International Convergence and Divergence of Material Input Structures: An Industry-Level Perspective

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Abstract. This note analyzes whether international material input structures have converged or diverged over time. Pooled variances for 25 industries were obtained from OECD input-output tables in constant prices for nine countries over the period 1971-1990. It is found that high-tech industries were mainly characterized by divergence of material input structures, whereas convergence was found for many low-tech, more mature industries. In line with studies on (labor) productivity growth rates, convergence of material input structures was prevalent in the 1970s, while divergence dominated in the 1980s.

Keywords: convergence, technology, specialization, input-output tables

JEL codes: C67, F40, O33, O47

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1. Introduction

Over the past couple of decades, globalization has become a keyword to describe the increased interrelatedness of nations with respect to trade and knowledge diffusion. The question we address in this note is how production processes of industrialized countries have changed as a consequence of international economic and technological linkages. Using information from input-output tables, we analyze for each industry whether the structures of material inputs have converged, or not.

Differences between countries with respect to changes in material input structures as observable from input-output tables can be attributed to two phenomena. First, trade does not only involve the exchange of manufactured goods, but also enhances the diffusion of technology (see, for instance, Coe & Helpman, 1995, and Verspagen, 1997). Technology flows from technological leaders to followers may induce technological catch-up and hence a tendency to converge. However, in so-called "technology gap" models of growth (Fagerberg, 1987), convergence will occur only if the effects of innovations by the leader are smaller than the effects of catch-up through assimilation of diffused technology by follower countries. Otherwise, the technology gap will not narrow but may even widen.[1] Since material input structure is a characteristic of technologies operated by industries, convergence and divergence of material input structures can thus also be explained by technology gap arguments.[2]

Second, trade theory predicts that countries will specialize in different production processes.[3] Input-output tables, however, are usually highly aggregated whereas specialization

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1 See Appendix A for a brief formal exposition of this issue.

2 The issue of convergence of technologies has been studied quite extensively, but almost exclusively on the basis of trends in (labor or multifactor) productivity. Baumol (1986) is a classic contribution in this respect.

3 In the Heckscher-Ohlin model, differences in factor endowments cause specialization in certain industries, which then gives rise to interindustry trade (Jones, 1956). On the other hand, the new trade theories explain

takes place at the level of subindustries, each of which can be characterized by its own material input structure. Once the subindustries are aggregated into an industry, the subindustries in which a country is specialized will have a larger share. Because countries specialize in different subindustries, this will induce increasing differences in the country-specific shares of subindustries within an industry over time. This will cause a tendency towards divergence of material input structures at the industry level.

The theories above emphasize different aspects of international trade and it is not at all clear how the material input structures will change. Empirical analyses should provide answers to the question whether convergence or divergence prevails.[4] In this note we propose the reduction in the pooled variance of the material input coefficients of an industry as an indicator of convergence. In this vein, we study the OECD input-output tables in constant prices for nine countries over the period 1971-1990, using a 25-industry classification.

2. Methodology

We base our analysis on input-output tables in constant prices. From these, we obtain the elements z_{ij} with the (domestic plus imported) intermediate deliveries from industry *i* to industry *j* (*i*, *j* = 1,…,*n*) and domestic gross outputs x_j in industry *j*. The elements $a_{ij} = z_{ij} / x_j$ denote the input coefficients of material input *i* per unit of output in industry *j*. Convergence (respectively divergence) of material input structures in industry *j* would imply that the *j*th columns of the matrices **A** of input coefficients for the various countries become more (respectively less) similar. In line with the well-known concept of σ-convergence, we

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empirically observed intra-industry trade as a result of specialization within industries as caused by, for example, scale economies (Krugman, 1981) or imperfect competition (Grossman, 1992).

4 A first study along these lines is contained in Hoen (2002, Chapter 7).

analyze the changes in the variability of the columns over time.

Let the countries be denoted by the index $r = 1,\ldots,m_t$ and note that the number of countries included in the sample differs over time. Then for each industry j (= 1,…,n) at time t, we have

$$v_{ij}(t) = \frac{1}{m_t - 1}\sum_{r=1}^{m_t}[a_{ij}^r(t) - \bar{a}_{ij}(t)]^2 \text{ , with } \bar{a}_{ij}(t) = \frac{1}{m_t}\sum_{r=1}^{m_t} a_{ij}^r(t) \qquad (1)$$

Next the pooled variance is obtained by taking the average of these variances, i.e.

$$v_j(t) = \frac{1}{n}\sum_{i=1}^{n} v_{ij}(t) \qquad (2)$$

If $v_j(t+1)$ is "substantially" smaller than $v_j(t)$, we will speak of convergence between period t and t+1. Analogously, we will take a $v_j(t+1)$ that is "substantially" larger than $v_j(t)$ as an indication of divergence between t and t+1. As a yardstick, we use the corresponding *F*-statistic. For example (also other percentiles will be used),

- convergence if $v_j(t+1)/v_j(t) < F_{n(m_t-1)}^{n(m_{t+1}-1)}(0.05)$
- divergence if $v_j(t+1)/v_j(t) > F_{n(m_t-1)}^{n(m_{t+1}-1)}(0.95)$

It should be stressed that we use the critical values of the *F*-distribution only as a yardstick to distinguish between "large" and "small" differences. The application of an *F*-test to decide whether the differences are significantly different (in a statistical sense), would require unrealistically strong assumptions. That is, we would have to assume that the observations

$a_{ij}^{r}(t)$ are normally distributed with mean $\mu_i(t)$ and a common variance $\sigma^2(t)$. Moreover, the observations would need to be independent across countries *r* and input industries *i*. In particular the assumption regarding independency seems to be violated in reality, because country-specific substitution effects, for example, may play a role.

3. Data

We studied the changes in material input structures in the way outlined in the previous section on the basis of a set of national input-output tables compiled by the OECD (OECD, 1995). It contains input-output tables for ten developed countries, using a 35-industry classification.[5] For each country, three to five tables are available, roughly for the period 1968-1990. Unfortunately, the years for which tables are compiled do not exactly coincide. We decided to follow the suggestion made in OECD (1995) to assign each table to a subperiod. Table 1 presents this grouping of tables.[6]

INSERT TABLE 1

Our analyses are based on the tables that contain all intermediate inputs, both domestically produced and imported (in the OECD database these tables are encoded as "TIOK"). This choice is in accordance with the idea that material input structures should resemble

[5] These countries are Australia (AU), Canada (CA), Denmark (DK), France (FR), Germany (GE), Japan (JP), The Netherlands (NL), the United Kingdom (UK) and the United States of America (US). The OECD database also contains a single table for Italy. Since changes in tables are considered, we could not include Italy in our analysis.

technologies of industries. Mere changes in the mix of domestically produced and imported inputs should not affect these representations. Further, the interindustry transactions recorded in the tables for any country are all denominated in the national currency for a base year. Hence, inflation and changes in relative prices hardly affect the composition of the intermediate inputs.

Since national statistical agencies did not construct their national input-output tables in exactly the same way, the OECD tables are not fully comparable. Some industries are not contained as separate entities in tables for some countries, whereas they do for others (see OECD, 1995, p. 12). To make the tables as comparable as possible we had to aggregate a limited number of industries. The aggregation scheme is included in Appendix B. We finally computed the pooled variances for 25 industries, each of them based on material input coefficients vectors that consist of 25 elements.

4. Results

Applying equations (1) and (2) to the OECD (1995) tables and using the specified criteria for convergence and divergence, yields the results documented in Table 2. The rightmost columns refer to trends over the entire period of analysis, i.e. 1971-1990. An overwhelming majority of industries (i.e., 19 out of 25) has experienced either convergence or divergence of material input structures, as measured by the yardstick of the 10^{th}, respectively the 90^{th}, percentiles of the appropriate *F*-distributions.

INSERT TABLE 2

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[6] We decided to adopt the grouping suggested by OECD (1995, p. 7), except for one table. That is, we included UK(1979) in the third subperiod, whereas OECD (1995) assigned it to the second subperiod. Our grouping

In particular, many manufacturing industries that are widely considered as "low-tech" – such as textiles (4), wood products (5), paper (6), petroleum (8), and basic metals (11) – appear to have converged. Convergence is also found for primary industries – agriculture (1) and mining (2) – and for a limited number of services industries. A possible, and admittedly somewhat speculative, explanation is that innovation by technological leaders has slowed down in these "mature" industries. The technology gap will thus be narrowed if the ability of follower countries to assimilate diffused technology has not decreased. This would yield clearcut tendencies towards convergence of the material input structures, as mentioned in the introduction. Further, low innovation rates are in line with limited product differentiation, and hence with a relatively stable intra-industry trade pattern. The tendency of divergence due to enhanced specialization will thus be absent.

The results for most high-tech and medium-tech manufacturing industries support this tentative explanation. Most industries that belong to this group – such as chemicals (7), plastics (9), machinery (13), ships (14), and transport equipment, (15) – show either divergence or no discernible tendency. An increase of the leaders' innovation rates will widen the technology gap inducing divergence, if abilities to assimilate knowledge remain unaltered. Further, industries – such as metal products (12) and business services (24) – that are characterized by a high degree of product differentiation, which may be taken as an indication of specialization, have diverged over time.

It should be noted, however, that we are not able to explain the findings for every industry. For example, the low-tech industry glass and stone (10) shows divergence, whereas the high-tech industry instruments (16) is found to have experienced convergent tendencies.

Not surprisingly, the results for shorter subperiods reveal a far more heterogeneous pattern than the results for the entire period. The bottom row shows that an initial tendency

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yields less variance within groups with respect to timing.

towards convergence was gradually overturned. In the late 1980s, divergence rather than convergence of material input structures was found most often. This result is in line with studies that focus on convergence and divergence of labor productivity levels (see, e.g., Bernard & Jones, 1996a, 1996b, and Los & Timmer, 2003). From the perspective of single industries, only few show a more or less persistent development, such as agriculture (1), ships (14), other manufacturing (17), utilities (18) and government services (25). For the other industries, it is remarkable that subperiods with convergence are often followed by subperiods of divergence (and vice versa). These counteracting short-run effects certainly call for further analysis at a more detailed industry level. At the present level, they seem to have blurred the long-run tendencies indicated by the results for the entire period.

5. Conclusions

This note explored opportunities to incorporate changing patterns of material input structures into analyses of international convergence and divergence. For the period 1971-1990, the analysis based on pooled variances of input coefficients revealed that high-tech industries were mainly characterized by divergence of material input structures, whereas convergence was found for many low-tech, more mature industries. Some tentative explanations for this result were put forward. As is in line with studies that focus on convergence and divergence of (labor) productivity growth rates, convergence of material input structures was prevalent in the 1970s, while divergence dominated in the 1980s.

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Appendix A: Technology gap models and convergence

In traditional neoclassical economics (Solow, 1956), international differences in levels of labor productivity were seen as transitory phenomena. Due to more attractive rates of return to capital in low-productivity countries, investment rates were thought to be higher than in high-productivity countries. Ultimately, all countries will tend towards the same productivity level. If (exogenous) technological progress is taken into account (countries increase their productivity at a constant pace), convergence towards a steady-state gap of productivity levels will result, and growth rates will tend to equalize. Characteristic of these models is that technology is considered to be common to all countries. Differences in savings rates are considered the main cause of productivity growth differentials.

In the technology gap literature (Fagerberg, 1987), a different approach is proposed. High-productivity countries attain productivity growth by means of innovation. Since the knowledge pertaining to these innovations is assumed to disseminate slowly (or, at least, not instantaneously), low-productivity countries will initially lose ground, both in terms of productivity levels and growth rates. As soon as low-productivity countries start to "benefit" from their technological backwardness (for instance, by imitating high-productivity processes and products) catch-up can occur. Thus, the dynamics of the productivity gap between high-productivity countries and low-productivity countries is basically viewed as the outcome of two opposing forces: innovation by the leaders and assimilation by followers.

Let us for simplicity assume that there is just one productivity leader, country 0. The productivity followers are denoted by i (i=1..n). Then, the basic technology gap model is given by

$$\dot{y}_i - \dot{y}_0 = (\alpha_i - \alpha_0) + \beta_i \ln\left(\frac{y_i^{INI}}{y_0^{INI}}\right) \qquad \text{(A1)}$$

where dots denote growth rates and the superscript *INI* indicates a value in the initial period. y stands for productivity. The constants α_i (i=0,...,n) and β_i (i=1,...,n) denote country-specific abilities to innovate ($\alpha_i \geq 0$), and abilities to assimilate technology that originated with the leader ($\beta_i \geq 0$), respectively. Countries that are unable to assimilate any technology will be characterized by $\beta_i=0$. The better country i is at assimilating (for instance due to a relatively well-educated workforce), the more negative β_i will be. For reasons of exposition, let us assume that follower countries cannot innovate at all by themselves ($\alpha_i=0$, i=1,...,n).

If we assume that the leader's ability to innovate leads to a stable, continuous flow of innovations that yields productivity growth at rate α_0, the equilibrium gaps for the productivity levels can easily be found by setting the left hand side of (A1) equal to zero, that is -in equilibrium- the leader and the followers experience identical productivity growth rates. Solving for the right hand side yields:

$$\frac{y_i^*}{y_0^*} = e^{(\alpha_0 / \beta_i)} \qquad \text{(A2)}$$

Thus, the equilibrium gaps for productivity levels are larger the faster innovations arrive in the leader country and the smaller are the rates of assimilation in follower countries.

In many cases, productivity growth rates due to innovation as captured by α_0 are not stable over time (see, e.g. Freeman & Soete, 1997). In the early stages of product life cycles, productivity growth is often slow (α_0 small), due to the initially limited scale at which innovated processes are used or innovated products are sold. Later on, productivity growth picks up ($\alpha_0\uparrow$), at the time the innovation has gained more popularity. Finally, at the time processes and products reach the stage of maturity, the rate of innovation usually goes down ($\alpha_0\downarrow$), because opportunities for further improvement get fished out. If it is assumed that the abilities to assimilate remain constant over time, the product life cycle can be held responsible for changes in the distribution of gaps, as reflected in its variance. The variance of equilibrium gaps is likely to increase (σ-divergence) during the transition from the early stage to the stage of growth. During the subsequent transition from the stage of growth to the maturity stage, however, the variance of equilibrium gaps could well decrease (σ-convergence). Since adaptation to the equilibrium distribution of gaps is generally considered as a slow process due to relatively modest abilities to assimilate, actual convergence and divergence processes are long-run phenomena.

Appendix B: Industry classification for analyses based on OECD (1995) data

No.	Description	OECD IO code	ISIC Rev. 2 code
1.	Agriculture, forestry and fishery	1	1
2.	Mining and quarrying	2	2
3.	Food, beverage and tobacco	3	31
4.	Textiles, apparel and leather	4	32
5.	Wood products and furniture	5	33
6.	Paper, paper products and printing	6	34
7.	Chemicals, including drugs and medicines	7+8	351+352
8.	Petroleum and coal products	9	353+354
9.	Rubber and plastic products	10	355+356
10.	Non-metallic mineral products	11	36
11.	Basic metals	12+13	37
12.	Metal products	14	381
13.	Machinery, including electronics	15+16+17+18	382+383
14.	Shipbuilding and repairing	19	3841
15.	Other transport equipment	20+21+22	384-3841
16.	Professional goods	23	385
17.	Other manufacturing	24	39
18.	Electricity, gas and water	25	4
19.	Construction	26	5
20.	Wholesale and retail trade	27	61+62
21.	Restaurants and hotels	28	63
22.	Transport and storage services	29	71
23.	Communication services	30	72
24.	Financial and business services	31+32	8
25.	Community, social and government services	33+34+35	9

Table 1: Availability and grouping of OECD tables*

"1971"	AU(68)	CA(71)	DK(72)	FR(72)		JP(70)	NL(72)	UK(68)	US(72)
"1976"	AU(74)	CA(76)	DK(77)	FR(77)	GE(78)	JP(75)	NL(77)		US(77)
"1980"		CA(81)	DK(80)	FR(80)		JP(80)	NL(81)	UK(79)	US(82)
"1985"	AU(86)	CA(86)	DK(85)	FR(85)	GE(86)	JP(85)	NL(86)	UK(84)	US(85)
"1990"	AU(89)	CA(90)	DK(90)	FR(90)	GE(90)	JP(90)		UK(90)	US(90)

* First column contains labels for subperiods. Values between parentheses refer to years.

Table 2. Results for the OECD tables, 1971-1990.

Industry	71-76		76-80		80-85		85-90		71-90	
1	0.695	C***	1.072		0.714	C**	0.823	C*	0.438	C***
2	0.970		0.769	C**	0.746	C**	1.408	D***	0.783	C*
3	0.791	C*	1.219		0.730	C**	1.190		0.838	
4	1.072		0.774	C*	1.283	D*	0.709	C***	0.755	C**
5	0.587	C***	1.263	D**	0.686	C***	1.243	D*	0.632	C***
6	1.042		1.113		0.655	C***	1.084		0.824	C*
7	1.406	D**	0.910		0.696	C***	1.147		1.020	
8	0.918		0.219	C***	4.328	D***	0.422	C***	0.367	C***
9	0.747	C**	1.023		0.988		1.504	D***	1.136	
10	0.969		1.119		0.938		1.203		1.223	D*
11	0.969		0.362	C***	1.194		1.033		0.433	C***
12	1.074		0.918		1.257	D*	1.093		1.354	D**
13	1.033		0.940		0.759	C**	2.180	D***	1.606	D***
14	1.109		1.337	D**	1.265	D*	1.563	D***	2.934	D***
15	1.928	D***	0.778	C*	1.086		1.363	D**	2.220	D***
16	0.965		0.792	C*	0.946		0.984		0.711	C**
17	0.845	C*	0.771	C*	0.849		0.807	C*	0.446	C***
18	0.761	C**	0.770	C**	0.991		1.052		0.611	C***
19	0.882		1.862	D***	0.796	C*	1.104		1.444	D***
20	1.174		0.548	C***	1.187		1.094		0.836	
21	0.738	C**	0.574	C***	1.457	D***	0.979		0.604	C***
22	0.810	C*	0.826		1.157		1.152		0.892	
23	0.523	C***	0.985		1.094		1.483	D***	0.837	
24	0.559	C***	1.362	D**	0.616	C***	2.847	D***	1.336	D**
25	0.537	C***	0.469	C***	0.806	C*	1.181		0.240	C***
Total	C: D:	11 2		11 4		10 5		4 8		12 7

Notes.
C: convergence, *, **, *** indicates that the observed ratio is smaller than the 10th, 5th, or 1st percentile, respectively, of the corresponding *F*-distribution.
D: divergence, *, **, *** indicates that the observed ratio is larger than the 90th, 95th, or 99th percentile, respectively, of the corresponding *F*-distribution.