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Changing Patterns of Specialisation in Global High Technology Markets: An Empirical Investigation of Advanced Countries

By Andre Jungmittag, Hariolf Grupp and Angela Hullmann*

Abstract

This paper investigates whether patterns of technological specialisation of advanced countries change over a period of time in which globalisation in technology occurs. The theoretical analysis of this question is based on models of new growth and trade theory — especially a model by GROSSMAN/HELPMAN (1991) — as well as on evolutionary economics. The empirical analysis, based on the patent applications in 42 R&D-intensive product groups of the ten strongest patent producing countries, is divided into two parts. First, structural decomposition analysis is used to investigate the effects that determine changes of technological specialisation. Secondly, the concepts of β and σ -despecialisation (or -specialisation), which are very similar to the concepts of β - and σ -convergence (or divergence), are operationalised and applied to investigate whether countries are moving towards an average specialisation and whether dispersions of relative patent shares of the firms in the individual countries have been reduced during the time. Taking all results together, evidence points to rather stable dispersions of technological specialisations. However, results indicating β -despecialisation also show that the majority of national innovation systems are now moving towards an average technological specialisation. This is quite in accord with the results of the structural decomposition analysis where the technology share effects and not the structural effects are predominant.

1. Introduction

The positive impact of technological change and innovation on fostering economic growth is generally acknowledged today. Although the growth enhancing effects of new products and processes had been known for some time, it took some decades to attract the interest of researchers to study technical change. This lack of interest may be explained in part by complex procedures ruling science and technology (S&T) and the unknown mechanisms translating innovations into broad-based economic effects. However, if it is a matter of fact that technological change is a driving force behind economic growth, the analysis of its structural dynamics allows insights into economic change as well. We have witnessed a tremendous expansion of trade in goods and services over the world and, anticipating and securing world markets, an increase in external patenting. The aim of this contribution is to investigate detailed structural changes from patent statistics of the ten advanced countries, in which the largest number of technical inventions is produced.

If economic theory dealing with the long-term aspects of structural changes and sectoral differences is taken as the starting point, it can be expected that nowadays — in the age of globalisation of research and development (R&D) and technology markets — structural changes in technolo-

gical specialisation occur much faster because of enhanced networking and knowledge spillovers.¹ Thus, considering a rather short, but most recent period of time will also provide meaningful insights into changes in technological specialisation. However, economic theory — even with a long-term point of view — can help to provide hypotheses for empirical testing.

The empirical analysis presented in this paper draws on a dozen or so years of annual reporting to the German government on the technological competitiveness of the German economy deeply disaggregated by sectors or markets, which one of the authors initiated in 1985, developed and directed.² This work was also used by such

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¹ Recent trends and consequences of the globalisation of R&D and technology markets are discussed in Jungmittag/Meyer-Krahmer/Reger (1997).

² The annual reports are available in German; some of them have been published in English publications, such as Grupp, (1991), Grupp et al. (1992), Grupp (1995). We are grateful to several sections of the German Federal Ministry of Education and Research for over twelve years of continued financial support. The respective annual reports were organised by either H. Legler or one of the authors (H. Grupp) in rotating directorship up until 1997.

organisations as the OECD and the European Commission for supranational analysis and reporting.³

The econometric analysis is divided into two parts. First, structural decomposition analysis — well-known as “constant-market-share analysis” from the analysis of trade flows — is applied to investigate structural shifts in the patenting of the countries under consideration. Secondly, based on relative patent shares, we use the concepts of — β - and σ -specialisation (or despecialisation) which are very similar to the concepts of β - and σ -convergence (or divergence) as introduced by Barro and Sala-i-Martin (1991). These concepts can show whether the specialisation pattern of an individual country moves towards the average of the ten advanced countries (despecialisation) or not.

The paper proceeds in four parts. Section 2 presents an overview of the theoretical literature dealing with the long-term and dynamic aspects of structural differences. A description of the methodology applied in the empirical analysis follows in section 3. In this context, the “dual” existence of the concepts of β - and σ -specialisation and the problems of interpretation resulting from this are also considered. Section 4 contains the empirical results and finally, in section 5 the conclusions are presented.

2. Changes in Technological Specialisation: Theoretical Issues⁴

The search for the causes of economic growth has haunted economists since the early days of the profession. One outstanding result, common to almost every analysis in this area, is the multitude and variety of determinants necessary to explain economic development consistently. The confusing diversity of competing explanations rests partly upon the fact that important results of industrial economics pointing to sector disparities in growth explanation were neglected in the early attempts. Thus neo-classical growth theory limited the focus to the traditional production factors capital and labour, for the sake of clarity. In these models marginal productivity of both factors ceases to vanish in the course of development because of an additional but rather unspecified determinant called “technical progress”.

Models by Solow and studies in the subsequent wave of interest painted an optimistic picture of the world: first, even if growth rates of capital and labour productivity were decreasing in the long-run with higher volumes of inputs, rates of technical progress would help aggregate growth rates of economic activity to remain constant at the same level. Secondly, and more important for development, as technical knowledge and conventional production factors were assumed to move freely beyond borders, convergence of worldwide per capita income was predicted. Thus, in the long run economic development should be observed at comparable levels and speed in all countries (Solow, 1991).

Somewhat contrary to this, new growth theory, although “optimistic”, too, as far as growth rates in the long run are concerned, is much more cautious when it comes to inter-country convergence. Most of the models in this vein developed so far object to the long-held conclusion of similar per capita income levels among developed and developing countries. Instead, they predict that the group of countries will divide into one class of highly industrialised countries with constantly high or even increasing growth rates, and a second one of developing economies which continuously falls behind. The main reason for this bipartition lies in some specific characteristics of technological change or its “mate”: human capital. Two different sectors of the national economy are allowed for: a large part of new growth theory assumes a beneficial know-how “transfer” from the knowledge-generating sector to the sector of the economy in which companies simply adopt it. Part of this knowledge is paid for by the receiving firm while some part diffuses without appropriate compensation. Thus, external effects of knowledge creation are followed by increasing returns in production of the remaining sectors and cause all-over economic growth. One essential difference between neo-classical and new growth theory may be found in the reach of those growth-creating external effects. This recent line of research regards national growth to be independent of stocks of knowledge and human capital elsewhere. Thus, economies with own knowledge- or human capital-creating sectors are growing faster in the long run than those without.

New growth theory is no exception to other economic modelling, as it does not pay much attention to the details either of what generates external effects in innovation or of the channels which link knowledge-generation and adaptation. We should not concern ourselves here with these problems; they are tackled elsewhere.⁵ Instead, we are interested in the basic idea common to at least some models (e.g., Romer, 1990): in the long run growth rates are dependent on the sectoral structure of the economy.⁶ Countries which show a “better” fit between sectors experience higher growth rates than others.⁷ Obviously, the central question: “What is the optimal structure of an economy?” has neither been answered by growth theory nor by any other theoretical or empirical analysis up to now.

³ See OECD (1991) or European Commission (1997).

⁴ This section draws on an earlier publication by one of the authors with Münt (Münt/Grupp, 1996).

⁵ See for example the work on innovation research, e.g. Jaffe/Trajtenberg/Henderson (1992).

⁶ Strictly speaking, the main interest of growth theory lies in explaining differences in macroeconomic growth rates, not in analysing the growth effects of differences in economic structure, one of the focal points of industrial economics. However, this aspect is often alluded to implicitly without being fully worked out.

⁷ “Better” in this sense means an economic structure which optimally or completely absorbs the external effects or other mechanisms leading to higher growth.

The answer will probably never be found, because “optimality” in the dynamics of structural change is a highly elusive and ambiguous concept. Instead, a partial approach to shed some light on the issue might prove to be of better help. As pointed out above, it is useful to switch from an inward to a more outward, “global”, perspective, thus analysing economic structure in terms of a growing international economy.

The relevance of taking an international view on structural change and growth will become evident if we resume the argument of new growth theory developed above: when sectoral links and the diffusion of technology are always limited to single countries we do not have to worry about internationalisation. But it would be highly unrealistic — and for the economies of the European Union, facing the introduction of a common currency, it would be simply wrong — to assume that knowledge flows will not leak out of the area delimited by national borders. In view of the increasing share of trade in worldwide production and the recent surge in the exchange of production factors, we can conclude that national patterns of structural change and development are influenced to a non-negligible degree by other economies via the world markets. In this respect think, for example, of those channels where scientific and technological knowledge accompanies exports of goods and services, the mobility of human capital within global firms or the policy of the European Commission to support preferentially trans-border R&D.

Thus, confining ourselves to the OECD countries, we find new growth theory not fully appropriate to explain long-term records.⁸ At a more aggregate level differences in the sectoral composition of single economies are negligible, thus, they cannot account for patterns of growth divergence or convergence. In addition, a large part of trade in manufactured goods among industrialised countries has an intra-industry character. Under the condition of external effects leaking out of a country via trade we cannot consistently predict the dynamics of global trade patterns, nor the effects on domestic industry structure or on growth.

Focusing on the structural relationship between technology, globalisation and growth, we are especially interested in the dynamic properties in the most recent dozen or so years. Currently, new trade theory and a branch of evolutionary economics are dealing with the effects of differences in technological, production and trade patterns on economic growth and development. Both have in common a certain overlap with the traditional theory of comparative advantages, but stress the importance of technology and innovation as complementary determinants.

As far as new trade theory is concerned, we refer to a model that has been developed as part of a comprehensive analysis by Grossman and Helpman (1991, chap. 9). It deals with the situation most common to high-technology trade among OECD countries. The focus is on the long-term growth prospects of countries opening up — step by step — to different degrees of market integration. Basically, the

model is constructed according to the following principles: countries are “endowed” with labour, human capital and technological knowledge. To keep the analysis of the model’s main properties simple, Grossman and Helpman restricted complexity in that the economy consists of one sector only. The focus is set on the workings of integration — not on structural change within any one country. Technological knowledge generates external effects and increasing returns for the production of traded goods. In the long run, adding some further — more technical — assumptions, growth rates depend on innovation rates — that is, on the speed with which new technological knowledge is built up.

Integrating two economies similar (or even identical) in terms of traditional endowments would lead to either unchanged trade patterns and growth rates or to increased specialisation and higher growth rates in both countries. The dynamic properties of this model heavily depend on the characteristics of the stock of accumulated knowledge before integration. Because of similar endowments with traditional factors the only difference before globalisation lies in the degree of knowledge specialisation in different areas. Given that both economies are completely specialised in complementary fields of knowledge, integration will have no effects, neither on technological, production and trade pattern nor on long-term growth. Instead, if the stocks of knowledge have a certain overlap in both economies (e.g. knowledge accumulated in the same fields of S&T) integration will weed out these “inefficiencies”. Each country will specialise in one part of this knowledge available to both economies via full integration of markets. In this situation growth is higher in both countries compared with that in closed economies.

Thus, in the course of trade intensification and foreign direct investment (FDI) we would presume that among OECD countries (with comparable endowment of conventional production factors) knowledge specialisation in complementary fields of scientific or technical know-how has increased, leading to higher growth than in other regions of the world. Seen from an empirical perspective we would expect specialisation in technology, trade and, to some extent, production to have risen. As a consequence, sector or market disparities will grow. This development should be observed especially within Europe.

Apart from new growth and new trade theory, evolutionary economics is likewise concerned with the relationship between technology, trade and growth. Although it lacks a consistent body of formal modelling tools, evolutionary economics has provided a lot of interesting insights into the details of the working of economic systems. Evolutionary thinking is fundamentally based on the varia-

⁸ Up to now most new models of growth are still open to close empirical investigation. One crucial point will be to provide evidence for the more or less intuitive assumption that technology flows might be limited to national, sectoral or even firm boundaries. For the following analysis we do not question this assumption.

tion -selection principle which allows consideration of the dynamic properties of developing economic systems. Basically, evolution is thought of as being generated by creating a variety of different products and processes. Selection processes (via markets) then work on reducing this variety to a certain number of viable products.⁹ One of the main forces that generate new products or processes (and, thereby, increase variety) is innovation and technical change.

Concentrating first on variation, empirical studies have found that higher rates of innovation lead to higher rates of economic growth.¹⁰ The larger the number of different products and the higher the rate of new product generation, the higher the rate of long-term growth.¹¹ This mechanism mainly works through better adaptation to specific consumer needs (higher utility), as well as through higher efficiency of production processes. When we turn to the selection environment, most studies have found that tighter selection mechanisms favour higher growth.¹² Market competition as one of several possible selection environments in an ideal sense weeds out all inefficient types of products in order to ensure the survival of the best-fitting alternatives. Then, in the face of selection, generation of new products adapts to the characteristics of the successful variants. Therefore, it is essential for economic agents to learn quickly from the fate of successful as well as unsuccessful products on the market and, then, to develop better variants which sell at higher prices or in larger quantities. Thus, the particular strength of companies comes from learning adaptation. However, learning and adaptation are fundamentally path-dependent processes. That means, the probability to learn something useful will be much higher in areas where knowledge has already been accumulated in former periods. This path-dependency of technological change and learning may be observed at the level of single companies, industries, regions and countries. It does not only explain a great deal of innovation,¹³ but also the dynamics of division of labour and economic development.

The stock of accumulated knowledge does not only consist in scientific or otherwise codified and easily accessible findings, but also of acquired "tacit" practical skills. Knowledge therefore has a "public" and a "private" part. Apart from a few really globalised and highly science-based technologies, the main part of worldwide knowledge has a local character in that its geographical diffusion is limited in scope because of mobility barriers to human capital or skilled labour. Accordingly, empirical studies have found a lot of evidence that the ability to learn and to innovate greatly differs between sectors, regions and countries.¹⁴ Thus, stocks of technological knowledge differ in scope and character between economic entities over long periods of time. They can account for innovation and growth rate differentials.

Irrespective of the differences between the economic schools of thought, one particular field for studying the

implications of technological change for innovation and growth is international trade. Depending on the degree of integration, a large number of foreign products of different quality and price characteristics as well as production factors meets with domestic ones. Global competition, and therefore selection, is tighter than in home markets. Compared with conventional notions of international trade theory based on static comparative advantages, evolutionary economics stresses the dynamic aspects of changing trade patterns more than other schools of thought. According to concepts such as "technology gaps" (Posner, 1961) or "product life cycles" (Vernon, 1966), studies with an evolutionary background have highlighted the importance of technological change and innovations as determinants of international trade.¹⁵ Due to the mostly local nature of technological learning, we observe a clear-cut structure of technological leads and lags in particular fields of technology for single industrialised countries. The patterns of technological specialisation are replicated in trade structure by markets.

When it comes to the analysis of the relationship between technology, trade and growth, we have to switch from a static to a dynamic perspective.¹⁶ If the focus of analysis is on differences in technology only and not on endowments with traditional factors of production, we might concentrate on what will happen to sectoral technology and trade patterns after integration, a topic of industrial economics.

First, opening up for trade in goods creates a larger market for selling goods. Competitive, and therefore selec-

⁹ The diversity of "appreciative" evolutionary theorising cannot be dealt with here; for further reference see Dosi/Pavitt/Soete (1990), Witt (1993) or Hodgson (1993)

¹⁰ See, for example, Fagerberg (1988).

¹¹ Saviotti has worked out a conceptual and semi-formal tool to show that we are observing a constantly increasing number of different products. Higher degrees of product variety cause higher consumer utility. This is a main reason for economic growth. See, for example, Saviotti (1991).

¹² From a theoretical point of view, tighter selection does not necessarily prove more efficient, because in this case a large number of product variants which have incurred development costs are not selected and their development costs, therefore, become obsolete. But this waste of resources may be compensated by long-term efficiency of fewer, but superior products. See e.g. Cohendet et al. (1992) for a discussion of this fundamental problem in evolutionary economics.

¹³ Dosi (1982) used this basic principle for a "theory" of technological change. Scientific and technological change are following "trajectories" until a "breakpoint" (radical change) disrupts the smooth and gradual development.

¹⁴ See, for example, Pavitt (1984), Pavitt et al. (1987), Dosi/Pavitt/Soete (1990), Gehrke/Grupp (1994) and Grupp (1998).

¹⁵ The basic reference here is Dosi/Pavitt/Soete (1990).

¹⁶ In this respect it would be interesting to compare the implications of the Grossman/Helpman (1991) model with those of evolutionary theory, a theoretical challenge which cannot be taken up in this empirical investigation.

tive, pressure rises because of large numbers of similar products. Thus, enlarged markets increase opportunities to sell larger numbers of excellent products while those variants which do not meet the quality or price standards disappear. The intensification of trade competition will then be followed by increasing degrees of knowledge, technological and trade specialisation on those products where a country is traditionally most advanced. Changes in the patterns of specialisation will occur slowly, as adaptation (mainly restructuring) through trade takes time. Especially, learning and building up new (or larger) stocks of knowledge in particular areas is not a matter of days or even years because of institutional inertia. Besides, we should not expect each country to completely specialise in a small number of products or markets. Instead, smaller countries will always be more specialised than larger countries, where large parts of domestic production are still sold on home markets. The impact of globalisation on domestic restructuring therefore depends on the size of national economies.

But what will happen if integration is further deepened to include the exchange of production factors? In this case, parts of (technological) knowledge move more easily across borders. Knowledge which is linked to the traditional production factors, capital and labour (e.g. practical skills), may start to diffuse from the country where it is generated to neighbouring ones. Thus, by sectors or markets, the strictly localised linkage of technological learning and innovation is in part dissolved. Companies investing in production or even R&D facilities abroad exchange tacit knowledge which would have been firmly attached to the home-base in former times. While competition on world markets constantly forces to concentrate on one's own strengths, thus leading to increased specialisation, integration of factor markets may lead to a situation where higher degrees of specialisation are combined with converging sectoral patterns of technological strengths, because of a wider geographical expansion of knowledge diffusion.

This last implication differs from what Grossman/Helpman propose: in their model, knowledge diffusion meets no borders when countries open either for trade or for the exchange of production factors. In our synthesis theory it is assumed that knowledge is local in character and linked to conventional factors of production. Consequently, different degrees of integration will be followed by differences in the long-term development of technological and trade patterns: increasing degrees of specialisation but converging trends within those sectors or markets, such as common markets. This is the main hypothesis tested in the remaining parts of this paper.

3. Data and Methodology

3.1 Data Compilation and Aggregation

The analysis is based on the patent applications of the ten strongest patent producers, i. e. the G7 countries (USA,

Table 1
List of Schumpeter markets (or high technology product groups above average in R&D intensity)

SITC III	Short description
Leading-edge technology:	
516	Advanced organic chemicals
525	Radioactive materials
541, 542	Pharmacological active ingredients and medicaments
591	Herbicides, etc.
714	Turbines and reaction engines
718	Nuclear, water, wind power generators
751, 752, 759	ADP, office machines, word processing and parts
764	Telecommunications equipment
774	Medical electronics
776	Semi-conductor devices
778	Advanced electrical engineering
792	Aircraft and spacecraft
871	Optical instruments
873, 874	Measuring and control technology and instruments
891	Arms and ammunition
High-level technology:	
266	Synthetic fibres
515	Heterocyclic chemistry
522	Rare anorganic materials
524	Other anorganic materials
531	Synthetic dyes
533	Pigments, paints, varnishes
551, 598	Essential oils, perfume, flavour and other advanced chemicals
574, 575	Polyethers, resins and plastics
724	Textile and leather machinery
725	Paper and pulp machinery
726	Printing and bookbinding machinery
727	Industrial food-processing machines
728	Advanced machine tools
731, 733, 735	Metal and cermet machine tools and components
737	Other machine tools
741	Heating and cooling equipment
744	Mechanical handling equipment
745	Other non-electrical machinery
746	Ball and roller bearings
761, 762, 763	Television, video equipment, radio-broadcast and radiotelephony products, sound recording & reproduction
772	Traditional electronics
773	Electrical distribution equipment
781, 782	Passenger cars and commercial vehicles
791	Railroad vehicles
872	Medical instruments
881, 884	Photographic apparatuses and equipment, optical fibres, contact lenses
882	Photographic chemicals

Japan, Germany, France, United Kingdom, Italy, Canada) as well as the Netherlands, Sweden and Switzerland, taken from the European Patent Office in conjunction with international patent applications. For these countries a breakdown of technology in 42 R&D-intensive markets, which we term "Schumpeter" markets following a convention used elsewhere in the high-technology debate (Grupp, 1998, pp. 270-71), and a residual non-disaggregated market containing the remaining patent applications ("low technology") is provided for the priority or invention years of 1989 to 1995. The 42 R&D-intensive fields are not defined by technological items but by product groups (markets) matching with three-digit classes of the Standard Industrial Trade Classification (SITC, rev. III).¹⁷

Thus, the economic interpretation of technological change is facilitated as it turns out that industries or sectors are too inhomogeneous in terms of technology, and the best match of technology and economic dynamics is achieved via markets.¹⁸ The high technology markets are listed in table 1. These are the above-average markets in terms of R&D expenditure per turnover. In order to avoid too much short-term fluctuation in patent shares, two year averages were calculated. The averages of the years 1989/1990 and 1994/1995 are compared in the dynamic analysis.

Altogether, the ten countries under consideration account for 96.3 % resp. 96.0 % of all 61,120 resp. 62,797 patent applications in 1989/1990 or 1994/1995, respectively. Thus, a limitation to these countries will not reduce the general significance. The shares of patent applications of the individual countries are displayed in table 2. In spite of considerable bulk shifts of shares the ranking of the countries remains nearly unchanged. Only Japan and Germany have exchanged the second and the third positions.

The list of Schumpeter markets used here is subdivided into leading-edge and high-level markets. In leading-edge markets R&D intensity is very high (above 8.5 %), whereas high-level markets are slightly above the industry average (R&D intensity between 3.5 % and 8.5 %). The reason for this bipartition is discussed in Grupp (1995). Very briefly, leading-edge markets are often subject to government intervention and protectionism (aircraft, pharmaceuticals, telecommunications, armaments and the like). High-level Schumpeter markets are certainly above average in R&D intensity and thus depend on technical change more than low technology product groups. Yet these markets are generally free trade markets and contain many consumer goods (such as automobiles, consumer electronics and the like).

3.2 Structural Decomposition of Patents

One way of looking at the dynamics of technological specialisation is to apply a structural decomposition of patent data. The method of structural decomposition is often used for the analysis of trade flows, here also known

Table 2

**Patent shares of ten countries
(42 R&D-intensive technology fields and other technology;
three-digit country codes by ISO)**

Country	Average 1989—1990	Average 1994—1995
USA (USA)	29.3 %	32.3 %
JPN (Japan)	22.1 %	18.0 %
DEU (Germany)	20.5 %	22.0 %
GBR (United Kingdom)	6.6 %	6.2 %
FRA (France)	8.7 %	8.6 %
CHE (Switzerland)	3.2 %	3.2 %
CAN (Canada)	1.1 %	1.3 %
SWE (Sweden)	1.7 %	2.3 %
ITA (Italy)	4.0 %	4.0 %
NLD (Netherlands)	2.8 %	2.7 %

under the name of "constant-market-share analysis". In regional research the method is used in a modified and simplified manner as "shift-share analysis". In the field of patent statistics its application is methodologically new, so to the best of our knowledge only one recent discussion paper by Laursen (1996) exists.

When analysing patent data, the initial question is whether a country increases or decreases its share of total patent applications at the European Patent Office over time. For example, Germany's average share was 20.5 % in 1989/1990 and 21.5 % in 1994/1995, which is equivalent to a growth rate of 5.0 %. This aggregated growth rate should now be decomposed in such a way that structural changes are isolated. Then, it can be ascertained whether the increase (or decrease) of a country's share of patent applications is due to

- an improvement (or worsening) of its position when it is assumed that the structure is the same in both periods under consideration,
- a favourable (or unfavourable) specialisation pattern in view of the development of the general world trend,
- a movement into technology fields with totally growing (or decreasing) patent activities,
- a movement out of technology fields with totally decreasing (or growing) patent activities.

Formally, the decomposition is yielded as follows. Let P_{ij} represent the number of patents of country j in the market i , then

$$(1) \quad p_j = \frac{\sum_i P_{i,j}}{\sum_i \sum_j P_{i,j}}$$

is country j 's aggregated share of patents in all product groups, and

¹⁷ Matching patent classification to product groups or markets on this level of disaggregation is a very tedious task. Preliminary work is acknowledged in footnote 2. Here, we equate the terms "market" and "product group".

¹⁸ See Scherer (1982) or Grupp (1998), pp. 204. The definition of R&D-intensive markets is given in the latter sense.

$$(2) \quad p_{ij} = P_{ij} / \sum_j P_{ij}$$

is country j 's share of total patents in the product field i . Furthermore,

$$(3) \quad q_i = \sum_j P_{ij} / \sum_i \sum_j P_{ij}$$

is product field i 's share of total patent applications.

Now, the change of country j 's aggregated share of patents in all markets Δp_j can be decomposed into

$$(4) \quad \Delta p_j = \sum_i (\Delta p_{ij} q_i^{t-1}) + \sum_i (p_{ij}^{t-1} \Delta q_i) + \sum_i (\Delta p_{ij} \Delta q_i) .$$

The first term on the right-hand side of equation (4) is called the technology share effect. It measures whether the patent share of a country increases or decreases, assuming the same patent structure in both periods. The second term represents the structural technology effect. It measures whether a country is gaining or losing patent shares due to a specialisation pattern in the initial period which anticipates the general world trend or not. The last term can be interpreted as technology adaptation effect. It measures whether a country is gaining or losing patent shares due to an active movement into (or out of) the "right" markets or due to an active movement out of (or into) the "wrong" markets. Here, in the quantitative analysis the "right" markets are those whose shares of total patent applications are growing (i. e. Δq_i is positive) and the "wrong" markets are those whose shares of total applications are decreasing (i. e. Δq_i is negative). In other words, Schumpeter markets are divided into those drawing more on technical change in the period considered as compared to those relying less on new technology. For a more exact analysis, this last term can be further decomposed into

$$(5) \quad \sum_i (\Delta p_{ij} \Delta q_i) = \sum_i \Delta p_{ij} (\Delta q_i + |\Delta q_i|) / 2 + \sum_i \Delta p_{ij} (\Delta q_i - |\Delta q_i|) / 2 .$$

Now, the first term on the right-hand side of equation (5) represents the technology growth adaptation effect which is positive when a country moves into a growing market. The second term captures the technology stagnation adaptation effect which is positive when a country moves out of a market with decreasing patent activities. Both terms are corrected by all trend effects and contain only deliberate movements against the trends.

3.3 Testing for β - and σ -Specialisation

The starting point of most empirical studies of international patterns of technology (or trade) is to calculate some specialisation indicators. Most indicators are based on Balassa's "Revealed Comparative Advantage" index.¹⁹ Often, some modifications are used to yield a symmetric version of this indicator. We are following this approach and measure technological specialisation analogously by the "Relative Patent Share" (RPS) in the version:

$$(6) \quad RPS_{ij} = 100 \tanh \ln [(P_{ij} / \sum_j P_{ij}) / (\sum_i P_{ij} / \sum_i \sum_j P_{ij})]$$

The logarithm is used to yield a symmetric version and the hyperbolic tangent is used to limit the indicator between -1 and $+1$.²⁰ Positive values of this measure indicate above-average specialisation in single high technology markets (resp. product groups); negative values hint at below-average specialisation. The upper limit of the indicator is set to $+100$; the lower limit to -100 .

The testing procedure is very similar to the well-known procedures applied to the test for β -convergence in empirical studies inspired by growth theory. Changes of specialisation patterns are tested by means of the regression equation

$$(7) \quad RPS_{ij}^t = \alpha_j + \beta_j RPS_{ij}^{t-1} + u_j^t$$

for each country j .²¹ The superscripts $t-1$ and t refer to the initial period and the final period, respectively. The coefficients α and β are linear regression parameters and u is the error term. If $\beta_j = 1$, the specialisation pattern of country j remains unchanged from the initial to the final period. The country becomes more specialised in technology fields where it is already specialised and less specialised in technology fields where initial specialisation is low if $\beta_j > 1$. In this case, the initial specialisation is reinforced. On the other hand, if $0 < \beta_j < 1$ the specialisation pattern of country j moves towards the average of the countries considered, i. e. on average low initial RPS s increase over time and high initial RPS s decrease. In the case where $\beta_j \leq 0$ the specialisation pattern of a country is either reversed (changed fundamentally) if $\beta_j < 0$, or random if $\beta_j = 0$. This result would be contrary to the hypothesis of cumulativeness and path dependency of economic theory. Thus, the case where $\beta_j > 1$ can be termed β -specialisation and the case where $0 < \beta_j < 1$ β -despecialisation.²²

¹⁹ See Balassa (1966). For applications see, for example, Dosi et al. (1990), Münt/Grupp (1996), NIW/DIW/ISI/ZEW (1997) or Dalum et al. (1996) and Dalum/Villumsen (1996). Note that the original notation by Balassa is now used in a slightly confusing way, see Grupp (1998), p. 217. We stick, nevertheless, to the recent literature.

²⁰ For details, see Gehrke/Grupp (1994).

²¹ See Pavitt (1988) and Cantwell (1989). This procedure was adopted for the analysis of changes in trade specialisation by Dalum/Villumsen (1996) and Dalum et al. (1996).

²² Most of the empirical work concerning β -convergence has been based on the regression equation in first differences form

$$y^t - y^{t-1} = \beta^* y^{t-1} + u$$

where $y^t = \ln Y^t$, $y^{t-1} = \ln Y^{t-1}$, and the intercept is suppressed for simplicity. This equation can also be written in the form

$$y = (1 + \beta^*) y + u = \beta y + u$$

where it is assumed that $-1 \leq \beta^* \leq 0$ and that $0 \leq \beta \leq 1$. So, either the first or second equation can be estimated in order to test the equivalent hypotheses that $\beta^* < 0$ or that $\beta < 1$ (see Lichtenberg, 1994).

The hypothesis of β -despecialisation can — analogously to the hypothesis of β -convergence — also be termed “mean-reversion hypothesis”. However, β -despecialisation is only a necessary, but not a sufficient condition for σ -despecialisation, which may be expressed for a country j as

$$(8) \quad [\sigma_{j(RPS_y^t)}^2] / [\sigma_{j(RPS_y^{t-1})}^2] < 1$$

where σ_j^2 denotes the variance of the RPS s of country j . A β -coefficient which is significantly smaller than 1 does not always mean that the dispersion of RPS s within a country decreases. It is true, $0 < \beta_j < 1$ reduces the dispersion, but new shocks captured by the error term can increase it again.²³ So the degree of σ -despecialisation depends also on the coefficient of determination R_j^2 of equation (7), i. e., on the relative importance of random disturbances (Lichtenberg, 1994). Thus, β -despecialisation and σ -despecialisation only occur if and $0 < \beta_j < 1$ and

$$(9) \quad \frac{\beta_j^2}{R_j^2} = \frac{\left(\frac{\sigma_{j(RPS_y^{t-1})}^2}{\sigma_{j(RPS_y^t)}^2} \right)^2}{\left(\frac{\sigma_{j(RPS_y^{t-1})}^2}{\sigma_{j(RPS_y^t)}^2} \right)^2} = \frac{\sigma_{j(RPS_y^t)}^2}{\sigma_{j(RPS_y^{t-1})}^2} < 1$$

or equivalent $\frac{\beta_j}{R_j} = \frac{\sigma_{j(RPS_y^t)}}{\sigma_{j(RPS_y^{t-1})}} < 1$

Conversely, σ -specialisation occurs if β_j^2 / R_j^2 and β_j / R_j are greater than 1. Adapting the conclusions referring to convergence in Barro/Sala-i-Martin (1991) to despecialisation, it can be argued that the concepts of β - and σ -despecialisation are suitable for the investigation of different objects of research. If the subject of investigation is how fast and to which extent specialisation patterns are moving towards the average, then β -despecialisation is a suitable concept. However, if the distribution of RPS s over time should be determined, σ -despecialisation is the more suitable concept.

4. Empirical Results

First, the results of the structural decomposition of patent data displayed in table 3 will be considered. It can be seen for nearly all countries that the technology share effects are explaining the dominant part of growth or decrease in the era of globalisation since 1989. So, the changes in shares are not caused by structural shifts. The United States is conspicuous because the other three effects have nearly no significance. Also, only a very small part of the considerable loss of Japan's patent share can be assigned to the structural technology effect which shows that Japan's specialisation in high technology markets was “wrong” in the initial period. The fact that Japan is actively moving out of growing technology fields explains only 0.9 percentage points of its total decrease of —18.8 per cent. Nearly the same share is explained by the technology stagnation adaptation effect so that Japanese firms are leaving high technology markets with decreasing patent activities to a small extent.

The increase in Germany's patent share would have been somewhat larger if Germany had not had slight initial disadvantages in specialisation (namely 5.5 per cent). The growth adaptation effect hardly plays a role, whereas the stagnation adaptation effect shows that German companies move out of decreasing technology fields, at least to a small extent.

Both the British and Swiss firms gain from specialisation patterns in the initial period which are already — at least to some extent — anticipating future development. Otherwise, the decrease in both countries' patent shares would have been larger. However, they are not able to strengthen these advantages. In the case of the United Kingdom, the larger decrease due to the movement out of growing high technology markets cannot be compensated for by leaving decreasing product groups. In the case of Switzerland,

²³ For the case of β - and σ -convergence see Barro/Sala-i-Martin (1991).

Table 3

Structural Decomposition Analysis 1989/1990 vs. 1994/1995 (in per cent)

Country	Total Change	Technology Share Effect	Structural Technology Effect	Growth Adaptation Effect	Stagnation Adaptation Effect
USA	10.1	9.8	0.3	0.5	−0.4
JPN	−18.8	−17.4	−1.5	−0.9	1.0
DEU	5.0	5.5	−0.7	−0.1	0.3
GBR	−7.0	−8.0	1.5	−0.6	0.2
FRA	−1.0	−0.5	−1.1	0.5	0.2
CHE	−1.0	−2.0	1.9	−0.3	−0.5
CAN	16.0	13.1	1.0	2.3	−0.4
SWE	40.0	34.3	2.8	4.0	−1.0
ITA	1.6	2.3	−0.1	−0.4	−0.3
NLD	−5.6	−5.3	−0.5	−0.01	0.3

remaining in decreasing fields clearly has a negative impact. France's patent share is falling mainly due to a "wrong" specialisation pattern in the initial period. However, the growth adaptation effect signals that French enterprises then moved into growing markets.

Even in both countries with the highest growth rates of patent shares — Canada and Sweden — a large part of growth must be assigned to the technology share effect. At the same time Sweden shows a relatively high structural technology effect which made growth easier. Furthermore, firms in both countries moved actively into growing high technology markets. The growth of Italy's patent share has been slowed down by moving out of growing Schumpeter markets while moving into decreasing ones. The fall of the patent share of the Netherlands can only be explained to a small extent by structural technology effects and growth resp. stagnation adaptation effects.

Judging from the initial specialisation patterns, it can be seen — at least partly — that enterprises in the United States, the United Kingdom, Switzerland, Canada and Sweden were already orientated in 1989/1990 in the direction that proved to be "right" by the mid 1990s. Nearly all countries are to a small extent able to undertake actively structural adjustments in such a way that they are moving into growing product groups and that they are leaving decreasing ones. Here, France, Canada and Sweden are exceptions. In the case of some countries, an active movement in one direction is compensated by persistence in the other direction. With opposite signs, the United States and Japan can be mentioned as good examples of this.

Now, let us consider the regression results. First, for each country considered equation (7) was estimated for the 42 R&D-intensive high technology product groups and a

residual group containing the remaining low technologies. The results are displayed in table 4. It can be seen that in all cases coefficients β_j are greater than 0 at a high level of significance ($\alpha \leq 0.01$). At the same time, coefficients β_j are significantly smaller than 1 for seven countries (the United States, the United Kingdom, France, Canada, Sweden, Italy and the Netherlands). So, the specialisation patterns of these countries are moving towards the average of the ten countries considered, i. e. in these cases σ -despecialisation occurs. However, as can be seen from the relations $\hat{\beta}_j / R_j$ and the F-values belonging to them σ -despecialisation or -specialisation occurs in none of the cases. Thus, the reduced dispersions in seven countries indicated by $0 \leq \beta_j \leq 1$ were compensated for by new shocks captured by the error terms.

When the residual group is dropped from the sample, the results remain nearly unchanged, so that the corresponding results are not reported here. However, splitting the sample into the two subsamples containing on the one hand 15 markets concerning leading-edge technologies and on the other hand 27 markets concerning high-level technologies (see section 3.1) can provide further insight into changes in patterns of technological specialisations.

The results for the subsamples of the 15 leading-edge product groups are displayed in table 5. Now, only seven countries are showing coefficients $\beta_j > 0$. In three cases, for firms in the United Kingdom, Canada and the Netherlands, changes in technological specialisation seem to be random because the hypothesis $\beta_j = 0$ cannot be rejected. Movements towards the average specialisation of the ten countries considered can only be observed in the cases of the United States and Germany. However, again, neither σ -despecialisation nor -specialisation occur in any of the cases.

Table 4

Regression results for all product groups (RPS94/95 on RPS89/90)

Country	$\hat{\beta}_j$	t-value $H_0: \beta_j = 0$ against $H_A: \beta_j > 0^1)$	t-value $H_0: \beta_j = 1$ against $H_A: \beta_j < 1^1)$	R_j^2	$\frac{\hat{\beta}_j}{R_j}$	F-value $H_0: \sigma_{j(t-1)}^2 = \sigma_{jt}^2$ against $H_A: \sigma_{j(t-1)}^2 \neq \sigma_{jt}^2$
USA	0.8135	10.7540**	-2.4669**	0.6766	0.9890	1.0224
JPN	0.9655	18.9369**	-0.6765	0.8714	1.0343	1.0698
DEU	0.9060	13.4095**	-1.3905	0.8355	0.9912	1.0179
GBR	0.4243	2.3329**	-3.1649**	0.1905	0.9721	1.0582
FRA	0.8333	11.2519**	-2.2497**	0.7042	0.9930	1.0141
CHE	0.9047	14.5663**	-1.5346	0.7165	1.0688	1.1423
CAN	0.6082	5.0629**	-3.2814**	0.4022	0.9496	1.1091
SWE	0.8294	12.1906**	-2.5088**	0.6247	1.0494	1.1012
ITA	0.8426	13.0574**	-2.4403**	0.7754	0.9569	1.0922
NLD	0.6559	5.0035**	-2.6247**	0.4694	0.9573	1.0911

Remarks: ¹⁾ White's heteroscedasticity-consistent estimators of the variance matrix of the regression coefficients are used to calculate t-statistics

* Significant with $0.01 < \alpha \leq 0.05$

** Highly significant with $\alpha \leq 0.01$.

Table 5

Regression results for leading-edge product groups (RPS94/95 on RPS89/90)

Country	$\hat{\beta}_j$	t-value $H_0: \beta_j = 0$ against $H_A: \beta_j > 0^{(1)}$	t-value $H_0: \beta_j = 1$ against $H_A: \beta_j < 1^{(1)}$	R_j^2	$\frac{\hat{\beta}_j}{R_j}$	F-value $H_0: \sigma_{jt(t-1)}^2 = \sigma_{jt}^2$ against $H_A: \sigma_{jt(t-1)}^2 \neq \sigma_{jt}^2$
USA	0.6352	3.1153**	-1.7891*	0.2586	1.2493	1.5607
JPN	0.9912	25.3859**	-0.2256	0.9649	1.0091	1.0182
DEU	0.7202	4.6508**	-1.8063*	0.5868	0.9402	1.1313
GBR	0.3010	0.9949	-2.3100**	0.1393	0.8065	1.5375
FRA	0.9563	8.3957**	-0.3837	0.7780	1.0842	1.1755
CHE	0.8695	5.3232**	-0.7991	0.6553	1.0741	1.1537
CAN	0.4077	1.1217	-1.6294	0.1215	1.1696	1.3681
SWE	0.9915	14.1640**	-0.1214	0.7005	1.1846	1.4034
ITA	0.8779	4.8669**	-0.6768	0.6263	1.1093	1.2306
NLD	0.3091	1.0139	-2.2660*	0.0824	1.0768	1.1595

Remarks: ¹⁾ White's heteroscedasticity-consistent estimators of the variance matrix of the regression coefficients are used to calculate t-statistics

* Significant with $0.01 < \alpha \leq 0.05$

** Highly significant with $\alpha \leq 0.01$.

The results for the subsamples of 27 high-level product groups (table 6) are rather similar to the results for all technology fields. The coefficients β_j are greater than 0 in all cases. β -despecialisation occurs now for six out of the seven countries which show β -despecialisation in all technologies as well. Only for Italy, which also shows β -despecialisation in the sample of all technology fields, the hypothesis of β -despecialisation must now be rejected. This special result may be caused by the fact that Italy shows in the leading-edge as well as in the high-level markets a few very strong and persistent specialisations which yield stronger weights in the smaller subsamples.

Again, neither σ -despecialisation nor -specialisation occur in any of the cases.

In summarising these results it can be emphasised that the tendencies to move specialisation patterns towards the average are stronger in the fields of high-level technologies than in the fields of leading-edge technologies. As leading-edge products are more often not traded under conditions of free markets and are also more often subject to government interventions, it is obvious from our analysis that the more perfect markets and the fiercer competition in high-level markets facilitates global forces and international assimilation.

Table 6

Regression results for high-level product groups (RPS94/95 on RPS89/90)

Country	$\hat{\beta}_j$	t-value $H_0: \beta_j = 0$ against $H_A: \beta_j > 0^{(1)}$	t-value $H_0: \beta_j = 1$ against $H_A: \beta_j < 1^{(1)}$	R_j^2	$\frac{\hat{\beta}_j}{R_j}$	F-value $H_0: \sigma_{jt(t-1)}^2 = \sigma_{jt}^2$ against $H_A: \sigma_{jt(t-1)}^2 \neq \sigma_{jt}^2$
USA	0.7923	11.4812**	-3.0101**	0.7942	0.8890	1.2652
JPN	0.9236	10.9739**	-0.9074	0.8133	1.0241	1.0489
DEU	0.9803	12.4187**	-0.2497	0.9109	1.0271	1.0550
GBR	0.4839	2.3266**	-2.4813**	0.2094	1.0575	1.1182
FRA	0.7536	8.0606**	-2.6353**	0.6382	0.9433	1.1238
CHE	0.9073	12.6348**	-1.2911	0.7249	1.0656	1.1356
CAN	0.6870	6.9613**	-3.1712**	0.6013	0.8860	1.2740
SWE	0.7530	7.6902**	-1.9783*	0.6126	0.9621	1.0804
ITA	0.9161	11.4568**	-1.0487	0.8376	1.0010	1.0020
NLD	0.7944	8.5864**	-2.2227*	0.7545	0.9146	1.1956

Remarks: ¹⁾ White's heteroscedasticity-consistent estimators of the variance matrix of the regression coefficients are used to calculate t-statistics

* Significant with $0.01 < \alpha \leq 0.05$

** Highly significant with $\alpha \leq 0.01$.

With this interpretation, one exception is Germany, where β -despecialisation only occurs in the subsample of leading-edge technologies. In the high-level category, the unification of West and East Germany prevented German firms from “going global” and special structures were maintained (“unification business cycle”). The other exception is the United States which shows β -despecialisation in the sample of all technology fields as well as in both subsamples. We have to mention here that US enterprises during the years of the “cold war” pursued special trajectories with a very high defence-oriented component in technology. In the period considered here, this idiosyncratic pattern was partly given up.

However, whenever β -despecialisations reduced dispersions of technological specialisation patterns these effects were compensated by new shocks captured by the error terms. So, σ -despecialisation cannot be established for any country and any sample or subsample. Also, the hypothesis of reverse or random patterns can be rejected in most cases, thus the hypothesis of cumulativeness and path dependency, which some schools of economic thought brought up, is supported. Exceptions in the field of leading-edge technologies are the United Kingdom and the two small economies of Canada and the Netherlands.

5. Conclusions

A key issue explored in this paper is whether patterns of technological specialisation of advanced countries change over a period of time in which globalisation in technology occurs. Furthermore, the question was considered whether changes occurring can be characterised as despecialisation or further specialisation of countries. The theoretical analysis of these questions is based on models of new growth and trade theory — especially a model by Grossman/ Helpman (1991) — as well as on evolutionary economics. These have shown that continuous innovation and intra-sectoral knowledge transfer lead to changes of specialisation patterns depending on the degree of openness of economies.

First, structural decomposition analysis is used to investigate the effects that determine changes in technological specialisation. From this analysis it can be seen that growth or decrease of an individual country's patent shares (the proxy for technology output) are mainly determined by technological share effects. Structural effects are only of secondary importance, i. e. firms in most countries are “following the crowd” and are putting only little effort into changing their patterns of specialisation. Most countries are only moving actively to a small extent into growing high technology markets or out of decreasing ones. These results correspond with the findings of Archibugi/Pianta (1992). They conclude that specialisation advantages emerge “regardless of the particular sectors in which individual countries concentrate their efforts; in other words, for advanced countries being specialised appears

to be even more important than choosing the ‘right’ fields” (loc. cit.). So, there is no simple mechanistic panacea for a ‘Paradise on Earth’ by means of specialisation in leading-edge technology sectors or fast growing sectors only (Dalum/Villumsen, 1996). Our findings also support the view that cross-border spillover effects must be effective in some way.

Secondly, the concepts of β - and σ -despecialisation (or -specialisation) were operationalised and applied to investigate whether countries are moving towards an average specialisation (β -despecialisation) and whether dispersions of relative patent shares of the firms in the individual countries have been reduced during the time (-despecialisation). Regression results show that β -despecialisation occurs in seven out of ten advanced “national innovation systems” which are the largest technology producers. Furthermore, the analysis of two subsamples of leading-edge and high-level technologies show that movements towards the average are caused to a greater extent by changes in specialisation patterns in the case of more perfect markets with fiercer competition. The hypothesis that changes in patterns of specialisation are random must be rejected in almost all cases.

The changes of specialisation patterns in leading-edge technologies in the United Kingdom, Canada and the Netherlands are the only exceptions. However, σ -despecialisation is in no case statistically significant. So, whenever β -despecialisation reduced dispersions of technological specialisation patterns, these effects were compensated by new “random” shocks. On the other hand, σ -specialisation due to an increase in dispersion also does not occur.

These results correspond with those of Dalum/Villumsen (1996) and Dalum et al. (1996) concerning changes in trade specialisation of OECD countries observed over the much longer period from 1961 to 1992. They also found many indications of β -despecialisation, but nearly no indicators of statistically significant σ -despecialisation. Furthermore, considering 16 OECD countries from 1964 to 1990, Münt/Grupp (1996) found statistically significant increases in technological specialisation (σ -specialisation) in two cases (United States and United Kingdom) and a decrease in trade specialisation (σ -despecialisation) in one case (Spain). Obviously, in the decade of “globalisation” in technology, these effects are not much different from those in the longer post-war period with a lesser degree of globalisation.

Taking all these results together, the evidence points to rather stable dispersions of technological as well as trade specialisations. However, results indicating β -despecialisation also show that the majority of national innovation systems are now moving towards an average technological specialisation. This is quite in accord with the results of the structural decomposition analysis where the technology share effects and not the structural effects are predominant.

As a disaggregation of such effects to the level of products or markets is now accessible for industrial economics, both from a theoretical and from an empirical

point of view, new opportunities for economic analysis seem to emerge. In this field further research is necessary from an analytical as well as from a normative point of view.

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Zusammenfassung

Dieser Beitrag beschäftigt sich mit der Frage, ob die technologischen Spezialisierungsmuster hochentwickelter Volkswirtschaften im Zeitalter der technologischen Globalisierung sich angeglichen haben oder divergieren. Die Grundlage der theoretischen Analyse bilden dabei die Modelle der neuen Wachstums- und Außenhandelstheorie — insbesondere ein Modell von Grossman/Helpman (1991) — sowie die evolutorische Ökonomik. Die empirische Analyse, basierend auf den Patentanmeldungen der zehn patentstärksten Länder in 42 FuE-intensiven Produktgruppen ist in zwei Teile aufgegliedert. Zum einen wird die strukturelle Dekompositionsanalyse verwendet, um die Effekte herauszuarbeiten, die Veränderungen der technologischen Spezialisierung determinieren. Zum anderen werden — in Analogie zu den Konzepten der β - und σ -Konvergenz (oder Divergenz) — die Konzepte der β - und σ -Despezialisierung (oder Spezialisierung) operationalisiert und genutzt, um zu untersuchen, ob sich die Länder auf eine Durchschnittsspezialisierung zubewegen und ob sich die Streuungen der relativen Patentanteile der Unternehmen in den einzelnen Ländern im Zeitablauf reduzieren. Insgesamt deuten die empirischen Evidenzen auf recht stabile Streuungen bei den technologischen Spezialisierungen. Zahlreiche Resultate, die eine β -Despezialisierung anzeigen, belegen aber auch, daß sich die Mehrheit der Länder der Durchschnittsspezialisierung annähert. Dieser Befund steht im Einklang mit den Ergebnissen der strukturellen Dekompositionsanalyse, bei denen die Technologieanteils-effekte und nicht die strukturellen Effekte dominieren.