1	Statistic	Max. EV Test H_0 vs. H_1	Statistic
0.6428	$r = 0$ vs. $r = 3$	33.16**	$r = 0$ vs. $r = 1$	19.56*
0.4828	$r \leq 1$ vs. $r = 3$	13.60*	$r = 1$ vs. $r = 2$	12.16*
0.0727	$r \leq 2$ vs. $r = 3$	1.43		

Note: r denotes the number of cointegrating relationships. ** denotes significance at 5% level, * at 10% level. Critical values are from Osterwald-Lenum (1992), p. 468, table 1.

Table 7: continued

Sector: Manufacturing				
G-7: CAN, JPN, ITA, GBR				
Eigen-	Trace Test		Max. EV Test	
values	H_0 vs. H_1	Statistic	H_0 vs. H_1	Statistic
0.7676	$r = 0$ vs. $r = 4$	38.75	$r = 0$ vs. $r = 1$	27.72^{**}
0.3101	$r \leq 1$ vs. $r = 4$	11.03	$r = 1$ vs. $r = 2$	7.05
0.1794	$r \leq 2$ vs. $r = 4$	3.97	$r = 2$ vs. $r = 3$	3.76
0.0113	$r \leq 3$ vs. $r = 4$	0.22		

Sector: Mining				
G-7: USA, CAN, JPN, GBR				
Eigen-	Trace Test		Max. EV Test	
values	H_0 vs. H_1	Statistic	H_0 vs. H_1	Statistic
0.6834	$r = 0$ vs. $r = 4$	49.86^{**}	$r = 0$ vs. $r = 1$	21.85
0.5721	$r \leq 1$ vs. $r = 4$	28.00^{*}	$r = 1$ vs. $r = 2$	16.13
0.3082	$r \leq 2$ vs. $r = 4$	11.88	$r = 2$ vs. $r = 3$	7.00
0.2262	$r \leq 3$ vs. $r = 4$	4.88		

Sector: Retail				
G-7: DEU, FRA, ITA, GBR				
Eigen-	Trace Test		Max. EV Test	
values	H_0 vs. H_1	Statistic	H_0 vs. H_1	Statistic
0.9043	$r = 0$ vs. $r = 4$	68.61^{**}	$r = 0$ vs. $r = 1$	44.58^{**}
0.5793	$r \leq 1$ vs. $r = 4$	24.03	$r = 1$ vs. $r = 2$	16.45
0.3212	$r \leq 2$ vs. $r = 4$	7.58	$r = 2$ vs. $r = 3$	7.36
0.0116	$r \leq 3$ vs. $r = 4$	0.22		

Note: r denotes the number of cointegrating relationships. ** denotes significance at 5% level, * at 10% level. Critical values are from Osterwald-Lenum (1992), p. 468, table 1.

Table 7: continued

Sector: Services				
G-7: USA, JPN, DEU, FRA, GBR				
Eigen-	Trace Test		Max. EV Test	
values	H_0 vs. H_1	Statistic	H_0 vs. H_1	Statistic
0.9015	$r = 0$ vs. $r = 5$	93.60**	$r = 0$ vs. $r = 1$	44.04**
0.6633	$r \leq 1$ vs. $r = 5$	49.56**	$r = 1$ vs. $r = 2$	20.68
0.5015	$r \leq 2$ vs. $r = 5$	28.87**	$r = 2$ vs. $r = 3$	13.23
0.4590	$r \leq 3$ vs. $r = 5$	15.65**	$r = 3$ vs. $r = 4$	11.67
0.1888	$r \leq 4$ vs. $r = 5$	3.98**		

Sector: Transportation				
G-7: CAN, JPN, DEU, FRA, ITA				
Eigen-	Trace Test		Max. EV Test	
values	H_0 vs. H_1	Statistic	H_0 vs. H_1	Statistic
0.9073	$r = 0$ vs. $r = 5$	95.58**	$r = 0$ vs. $r = 1$	45.19**
0.8138	$r \leq 1$ vs. $r = 5$	50.39**	$r = 1$ vs. $r = 2$	31.94**
0.4899	$r \leq 2$ vs. $r = 5$	18.45	$r = 2$ vs. $r = 3$	12.79
0.2334	$r \leq 3$ vs. $r = 5$	5.66	$r = 3$ vs. $r = 4$	5.05
0.0317	$r \leq 4$ vs. $r = 5$	0.61		

Sector: Utilities				
G-7: USA, CAN, JPN, DEU, FRA, GBR				
Eigen-	Trace Test		Max. EV Test	
values	H_0 vs. H_1	Statistic	H_0 vs. H_1	Statistic
0.9876	$r = 0$ vs. $r = 6$	232.82**	$r = 0$ vs. $r = 1$	83.44**
0.9785	$r \leq 1$ vs. $r = 6$	149.38**	$r = 1$ vs. $r = 2$	72.96**
0.8471	$r \leq 2$ vs. $r = 6$	76.42**	$r = 2$ vs. $r = 3$	35.68**
0.7204	$r \leq 3$ vs. $r = 6$	40.74**	$r = 3$ vs. $r = 4$	24.21**
0.4411	$r \leq 4$ vs. $r = 6$	16.52**	$r = 4$ vs. $r = 5$	11.05
0.2501	$r \leq 5$ vs. $r = 6$	5.47**		

Note: r denotes the number of cointegrating relationships. ** denotes significance at 5% level, * at 10% level. Critical values are from Osterwald-Lenum (1992), p. 468, table 1.

Table 8: Results from Johansen Cointegration Tests; Countries: EU

Sector: Agriculture

EU: DEU, FRA, ITA, GBR, NLD, DNK, SWE, FIN

Eigen-	Trace Test		Max. EV Test	
values	H_0 vs. H_1	Statistic	H_0 vs. H_1	Statistic
1.0000	$r = 0$ vs. $r = 8$	3734.58**	$r = 0$ vs. $r = 1$	593.55**
1.0000	$r \leq 1$ vs. $r = 8$	3141.02**	$r = 1$ vs. $r = 2$	630.99**
1.0000	$r \leq 2$ vs. $r = 8$	2510.02**	$r = 2$ vs. $r = 3$	636.84**
1.0000	$r \leq 3$ vs. $r = 8$	1873.18**	$r = 3$ vs. $r = 4$	621.64**
1.0000	$r \leq 4$ vs. $r = 8$	1251.54**	$r = 4$ vs. $r = 5$	621.64**
1.0000	$r \leq 5$ vs. $r = 8$	629.90**	$r = 5$ vs. $r = 6$	608.18**
0.6512	$r \leq 6$ vs. $r = 8$	21.72**	$r = 6$ vs. $r = 7$	20.01
0.0861	$r \leq 7$ vs. $r = 8$	1.71		

Sector: Construction

EU: DEU, FRA, ITA, GBR, NLD, BEL, DNK, SWE, FIN

Eigen-	Trace Test		Max. EV Test	
values	H_0 vs. H_1	Statistic	H_0 vs. H_1	Statistic
1.0000	$r = 0$ vs. $r = 9$	5258.55**	$r = 0$ vs. $r = 1$	560.39**
1.0000	$r \leq 1$ vs. $r = 9$	4697.16**	$r = 1$ vs. $r = 2$	587.34**
1.0000	$r \leq 2$ vs. $r = 9$	4109.81**	$r = 2$ vs. $r = 3$	587.34**
1.0000	$r \leq 3$ vs. $r = 9$	3522.47**	$r = 3$ vs. $r = 4$	603.23**
1.0000	$r \leq 4$ vs. $r = 9$	2919.23**	$r = 4$ vs. $r = 5$	603.23**
1.0000	$r \leq 5$ vs. $r = 9$	2315.99**	$r = 5$ vs. $r = 6$	641.08**
1.0000	$r \leq 6$ vs. $r = 9$	1674.91**	$r = 6$ vs. $r = 7$	573.71**
1.0000	$r \leq 7$ vs. $r = 9$	1101.20**	$r = 7$ vs. $r = 8$	573.71**
1.0000	$r \leq 8$ vs. $r = 9$	527.49**		

Sector: Finance

EU: GBR, DNK, FIN

Eigen-	Trace Test		Max. EV Test	
values	H_0 vs. H_1	Statistic	H_0 vs. H_1	Statistic
0.6125	$r = 0$ vs. $r = 3$	31.46**	$r = 0$ vs. $r = 1$	18.01
0.4395	$r \leq 1$ vs. $r = 3$	13.45*	$r = 1$ vs. $r = 2$	11.00
0.1207	$r \leq 2$ vs. $r = 3$	2.44		

Note: r denotes the number of cointegrating relationships. ** denotes significance at 5% level, * at 10% level. Critical values are from Osterwald-Lenum (1992), p. 468, table 1.

Table 8: continued

Sector: Manufacturing

EU: ITA, GBR, NLD, BEL, FIN

Eigen-values	Trace Test H_0 vs. H_1	Statistic	Max. EV Test H_0 vs. H_1	Statistic
0.9313	$r = 0$ vs. $r = 5$	101.45**	$r = 0$ vs. $r = 1$	50.88**
0.7282	$r \leq 1$ vs. $r = 5$	50.57**	$r = 1$ vs. $r = 2$	24.75*
0.5501	$r \leq 2$ vs. $r = 5$	25.82	$r = 2$ vs. $r = 3$	15.18
0.3260	$r \leq 3$ vs. $r = 5$	10.64	$r = 3$ vs. $r = 4$	7.50
0.1525	$r \leq 4$ vs. $r = 5$	3.14		

Sector: Mining

EU: GBR, DNK, SWE, FIN

Eigen-values	Trace Test H_0 vs. H_1	Statistic	Max. EV Test H_0 vs. H_1	Statistic
0.8877	$r = 0$ vs. $r = 4$	61.64**	$r = 0$ vs. $r = 1$	41.54**
0.5295	$r \leq 1$ vs. $r = 4$	20.09	$r = 1$ vs. $r = 2$	14.32
0.2535	$r \leq 2$ vs. $r = 4$	5.77	$r = 2$ vs. $r = 3$	5.55
0.0112	$r \leq 3$ vs. $r = 4$	0.21		

Sector: Retail

EU: DEU, FRA, ITA, GBR, NLD, BEL, DNK, SWE, FIN

Eigen-values	Trace Test H_0 vs. H_1	Statistic	Max. EV Test H_0 vs. H_1	Statistic
1.0000	$r = 0$ vs. $r = 9$	4838.21**	$r = 0$ vs. $r = 1$	492.04**
1.0000	$r \leq 1$ vs. $r = 9$	4346.18**	$r = 1$ vs. $r = 2$	514.92**
1.0000	$r \leq 2$ vs. $r = 9$	3831.26**	$r = 2$ vs. $r = 3$	514.92**
1.0000	$r \leq 3$ vs. $r = 9$	3316.35**	$r = 3$ vs. $r = 4$	554.16**
1.0000	$r \leq 4$ vs. $r = 9$	2762.19**	$r = 4$ vs. $r = 5$	576.39**
1.0000	$r \leq 5$ vs. $r = 9$	2185.79**	$r = 5$ vs. $r = 6$	566.69**
1.0000	$r \leq 6$ vs. $r = 9$	1619.10**	$r = 6$ vs. $r = 7$	555.73**
1.0000	$r \leq 7$ vs. $r = 9$	1063.37**	$r = 7$ vs. $r = 8$	531.68**
1.0000	$r \leq 8$ vs. $r = 9$	531.68**		

Note: r denotes the number of cointegrating relationships. ** denotes significance at 5% level, * at 10% level. Critical values are from Osterwald-Lenum (1992), p. 468, table 1.

Table 8: continued

	Sector: Services			
	EU: DEU, FRA, GBR, BEL, DNK, SWE, FIN			
Eigen-	Trace Test		Max. EV Test	
values	H_0 vs. H_1	Statistic	H_0 vs. H_1	Statistic
1.0000	$r = 0$ vs. $r = 7$	1931.56**	$r = 0$ vs. $r = 1$	592.79**
1.0000	$r \leq 1$ vs. $r = 7$	1338.77**	$r = 1$ vs. $r = 2$	636.84**
1.0000	$r \leq 2$ vs. $r = 7$	701.93**	$r = 2$ vs. $r = 3$	610.31**
0.9211	$r \leq 3$ vs. $r = 7$	91.62**	$r = 3$ vs. $r = 4$	48.27**
0.7756	$r \leq 4$ vs. $r = 7$	43.35**	$r = 4$ vs. $r = 5$	28.39**
0.5353	$r \leq 5$ vs. $r = 7$	14.96*	$r = 5$ vs. $r = 6$	14.56**
0.0206	$r \leq 6$ vs. $r = 7$	0.40		

	Sector: Transportation			
	EU: DEU, FRA, ITA, BEL, DNK, SWE			
Eigen-	Trace Test		Max. EV Test	
values	H_0 vs. H_1	Statistic	H_0 vs. H_1	Statistic
0.9953	$r = 0$ vs. $r = 6$	209.14**	$r = 0$ vs. $r = 1$	101.69**
0.9162	$r \leq 1$ vs. $r = 6$	107.45**	$r = 1$ vs. $r = 2$	47.11**
0.8358	$r \leq 2$ vs. $r = 6$	60.34**	$r = 2$ vs. $r = 3$	34.32**
0.6573	$r \leq 3$ vs. $r = 6$	26.02	$r = 3$ vs. $r = 4$	20.35*
0.2409	$r \leq 4$ vs. $r = 6$	5.67	$r = 4$ vs. $r = 5$	5.24
0.0227	$r \leq 5$ vs. $r = 6$	0.44		

	Sector: Utilities			
	EU: DEU, FRA, GBR, NLD, BEL, DNK, SWE, FIN			
Eigen-	Trace Test		Max. EV Test	
values	H_0 vs. H_1	Statistic	H_0 vs. H_1	Statistic
1.0000	$r = 0$ vs. $r = 8$	3538.96**	$r = 0$ vs. $r = 1$	539.57**
1.0000	$r \leq 1$ vs. $r = 8$	2998.40**	$r = 1$ vs. $r = 2$	600.18**
1.0000	$r \leq 2$ vs. $r = 8$	2398.22**	$r = 2$ vs. $r = 3$	600.18**
1.0000	$r \leq 3$ vs. $r = 8$	1798.04**	$r = 3$ vs. $r = 4$	592.26**
1.0000	$r \leq 4$ vs. $r = 8$	1205.78**	$r = 4$ vs. $r = 5$	592.26**
1.0000	$r \leq 5$ vs. $r = 8$	613.52**	$r = 5$ vs. $r = 6$	584.79**
0.5911	$r \leq 6$ vs. $r = 8$	28.73**	$r = 6$ vs. $r = 7$	16.99**
0.4608	$r \leq 7$ vs. $r = 8$	11.74**		

Note: r denotes the number of cointegrating relationships. ** denotes significance at 5% level, * at 10% level. Critical values are from Osterwald-Lenum (1992), p. 468, table 1.

Table 9: Efficiency Convergence Regressions, entire OECD sample

Sector	α	β	N	R^2	SEE
Agriculture	-0.0167^{**}	-0.0303^{**}	12	0.343	0.003
	(0.0071)	(0.0133)			
Construction	-0.0010	-0.0316^{**}	14	0.563	0.001
	(0.0039)	(0.0080)			
Finance	-0.0082	-0.0040	6	0.025	0.000
	(0.0048)	(0.0126)			
Manufacturing	-0.0104	-0.0442^{**}	8	0.589	0.000
	(0.0062)	(0.0151)			
Mining	-0.0409^{**}	-0.0525^{**}	9	0.887	0.022
	(0.0103)	(0.0071)			
Retail	-0.0032	-0.0170^{**}	10	0.404	0.000
	(0.0026)	(0.0073)			
Services	0.0053	-0.0093	11	0.103	0.002
	(0.0075)	(0.0091)			
Transportation	-0.0063^{*}	-0.0211^{**}	10	0.607	0.000
	(0.0033)	(0.0060)			
Utilities	-0.0018	-0.0236^{**}	13	0.613	0.001
	(0.0085)	(0.0056)			

Note: Standard errors in parentheses; ** denotes statistical significance at 5% level; * denotes statistical significance at 10% level.

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