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Why growth rate differences persist

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Chapter 5

Technology diffusion at industry level, 1973-1993

5.1 Introduction

To what extent does international technology diffusion affect the follower economy via different diffusion channels? For instance, new technology can be widely applicable, such as ICT, or only relevant to a particular industry. Distinguishing different technology flows may add more insight to the macro-economic model in Chapter 4, leading to a more explicit statement about the functioning of the international technology diffusion mechanism.

The model estimated in the current chapter makes a distinction between two technology diffusion channels. The modeling of these diffusion channels requires disaggregation to the industry level. In the resulting industry model, industry purpose technology is directly transferred from a leading industry into a similar follower industry in another country. Secondly, general purpose technology is transferred from the domestic technology pool into the follower industry. By estimating this model, the current chapter aims to discriminate which technology diffusion channel is more important in the reduction of international growth rate differences at industry level. The focus of these estimations is on differences across industries rather than differences across countries. Again, international differences in technology systems and innovation systems are considered as fixed.

Section 5.2 describes the industry growth model. Section 5.3 discusses the data, the underlying time series are given in Appendix B.3.

Section 5.4 describes the correlations between the variables and the estimation method. Finally, the estimations in Section 5.5 try to uncover the impact of the two technology diffusion channels. Section 5.6 concludes.

5.2 The model

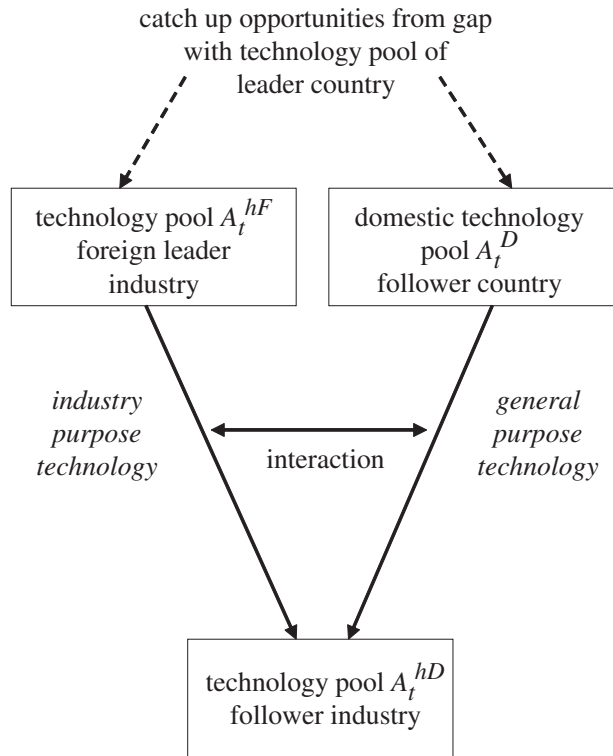
The macro-economic growth model in the previous chapter does not reveal the way leading edge foreign technology is absorbed by industries in a follower country. Technology might only be relevant for a specific industry. New technology in the American telecommunication equipment industry might be transferred only to the telecommunication equipment industry in France. Or technology may have characteristics which makes it applicable to various sectors in the economy, such as ICT. Industries may differ in the extent of absorption and impact of such different types of technologies.

The model in the current chapter distinguishes two technology diffusion channels. This requires disaggregation to the industry level. An additional advantage of an industry level model is that it meets the reality that there are substantial growth rate differences and differences in technology advancement across industries, as economic history shows. Compare, for instance, the technological development between high-technology industries like computer equipment and more traditional industries like textiles.

The core of the industry level growth model is displayed in Figure 5.1. Two technology diffusion channels from the technologically leading country are supposed to transfer technology into a follower country's industry. The relative importance of these two diffusion channels may differ across industries.

Industry purpose technology First, industry purpose technology (IPT) is transferred from an industry in the technologically leading country to a similar industry in the follower country. IPTs explicitly support the technology applied by the follower industry. For instance, in chemicals, technology on the working of various chemical substances is the basis for the ability to process these materials into particular products. In the model, I assume that US industries function as a benchmark in IPTs for European industries. The latter absorb the American leading edge IPT by means of their own R&D.

Figure 5.1: Diffusion mechanism at industry level



General purpose technology Alternatively, the follower industry absorbs general purpose technology (GPT) from the domestic technology pool, also supported by own R&D. A GPT is applicable in several, technologically non-similar, industries. A well-known example is information and communication technology (ICT), that increases the speed and complexity of production processes in many industries. ICT is a 'breakthrough' technology, comparable to the invention of the steam engine and the dynamo (David, 1991). However, there are also a number of minor technologies from other industries which are widely applicable after first stage development. For instance, technologies developed in the aerospace industry have been applied in the automotive and household

equipment industries.¹

In the model, GPTs are supposed to originate from the presumed technology leader, the US. The GPTs are not transferred directly from the US into the follower industry, because technology which is not industry specific may not be easily or immediately absorbed by the industry. Absorption of GPTs requires an adjustment to country-specific circumstances in order for the GPT to become productive. Therefore, it is assumed that GPTs are absorbed at national level.² The adjustments to the local circumstances are then already realized, when the GPTs are transferred from the domestic technology pool into the follower industry. This assumption captures the idea of the importance of a properly working domestic innovation system for an industry.

Interaction between GPT and IPT diffusion Finally, the model states that the two technology diffusion channels may interact with each other. A GPT like ICT may support the absorption of IPTs. This accelerates growth of technology and thereby the chance of higher productivity growth. On the other hand, interaction between IPTs and GPTs might also slow down technology growth. For instance, if a GPT is not well embedded in the domestic growth system, it may hamper IPTs to diffuse into the industry. Finally, there may be no interaction at all. Sometimes this is because GPT diffusion is not important to an industry, but only IPTs, or reversely. It is, for example, conceivable that a highly competitive high tech industry like the telecommunication equipment industry focuses on absorption of foreign leading edge IPTs, and that GPTs from the domestic technology pool plays no perceptible role in this industry's technology growth.

5.2.1 Technology diffusion at industry level

Formally, the growth of the average productivity of technology A_t^{hD} in industry h in its home country D is affected by two technology gaps: first, the gap with the foreign leading edge industry's technology level A_t^{hF} , and second, the gap with the domestic technology pool A_t^D . Furthermore, interaction between these gaps affects the industry's technology growth rate.

¹Helpman (ed., 1998) defines a GPT as a major innovation, that is, a breakthrough technology. I apply the broader definition including important minor innovations.

²This is international technology diffusion at macro-economic level, which is modelled in Chapter 4.

IPT diffusion Industry purpose technologies are transferred from a similar leading industry abroad. Define A_t^{hF} as the technology of the benchmark industry h in country F at time t . This leading industry technology pool grows at rate

$$g_{A_t^{hF}} = \frac{dA_t^{hF}/dt}{A_t^{hF}} = \hat{\varphi}\hat{v}_t,$$

where $\hat{\varphi}$ is the size of the innovations, and \hat{v}_t the arrival rate.

The industry under consideration will receive IPTs from the leading edge industry. The arrival of new blueprints will gradually replace existing average technology A_t^{hD} with the benchmark IPT from the leading edge technology A_t^{hF} . The speed at which this occurs, may be dependent on, among other things, own R&D efforts (cf. the macro-economic model).

The long run change in productivity dA_t^{hD}/dt is a function of the arrival rate of innovations v_t times the average change of technology $A_t^{hF} - A_t^{hD}$:

$$\frac{dA_t^{hD}}{dt} = v_t (A_t^{hF} - A_t^{hD}).$$

GPT diffusion General purpose technologies are transferred from the domestic technology pool A_t^D to the follower industry, by means of a reduction in the gap between their technology pools. The growth rate of the domestic technology pool $g_{A_t^D}$ is determined as $\hat{\theta}\hat{\eta}_t$. Assume that the industry's technology changes as a function of the arrival rate of innovations η_t times the average change of technology $A_t^D - A_t^{hD}$:

$$\frac{dA_t^{hD}}{dt} = \eta_t (A_t^D - A_t^{hD}).$$

Interaction between IPT and GPT diffusion Assume that the diffusion channels for IPTs and GPTs interact with each other. They may support or hamper each other, and investment in absorbing both types of technology may give more or less than proportionally returns. The joint effect of the two technology diffusion channels is expressed by

$$\Theta_t = (A_t^{hF} - A_t^{hD}) \times (A_t^D - A_t^{hD}).$$

This interaction term represents different regimes, by being either negative or positive. If it is negative, the gaps hinder or exclude each other. But if it is positive, the gaps complement each other, adding an extra effect to the growth rate of the industry's technology.

The industry's growth rate of technology Suppose that dA_t^{hD}/dt consists of a sum of the effect of both IPT and GPT diffusion and the interaction term

$$\begin{aligned}\frac{dA_t^{hD}}{dt} &= v_t (A_t^{hF} - A_t^{hD}) \\ &\quad + \eta_t (A_t^D - A_t^{hD}) \\ &\quad + \bar{\mu}_t (A_t^{hF} - A_t^{hD}) \times (A_t^D - A_t^{hD}),\end{aligned}$$

where $\bar{\mu}_t = (1/A^{hD}) \mu_t$, for convenience.³

Define $\Pi_t \equiv A_t^{hF}/A_t^{hD}$ as the technology gap of the industry with the leading edge industry, and $\Lambda_t \equiv A_t^D/A_t^{hD}$ the gap with the domestic technology pool. Then the growth rate of the industry's technology is as follows:

$$\begin{aligned}\frac{dA_t^{hD}/dt}{A_t^{hD}} &= v_t \left(\frac{A_t^{hF} - A_t^{hD}}{A_t^{hD}} \right) \\ &\quad + \eta_t \left(\frac{A_t^D - A_t^{hD}}{A_t^{hD}} \right) \\ &\quad + \bar{\mu}_t \left(\frac{(A_t^{hF} - A_t^{hD}) \times (A_t^D - A_t^{hD})}{A_t^{hD}} \right) \\ &= v_t (\Pi_t - 1) + \eta_t (\Lambda_t - 1) + \mu_t (\Pi_t - 1) \times (\Lambda_t - 1).\end{aligned}\tag{5.1}$$

The parameters v_t , η_t and μ_t depend on R&D efforts and other non-R&D factors like institutional changes. However, the speed at which new IPTs from the leading edge industry abroad will arrive in the industry under consideration needs not to equal the speed at which new ideas are absorbed from the domestic technology pool. If the interaction parameter $\mu_t > 0$, then the two technology diffusion channels enforce each other. If $\mu_t < 0$, then the two channels hinder each other. In this case, the ultimate compound effect of the two technology diffusion channels may be less than their 'sum'.

Long run properties In the steady state, the technology gaps of industry hD are supposed to be constant. All opportunities for industry

³ $1/A^{hD}$ can be considered as a scale factor.

hD to absorb technology from industry hF or from the domestic technology pool A^D are then exhausted. Even additional R&D efforts will not increase the speed of diffusion. The gap cannot be reduced further and the technology pools will evolve at the same speed. That is, the technology gaps grow at rate zero, and therefore the growth rates of the technology pools are equal to each other:

$$\frac{d\Pi_t/dt}{\Pi_t} = \frac{dA_t^{hF}/dt}{A_t^{hF}} - \frac{dA_t^{hD}/dt}{A_t^{hD}} = 0$$

and

$$\frac{d\Lambda_t/dt}{\Lambda_t} = \frac{dA_t^D/dt}{A_t^D} - \frac{dA_t^{hD}/dt}{A_t^{hD}} = 0.$$

The growth rate of the follower industry's technology pool is equal to the growth rates of the benchmark technology pools, namely $\hat{\varphi}\hat{v}_t$ and $\hat{\theta}\hat{\eta}_t$. In this steady state, $v_t = \eta_t = \mu_t$. Then the long run value of the technology gaps are as follows:

$$\begin{aligned} \hat{\varphi}\hat{v}_t = \hat{\theta}\hat{\eta}_t &= v_t(\Pi_t - 1) + \eta_t(\Lambda_t - 1) + \mu_t(\Pi_t - 1) \times (\Lambda_t - 1) \\ \iff \hat{\varphi} &= (\Pi_t - 1) + (\Lambda_t - 1) + (\Pi_t - 1) \times (\Lambda_t - 1) \\ \iff \hat{\varphi} &= \Pi\Lambda - 1. \end{aligned}$$

The compound value of the technology gaps is determined by a constant $\hat{\varphi} + 1$, the size of progress.

5.2.2 Empirical specification

Like in the macro-economic model, some *ad hoc* assumptions need to be made in order to arrive at a testable model.

Productivity growth The productivity growth of an industry is, cf. the macro-economic growth model, affected by the growth in capital intensity and technological change. Formally, the productivity growth function is for a follower industry h in country D as follows:

$$\Delta \ln y_t^{hD} = (1 - \alpha)\Delta \ln A_t^{hD} + \alpha \left[\Delta \ln(K/L)_t^{hD} + \Delta \ln A_t^{hD} \right] + u_t, \quad (5.2)$$

where productivity growth $\Delta \ln y_t^{hD}$ depends on growth in capital intensity $\Delta \ln(K/L)_t^{hD} + \Delta \ln A_t^{hD}$ measured in efficiency units, and growth in the technology level $\Delta \ln A_t^{hD}$.⁴ The parameter α represents the share of capital in output.

⁴Technological progress is Hicks-neutral, cf. Section 4.2.3.

Technology growth Define the empirical counterparts of the technology gaps Π_t and Λ_t as ⁵

$$-\ln \Pi_t = \ln A_t^{hD} - \ln A_t^{hF} = z_t^{hF}$$

and

$$-\ln \Lambda_t = \ln A_t^{hD} - \ln A_t^D = z_t^D.$$

That is, the change in the level of technology in industry hD depends on the technological gaps with the benchmark technology pools A_t^{hF} and A_t^D . Again, I impose an ECM structure which has a tendency to converge to the long run in which the technology growth in industry hD depends on the long run level of the gaps z_t and the growth of the benchmark technology pools.⁶ The dynamics are captured by

$$\begin{aligned} \Delta \ln A_t^{hD} &= -\lambda^{hF} (\ln A_{t-1}^{hD} - \ln A_{t-1}^{hF} - z_t^{hF}) + \beta^{hF} \Delta \ln A_t^{hF} \\ &\quad -\lambda^D (\ln A_{t-1}^{hD} - \ln A_{t-1}^D - z_t^D) + \beta^D \Delta \ln A_t^D. \end{aligned}$$

The additional cross effect between the two technology diffusion channels is empirically represented by the term

$$\hat{\Theta}_t = \left(\ln A_{t-1}^{hD} - \ln A_{t-1}^{hF} \right) \times \left(\ln A_{t-1}^{hD} - \ln A_{t-1}^D \right).$$

Now suppose, cf. Equation (5.1), that the growth in the level of technology in industry hD depends on the two technological gaps with the benchmark technology pools, the growth rate of these pools and the interaction effect:

$$\begin{aligned} \Delta \ln A_t^{hD} &= -\lambda_t^{hF} \left(\ln A_{t-1}^{hD} - \ln A_{t-1}^{hF} - z_t^{hF} \right) \\ &\quad -\lambda_t^D \left(\ln A_{t-1}^{hD} - \ln A_{t-1}^D - z_t^D \right) \\ &\quad +\chi \left(\ln A_{t-1}^{hD} - \ln A_{t-1}^{hF} \right) \times \left(\ln A_{t-1}^{hD} - \ln A_{t-1}^D \right) \\ &\quad +\beta^{hF} \Delta \ln A_t^{hF} + \beta^D \Delta \ln A_t^D + u_t. \end{aligned} \tag{5.3}$$

Equation (5.3) is the empirical counterpart of Equation (5.1). The parameters λ_t^{hF} and λ_t^D are the diffusion speed parameters. They indicate

⁵Note that for the industry under consideration, $0 < \Pi < 1$ and $0 < \Lambda < 1$, so that $z < 0$.

⁶Cf. the reasoning for Equation (4.7) in the macro-economic model.

how fast the follower industry's technology pool A_t^{hD} succeeds to catch up with the benchmark technology pools. Assume that both λ^{hF} and λ^D can be influenced by the industry's own R&D effort:

$$\lambda_t^{hF} = \psi^{hF} + \gamma^{hF} [n_t^{hD}] \quad (5.4)$$

and

$$\lambda_t^D = \psi^D + \gamma^D [n_t^{hD}], \quad (5.5)$$

where n_t^{hD} is the industry's relative R&D effort. It may be proxied by N_t^{hD}/Y_t^{hD} , which is the R&D effort of industry hD over the industry's value added Y .⁷

The impact of R&D is indicated by the coefficients γ^{hF} and γ^D . Non-R&D forces exert influence via the constants ψ^{hF} and ψ^D . The composite terms λ_t^{hF} and λ_t^D can be negative or positive. If a country D lags behind in terms of technology in industry h , then a positive value for λ_t^{hD} signals convergence to the foreign benchmark technology.

The productivity growth equation (5.2) and technology growth equation (5.3) with the diffusion speed equations (5.4) and (5.5) are estimated on industry level diffusion of technology from technology pools in the US to France, Germany and the UK between 1973 and 1993. The notes on empirical application of the macro-economic model do also apply to the industry level model here (see Section 4.2). The industry level growth model describes a steady state. Empirical applications just test the short run conditions, to see how the economy deviates from its long run growth path, and whether there is a different impact from different technology diffusion channels.

5.3 Data

Time series on labour productivity, capital intensity, technology and R&D effort in six manufacturing industries of the UK, France and Germany between 1973 and 1993 are presented in this section. The US is presented as the benchmark country, but it is not necessarily the technology leader in each industry. I discuss the proxies for the variables in Section 5.3.1. I compare the productivity and technology content of the six industries with each other and with other manufacturing industries (Section 5.3.2). In Section 5.3.3, I describe the developments in the time series.

⁷Cf. Equation 4.8 in the macro-economic model.

5.3.1 Proxies for the variables

A detailed description of the data for the six manufacturing industries is found in Appendix B.3. The variables are proxied in a similar way as for the macro-economic model in Chapter 4.

Labour productivity Labour productivity is measured as value added per hour worked, based on data from O’Mahony and De Boer (2002).

Capital intensity Capital intensity is proxied as capital services per hour worked. The data are from O’Mahony (1999), as O’Mahony and De Boer (2002) do not provide data before 1989 for German manufacturing industries.

Technology The technology level A is calculated as the stock of US grants cumulated over 10 years, with data from Verspagen (1996, updated). These data have three advantages. First, the patents are divided over several industries, with the possibility to construct industry-specific patent pools. Second, the US granting procedure is the same for all countries, increasing comparability between countries which are assigned US patents. Third, granted patents are supposed to contain a certain economic utility, increasing the chance that they affect economic activity.

It is assumed that the American market is so dominant in the world economy that it attracts all relevant new technology from own residents and from abroad, thereby representing a ‘leader technology pool’. The US grant stock of a follower industry hD is assumed to represent its technological level. Formally, this is calculated with cumulated US grants P assigned to residents from country D in industry h ,

$$A_t^{hD} \equiv \sum_{t-10}^t P_t^{hD}.$$

By definition, both the technology pools A_t^{hF} and A_t^D exclude the technology pool of industry hD , as they represent technologies not yet absorbed by industry hD .⁸ The technology level of the leader industry A_t^{hF} is constructed with the total number of US grants assigned to an

⁸Suppose A^D would include A^{hD} . If A^{hD} increases with a certain amount while the remainder of the technology pool $A^D - A^{hD}$ does not change, then the total technology pool A^D increases with a similar amount. In this case, the technology gap $A^{hD} - A^D$ does not decline.

industry h for all m countries, minus the grants for country D in the same industry h ,

$$A_t^{hF} \equiv \sum_{t-10}^t \sum_{j=1}^m P_t^{hj} - \sum_{t-10}^t P_t^{hD} \quad \forall \quad j = 1, \dots, D, \dots, m.$$

The domestic technology pool is the total number of US grants assigned to residents from country D in all n manufacturing industries, minus the grants for industry h of the same country D ,

$$A_t^D \equiv \sum_{t-10}^t \sum_{k=1}^n P_t^{kD} - \sum_{t-10}^t P_t^{hD} \quad \forall \quad k = 1, \dots, h, \dots, n.$$

R&D R&D intensity is measured by the log-level of business R&D expenditures per unit value added, with data from OECD databases. Before 1973, R&D data at industry level are not available.

5.3.2 Heterogeneity in productivity and technology

Six manufacturing industries were selected for model estimation on the basis of their characteristics in productivity and technology. Table 5.1 presents the productivity growth performance of twelve manufacturing industries and four aggregations of some of these industries between 1973 and 1993. The period after 1973 is the slowdown after the Golden Age. Annual growth rates of labour productivity are therefore not as high as in the Golden Age of 1950-1973. But the manufacturing industries in France, Germany and the UK generally reach slightly higher growth rates (0.5 to 2.4%) than most US industries (0.1 to 0.9%). The only industries where American growth rates were generally higher (1.4 to 2.5%) than in Europe (1.0 to 2.5%) are rubber and plastics, electronic equipment, and the office equipment and machinery industry. In the office equipment and machinery industry, the American growth was probably high in particularly the office and computing equipment branch.⁹ Together with the electronic equipment industry, the office and computing industry develops ICT hardware equipment.

Rough indicators for the capital and technology characteristics of the various manufacturing industries (Table 5.2) show that the electronic equipment and office and computing industries have a relatively

⁹Data for the American office and computing industry separately from the machinery industry were not available.

Table 5.1: Value added per hour worked (average annual growth rates) in 12 manufacturing industries, 1973-1993

	France	Germany	UK	US
Chemicals and allied products	1.6	1.2	1.3	0.8
... Chemical products	0.9	1.3	0.8	0.8
... Rubber and plastics	1.0	1.0	1.1	1.4
Basic metals and metal products	1.3	1.3	0.9	0.2
... Basic metals	2.3	1.5	1.1	0.1
... Metal products	0.8	0.9	1.2	0.5
Total machinery and equipment	1.6	1.1	1.3	0.9
... Office equipment and machinery	NA	0.7	0.8	1.4
... ... Machinery	1.2	0.4	0.5	NA
... ... Office and computing	NA	4.3	2.7	NA
... Electrical and electronic equipment	2.5	1.8	1.8	2.5
... Optical equipment and instruments	2.4	0.7	2.1	0.6
... Motor vehicles	0.5	1.0	1.1	0.3
... Other transport equipment	1.8	0.9	2.1	0.4
Food, beverages and tobacco	1.0	0.7	0.9	0.5
Textiles, clothing and leather	1.6	1.5	1.2	1.5

Source: See Appendix B.3. Note: French series start in 1976 for chemical products and rubber and plastics. Furthermore, the French data on electrical equipment include office and computing.

high technology content, with more than 10 patents per 10 million hours worked and R&D as percentage of value added exceeding 15%. Other industries with relatively high labour productivity growth rates are optical instruments (France and UK) and other transport equipment (think of aircraft, in the UK). These industries do also have a relatively high technology content.

The only branch with a high technology content but not a high labour productivity growth (around 1.0%, see Table 5.1) is the chemical products industry. The growth spurt in this industry came only by the 1990s, when technological progress in life sciences accelerated. Biotechnology is part of these life sciences, and of particular importance to pharmaceuticals, part of the chemical products industry.

Four industries stand out in Table 5.2 because of low technology content (less than 4 patents per 10 million hours worked and an R&D intensity smaller than 5%): basic metals, metal products, food and textiles. These industries differ in capital intensity. Basic metals and metal products have an average capital intensity, the food industry has a high

Table 5.2: Characteristics of 12 manufacturing industries in US, UK, France and Germany, 1973 and 1993

	capital per hour worked	patents per hour worked in previous year	R&D exp. per unit value added
... Chemical products	high	high	medium
... Rubber and plastics	high	medium	low
... Basic metals	medium	low	low
... Metal products	medium	low	low
... ... Machinery	low	medium	medium
... ... Office and computing	medium	medium	high
... Electrical and electronic equipm.	medium	high	high
... Optical equipm. and instruments	medium	high	medium
... Motor vehicles	high	low	medium
... Other transport equipment	high	medium	high
Food, beverages and tobacco	high	low	low
Textiles, clothing and leather	low	low	low

Source: See Appendix B.3. Rough numbers, based on data for US, UK, France and Germany in 1973 and 1993. Capital intensity: High = higher than 35\$ per hour worked; medium = 20 to 35\$; low = below 20\$ (actual classification capital data at higher aggregation level). Patent productivity: High = more than 10 patents per 10 mln hours worked; medium = 4-10 patents, low = less than 4 patents (some data are lacking). R&D intensity: High = above 15%; medium = between 5 and 15%, low = below 5%.

capital intensity, and textiles a low capital intensity. At first sight, the growth rates of these industries are not linked directly to their capital intensities. The growth rates of the food industry in the various countries are lower (0.5 to 1.0%) than, for instance, textiles (1.2 to 1.6%). But the capital intensity in textiles is much lower than in the food branch.

The industry growth model discriminates across industries in that differences in industry characteristics are related to differences in the impact of technology diffusion channels. Therefore, I estimate the model for six industries which range from high tech to low tech, and with high to low growth experience:

- Electronic equipment and office and computing: high tech; high growth performance in Europe, but even higher American productivity growth. It is expected that industry purpose technology is more important to these industries than general purpose technology, as these industries are already in the forefront.¹⁰

¹⁰The electronic equipment industry and office and computing industry develop

- Chemicals industry and rubber and plastics industry: medium tech; medium growth, but American productivity growth highest in rubber industry. The quantitative importance of the two technology diffusion channels in these industries is not clear beforehand.
- Food and textiles: low tech; but differing growth performance where the role of capital is not clear beforehand, and low American productivity growth. One might expect that these low tech industries mainly benefit from general purpose technology.

5.3.3 Comparative developments, 1973-1993

Figures 5.2 to 5.6 display the developments (with US=100 or US grant stocks=100) in labour productivity, capital intensity, technology gaps and R&D intensity in the six manufacturing branches of the three European countries. The US are not necessarily the leader in each industry, but in many respects, the US are a benchmark for European economies, so the discussion of comparative developments will tell much about the differences in industry level performance across the European countries between 1973 and 1993.

Labour productivity It is striking that European labour productivity levels are often higher than the American level in both the electronic equipment industry and the office equipment and machinery industry (Figure 5.2).¹¹ Particularly German productivity is relatively high. However, in electronic equipment, the German lead is reduced at great speed from the mid-1980s onwards. By 1993, American productivity is higher than that in France and the UK, and is going to catch up with the German level. In the office equipment and machinery industry, the comparative lead of Germany and the UK decreases during the whole period under consideration.

In chemicals, the American lead in productivity decreases gradually. In rubber and plastics, the European economies were leading in first instance, but by 1993, their comparative productivity levels lie between

ICT technologies which are general purpose technologies for other industries, but for these two industries this is industry-specific technology.

¹¹Separate time series for the office equipment branch and the machinery branch were not available for the US. The French data for office equipment are not separable from those for the electronic equipment industry.

80 and 90 percent of the American level. The differences in productivity level between the European economies are strikingly small in this industry.

In food, the European economies are behind, with a gap increasing until the mid-1980s and decreasing afterwards. Still, by 1993 the American food industry leads in terms of productivity. The French textiles industry's productivity level is high, and German and British levels low. Compared to the US level, the European productivity levels in textiles remain stable during the period 1973-1993.

In these six manufacturing industries, the UK has generally a low productivity in these six manufacturing industries compared to France and Germany, while Germany has often high productivity levels.

Capital intensity In electronic equipment, the European capital intensities grow smoothly compared to the US (Figure 5.3), while labour productivity levels decreased compared to the US (Figure 5.2). A potential explanation is that the European technology levels decreased compared to the US. Because American technology in electronic equipment probably progressed faster than in Europe, the American labour productivity growth might have been comparatively higher. Similarly, the increasing European comparative capital intensities in the rubber industry - while comparative labour productivity levels decreased - might have been accompanied by a comparatively low development of technology levels.

In office and computing, the European capital intensity levels reduced to below the American level. Simultaneously, comparative labour productivity also decreased. In chemicals, German comparative capital intensity did not grow fast from 1980s onwards, and apparently so its labour productivity developed smoothly. In contrast, French capital intensity increased at great speed, accompanied by increasing labour productivity. Apparently, capital intensity and labour productivity developments in office and computing and chemicals accompany each other.

In food and textiles, the development of capital intensities did not match the development of labour productivity. Again, the potential explanation for this development is technology growth. Alternatively, the business cycle exerts a strong influence in these industries.

Figure 5.2: Value added per hour worked (US=100), 1973-1993

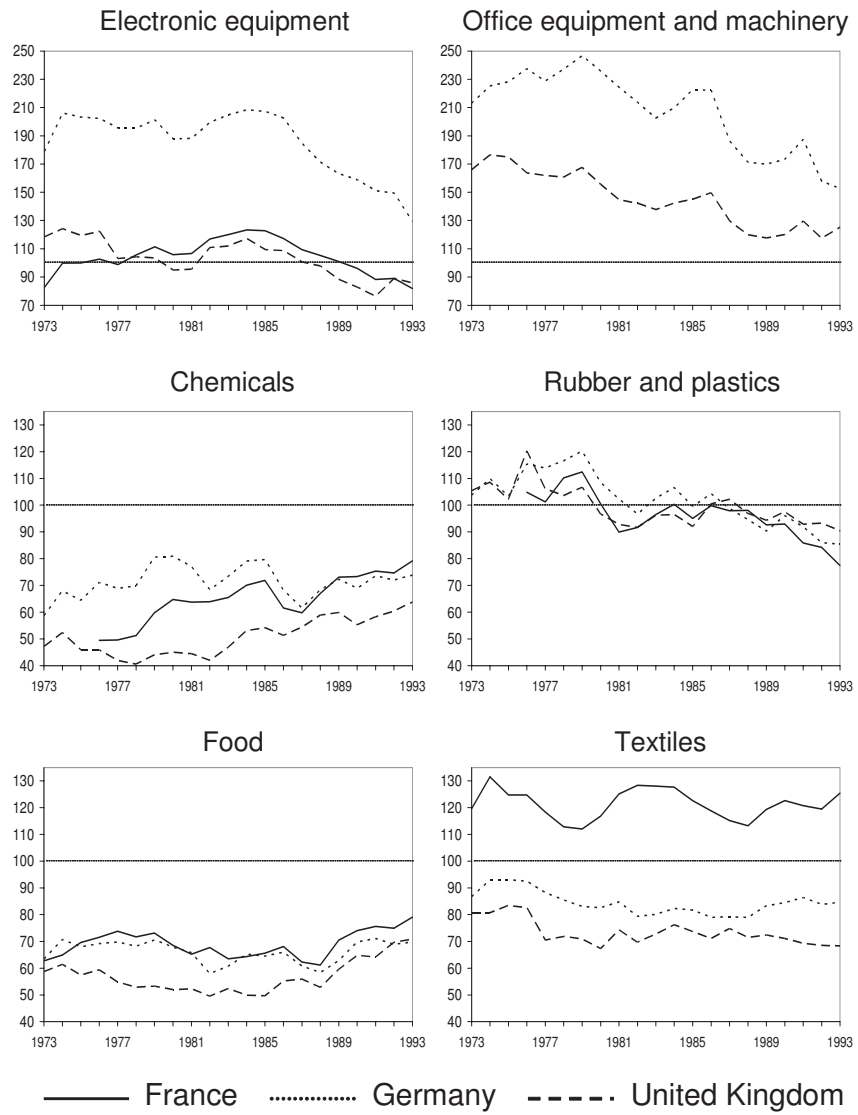


Figure 5.3: Capital per hour worked (US=100), 1973-1993

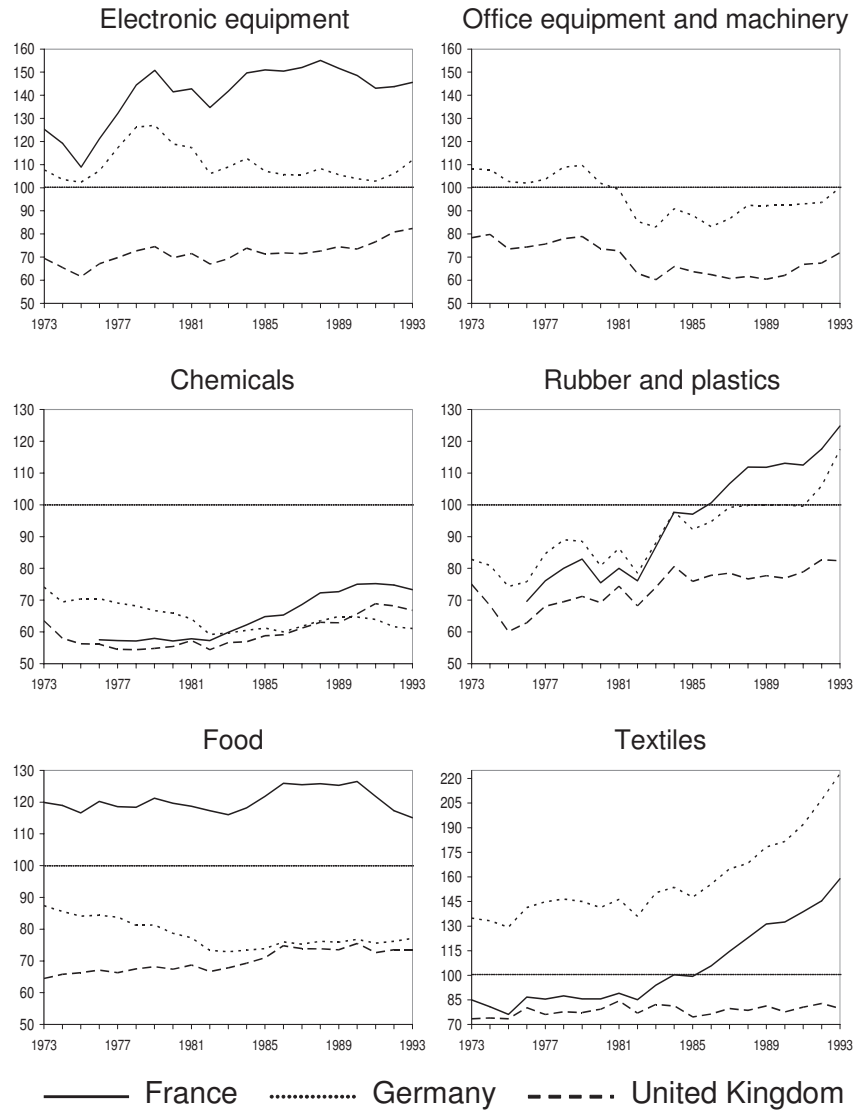


Figure 5.4: Stock of US grants cumulated over 10 years ($A^{hF}=100$, stock of US grants in industry h), 1973-1993

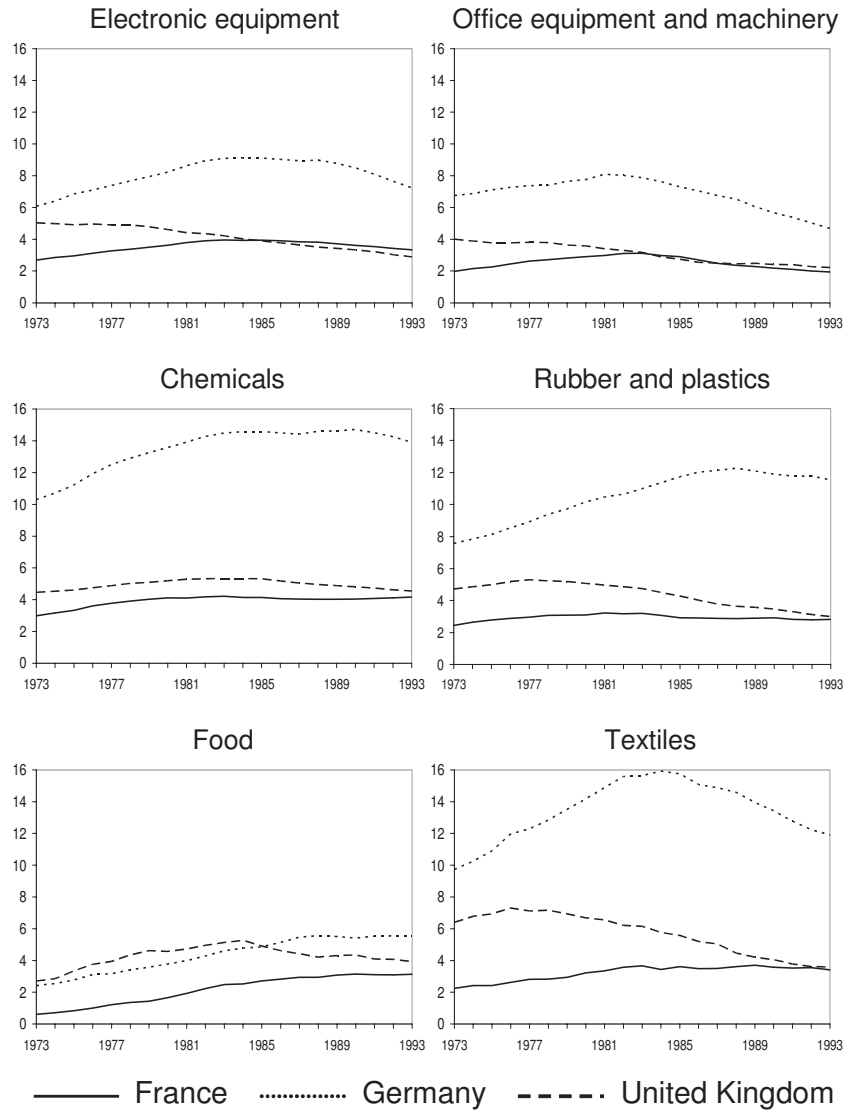


Figure 5.5: Stock of US grants cumulated over 10 years ($A^D=100$, stock of US grants for country D), 1973-1993

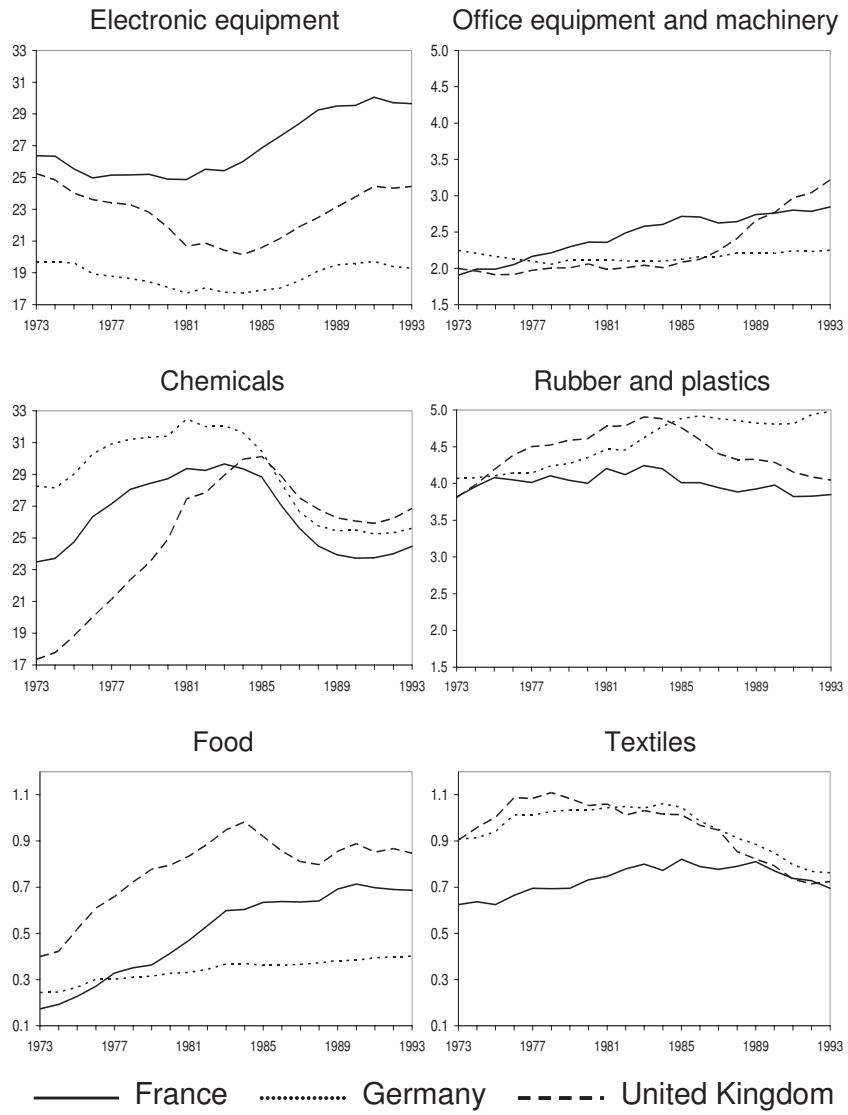
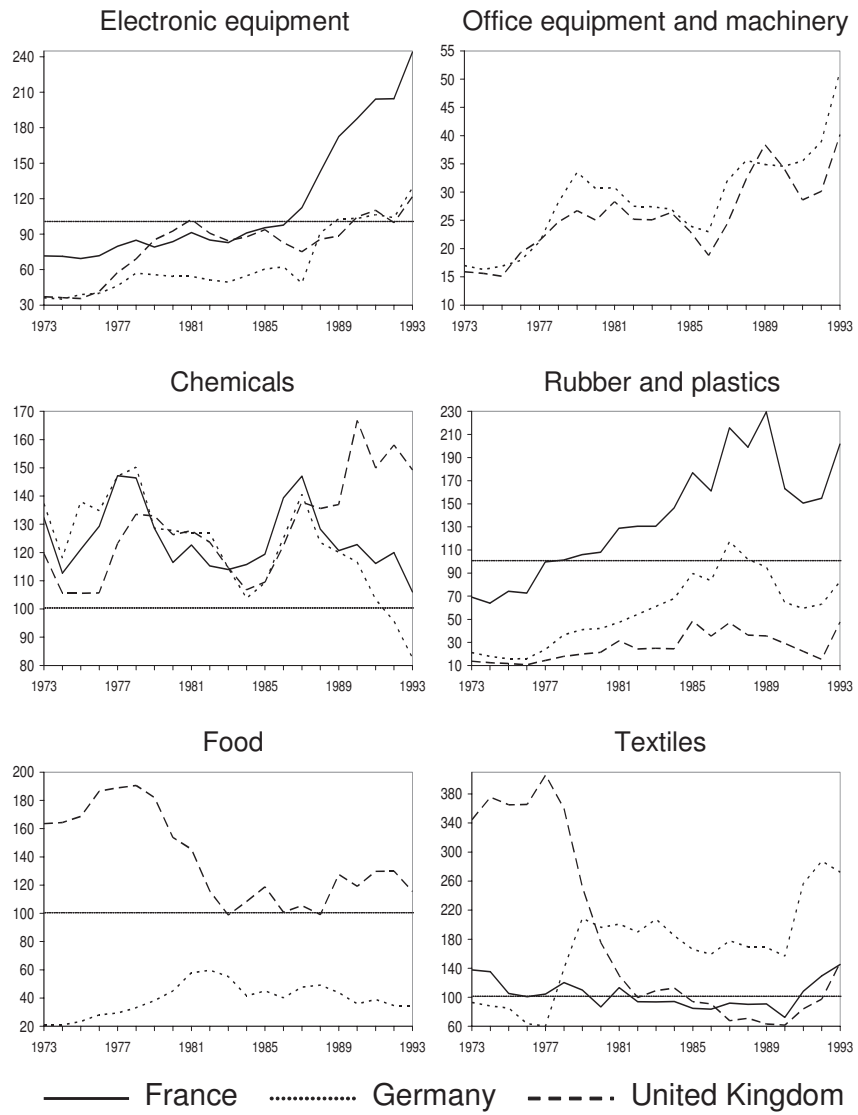


Figure 5.6: Business R&D expenditures per unit value added (US=100), 1973-1993



Technology gap The cumulated patent stocks develop smoothly by construction (Figure 5.4 and 5.5). The technology gaps between the follower industries and the leader industry technology pool A_t^{hF} generally appear to widen from the early 1980s onwards (Figure 5.4). According to the model, R&D efforts should enhance the speed of absorption of industry purpose technologies, thereby reducing the technology gap. However, the US patent stock of the leader industry A_t^{hF} increased more rapidly than the US patent stocks of the six industries in the three European countries.

In contrast, the developments in the industries' technology gaps with the domestic technology pools differ across industries (Figure 5.5). This is because industries differ in technology content. High tech electronic equipment and, to an increasing extent, office and computing, increased their share in the domestic technology pool. The share of chemicals in the domestic technology pools is high, but the increase up to the mid-1980s did not continue afterwards. Strikingly, the German rubber industry had a different experience than the UK and France. In the food sector, the technology gap decreased, and in textiles, the technology gap increased. But for both the low tech industries, their technology gap with the domestic technology pool is very large compared to the other four industries.

R&D efforts The European R&D efforts per unit value added in electronic equipment and office and computing rose compared to the US (Figure 5.6). R&D rose particularly in the French electronic equipment industry, possibly stimulated by the large French public programmes in aerospace research. Meanwhile, the European technology gaps with the leading industry technology pools for the electronic equipment industry and the office and machinery industry increased (Figure 5.6). Possibly the R&D efforts of the European industries did not yet reach a critical mass in order to enhance the speed of absorption of industry purpose technology.

In chemicals, comparative R&D intensity levels fluctuate strongly, to decrease quickly after 1987 for France and Germany, and becoming lower than the US level. Meanwhile, the British R&D intensity level increased fast compared to the US level. The increasing UK specialization in life sciences might be an explanation for this development. In the rubber industry, comparative R&D intensity levels increased with a temporary breakdown in the early 1990s. The French R&D intensity

level is comparatively high, possibly explained by French specialization in the modern life sciences. For chemicals and rubber, no clear link seems to be present between the technology gaps and R&D efforts.

In food and textiles, the international differences in R&D intensity levels are rather large.¹² The UK has a high R&D intensity level, possibly linked to its life science specialization. The UK R&D intensity level in textiles decreased very fast, while the German level increased. There seems to be no clear relationship between the technology gaps and R&D effort in the food and textiles industries.

5.4 Method

Before turning to the estimation results of the model, the data of the six manufacturing industries are scrutinized on correlations between the variables (Section 5.4.1). I do not test for unit roots and cointegrated relationships, as the number of observations for the time period 1973-1993 is relatively low. A small sample period weakens the power of the ADF tests and Johansen cointegration tests.¹³ The estimation method is discussed briefly (Section 5.4.2).

5.4.1 Correlations

Tables 5.3 and 5.4 present the pairwise correlations between the model variables in the labour productivity growth function and the technology growth function for the six manufacturing industries.

First, I expect a positive relationship between labour productivity growth on the one hand and the growth in capital intensity and technology on the other hand. The pairwise correlations appear to be positive in most cases, though the values are not always high. Lagging the capital intensity variable and technology growth variable does not seem to improve the values, and signs do also change in some cases. In estimation, I will follow the approach chosen in Chapter 4: the capital intensity growth rate enters the productivity growth equation with a lag of one period, whereas the technology growth rate is not lagged.

¹²For the French food industry, no value added data in comparative levels (US=100) were available.

¹³That is, there is an increased chance of the type II-error, namely accepting the null hypothesis of a unit root while the null is false.

Table 5.3: Pairwise correlations, 1973-1993

Correlation of labour productivity growth $\Delta \ln y_t^{hD}$ with

		$\Delta \ln(K/L)_t^{hD}$	$\Delta \ln A_t^{hD}$	$\Delta \ln(K/L)_{t-1}^{hD}$	$\Delta \ln A_{t-1}^{hD}$
EE	Fra	0.11	0.42	-0.17	0.41
	Ger	0.07	0.39	-0.21	0.43
	UK	0.33	-0.05	0.47	-0.09
OC	Fra	NA	NA	NA	NA
	Ger	0.36	0.07	0.70	0.16
	UK	0.15	0.10	0.13	-0.07
CH	Fra	0.26	0.06	0.10	0.14
	Ger	-0.24	0.17	0.48	0.17
	UK	0.10	-0.29	0.14	-0.06
RP	Fra	0.33	-0.26	-0.05	-0.15
	Ger	-0.24	-0.03	0.02	0.17
	UK	-0.08	-0.21	0.42	-0.31
FO	Fra	0.62	0.26	-0.10	0.28
	Ger	-0.14	0.14	0.08	0.35
	UK	0.08	-0.11	0.01	-0.29
TL	Fra	0.15	0.44	0.24	0.26
	Ger	0.55	0.38	0.14	0.39
	UK	0.30	0.25	0.29	-0.11

Correlation of technology growth $\Delta \ln A_t^{hD}$ with

		$(\ln A_{t-1}^{hD} - \ln A_{t-1}^{hF})$	$(\ln A_{t-1}^{hD} - \ln A_{t-1}^D)$	$\Delta \ln A_t^{hF}$	$\Delta \ln A_t^D$
EE	Fra	-0.63	0.33	0.67	0.86
	Ger	-0.55	0.40	0.52	0.83
	UK	-0.45	0.38	0.92	0.78
OC	Fra	-0.74	-0.63	0.15	0.84
	Ger	-0.36	0.63	0.40	0.84
	UK	-0.60	0.58	0.86	0.74
CH	Fra	-0.77	-0.74	0.87	0.75
	Ger	-0.80	-0.24	0.79	0.65
	UK	-0.80	-0.82	0.86	0.40
RP	Fra	-0.77	-0.76	0.76	0.85
	Ger	-0.70	-0.60	0.58	0.86
	UK	0.07	-0.84	0.65	0.75
FO	Fra	-0.74	-0.76	0.50	0.50
	Ger	-0.46	-0.56	0.57	0.49
	UK	-0.66	-0.66	0.64	0.42
TL	Fra	-0.63	-0.68	0.43	0.62
	Ger	-0.75	-0.02	0.34	0.70
	UK	0.13	-0.21	0.73	0.66

EE = electronic equipment, OC = office and computing, CH = chemicals, RP = rubber and plastics, FO = food, TL = textiles.

Table 5.4: Pairwise correlations, 1973-1993 (continued)

		<i>Correlation of technology gap...</i>			
		$\dots(\ln A_{t-1}^{hD} - \ln A_{t-1}^{hF})$ with		$\dots(\ln A_{t-1}^{hD} - \ln A_{t-1}^D)$ with	
		$\ln(RD/Y)_t^{hD}$	$\Delta \ln(RD/Y)_t^{hD}$	$\ln RD/Y_t^{hD}$	$\Delta \ln(RD/Y)_t^{hD}$
EE	Fra	0.20	0.43	0.79	-0.04
	Ger	0.56	-0.07	-0.32	-0.06
	UK	0.23	0.55	-0.81	0.28
OC	Fra	NA	NA	NA	NA
	Ger	0.23	-0.26	-0.52	0.39
	UK	0.63	0.40	-0.80	-0.35
CH	Fra	0.59	0.25	-0.35	0.37
	Ger	0.57	-0.17	-0.16	0.21
	UK	0.18	0.00	0.67	0.07
RP	Fra	0.60	-0.13	0.36	-0.26
	Ger	0.81	-0.22	0.71	-0.34
	UK	0.32	-0.06	0.46	-0.07
FO	Fra	0.83	0.16	0.82	0.17
	Ger	0.84	-0.79	0.84	-0.73
	UK	-0.27	-0.16	-0.23	-0.16
TL	Fra	-0.05	0.42	-0.09	0.33
	Ger	0.65	0.06	-0.26	0.06
	UK	0.58	-0.54	0.24	-0.64

EE = electronic equipment, OC = office and computing, CH = chemicals, RP = rubber and plastics, FO = food, TL = textiles.

The correlations between the technology growth rate and the technology gaps are expected to be negative. Table 5.3 shows that the signs are indeed negative in most cases, and often with an absolute value greater than 0.60.

Exceptions are the positive signs for general purpose technology diffusion in electronic equipment and office and computing. This might be related to the fact that these industries are high tech industries, which play a leading role in the innovation system of national economies. That is, they largely determine the development of domestic technology pools. In these industries, diffusion of industry purpose technology is probably more important. Estimations in Section 5.5 should point the relative weight of the diffusion of industry purpose technology compared to the diffusion of general purpose technology to these two industries.

The average absolute correlation value for the technology gap with the leading industry technology pool was slightly higher (about 0.60) than that for the domestic technology pool (about 0.55). This seems to

suggest that keeping in pace with leading industry purpose technology is slightly more important or has a more direct impact than diffusion from the domestic technology pool.

Finally, I expect positive signs for correlations between the technology gap with the leading industry technology growth and the domestic technology growth. The data indeed show positive correlations. The correlation values are high, on average 0.66 for the correlation between the technology growth rates of the follower industry and the leading industry, and 0.74 for the correlation between the follower industries' technology growth and domestic technology growth.

The correlations between the technology gap with the leading industry technology pool and the log-level of R&D intensity show that these have often a positive and sometimes very high value. That is, the higher the potential to catch up in the previous year, the higher the current R&D intensity level.

In contrast, the signs of the correlations between the gap with the domestic technology pool and the follower industries' R&D intensity level change across industries and countries, though they are often high. A negative correlation suggests that if the share of the industry in the domestic technology pool is higher, its R&D effort to reap a potential is lower. This is particularly the case for high tech industries like electronic equipment and office and computing, and maybe also chemicals. To these industries, the international diffusion of industry purpose technology may be of relatively large importance. Correlations with the growth of R&D intensity are less conclusive about the nature of the relationship. Therefore, in estimation, the log-level of R&D intensity is applied as a proxy for R&D effort.

5.4.2 Estimation method

Like in the estimation of the macro-economic growth model, the productivity growth equation and the technology growth equation in the industry model are estimated separately. But the focus of the estimations is on interindustry differences rather than cross-country differences, so no country-specific estimations are presented.

The productivity growth function is estimated with WTSLS, and the technology growth function is estimated with WLS. The instrumental variables for the WTSLS estimation of the productivity growth function are the log-level of R&D intensity and a constant.

Again, low DW values were found but addition of AR(1) do change the estimated values substantially for some industries compared to estimation without AR(1) terms, suggesting hidden complex dynamics in the underlying panel data. As discussed in Chapter 4, the use of AR(1) terms is not generally accepted in panel data estimation. In dynamic panels (with lagged endogenous variables on the right hand side) with a relatively small sample, OLS is biased and inconsistent. The smaller the number of observations over time compared to the number of cross-section units, the larger the problem. GMM estimation is an alternative, but the choice of instrumental variables is not easy with GMM.

Because of the small sample bias, I chose to discuss WTSLS estimations without AR(1) terms or lagged endogenous variables. For tentative comparison, Appendix D presents WLS and WTSLS estimations with AR(1) terms. For the technology growth function, the WLS estimations are presented without AR(1) terms. The addition of AR(1) terms show few statistically significant estimates of the autocorrelation coefficients, and if they are significant, the values are sometimes negative.

The estimation results of the productivity growth function for rubber and food did not show statistically significant estimations of α , or estimation values with economic meaning within the framework of the current growth model. This suggests that the current specification of the productivity growth function is not supported by the industry data. As Salter (1960) already noted, a production function like the Cobb Douglas production function does not represent industry level development adequately. Furthermore, the estimation results for the office and computing equipment industry are to be interpreted with care. In the estimation for this industry, France is not included. In fact, the French office and computing industry is included in the data for the French electronic equipment industry.

5.5 Estimation results

The productivity growth equation (5.2) and technology growth equation (5.3) with the two time-varying speeds of diffusion (5.4) and (5.5) are estimated for the six manufacturing industries in France, Germany and the UK for the period 1973-1993, with the data for the three countries pooled for each industry. These industries range from high-tech to low-tech industries: electronic equipment, office and computing, chemicals, rubber and plastics, food, and textiles. The estimation results for the

productivity growth function are presented in Section 5.5.1, and the results for the technology growth function in Section 5.5.2.

5.5.1 The productivity growth function

Table 5.5 presents the main estimation results for the productivity growth function for the six manufacturing branches in France, Germany and the UK in the period 1973-1993.

Table 5.5: WTSLS estimation productivity growth function, 1973-1993 (*t*-values between brackets)

$$\Delta \ln y_t^{hD} = (1 - \alpha)\Delta \ln A_t^{hD} + \alpha \left[\Delta \ln(K/L)_t^{hD} + \Delta \ln A_t^{hD} \right] + u_t$$

	EE	OC	CH	RP	FO	TL
<i>α̂ (common), impact capital intensity growth</i>						
	0.40 (5.08)	0.69 (3.80)	0.57 (2.57)	1.13 (5.16)	-1.18 (-2.98)	0.16 (1.29)
<i>Observations</i>	57	38	57	57	57	57
<i>Mean dependent variable</i>						
France	5.37		4.83	2.38	2.66	3.44
Germany	3.96	9.93	2.96	2.48	1.54	3.20
UK	4.47	6.11	2.53	2.85	2.36	2.81
<i>Standard error regression</i>						
France	3.01		5.11	5.16	11.85	3.92
Germany	3.32	6.87	6.43	4.50	9.45	4.17
UK	6.99	12.88	7.35	4.42	14.08	7.12
<i>Durbin Watson</i>						
France	1.17		1.27	1.18	2.34	1.43
Germany	1.30	1.91	2.18	2.10	2.22	0.94
UK	1.33	1.39	1.11	1.72	1.26	0.68

EE = electronic equipment, OC = office and computing, CH = chemicals, RP = rubber and plastics, FO = food, TL = textiles. Estimations for office and computing do not include data for France. These are covered in the French data for electronic equipment.

Capital and technology The statistically significant and economically meaningful values of the commonly estimated α , the capital share in output, range from 0.40 to 0.70. These values are substantially higher than the estimated value of about one third for the manufacturing sector

as a whole in the estimation of the macro-economic growth model (see Table 5.5).

A first potential explanation for the relatively high values is in the data. For instance, technology is measured with grants instead of applications. Moreover, the grant data concern patents assigned to the industry under consideration, whereas the application data in the macro-economic model did not discriminate across the non-manufacturing and manufacturing sectors. Another explanation is the different time period of estimation.

But a more fundamental explanation for the difference in estimated values of α between the macro-economic and industry level models is the level of aggregation. At a low aggregation level, differences between countries become more pronounced. If one country's industry has a very high capital share in output, this will bias the commonly estimated value for the three countries together. Furthermore, the lower the aggregation level, the more the dividing line between capital and technology is blurred. Technology development is often partially embodied in capital investment. Estimations of the separate weights of capital and technology are more precise at a higher aggregation level.

Industry differences It appears that in the electronic equipment industry, the commonly estimated capital share in output is lower (0.40) than in office and computing (0.69) and chemicals (0.57). On the basis of the capital and technology characteristics (Table 5.2), one would expect that the capital share would be highest in chemicals. However, patent productivity is also high in chemicals, so the relative role of capital is somewhat suppressed. In electronic equipment, patent productivity or technology level is very high, so the role of technology development is relatively large compared to capital growth. The electronic industry's capital share has consequently a low share of 0.40. For rubber, food and textiles, no significant or meaningful results are obtained. The estimations for the food industry are not meaningful within the growth model.¹⁴

I cautiously conclude that the estimations for electronic equipment, office and computing, and chemicals meet the expectations on the basis of capital and technology characteristics in Table 5.2, though the esti-

¹⁴Adding AR(1) terms only improved results for the textiles industry, with an estimated capital share of 0.40 (Table D.5 and Table D.6).

mations for the other industries seem to indicate that the data do not support the current specification of the productivity growth function.

5.5.2 The technology growth function

Estimation results for the technology growth equation (5.3) in the period 1973-1993 are presented in Table 5.6, continued in Table 5.7.

Growth of leading industry technology pool The estimated coefficients for the growth of the leading industry technology pool β^{hF} are statistically significant and positive for all six manufacturing industries. In the chemicals and food industries, however, the estimated value is slightly greater than one, the long run value in the growth model. But the model is applied on a small sample period, making the estimations more sensitive to outliers and panel data peculiarities. Alternatively, one might interpret the estimations as that international technology growth differences in chemicals and food are very small, indicating that the long run equilibrium is more or less achieved.

In the other four industries, the estimated value is smaller than one. This may indicate that the long run value $\beta^{hF} = 1$ is yet to be achieved. An alternative interpretation is that technology growth rate differences persist in the long run, conditional on the current technology systems and innovation systems. In office and computing, the estimator has a very low value. The data problems in estimation for this industry may give spurious results. Alternatively, one might interpret this as that the office and computing industry is a rapidly changing industry in the time under consideration, and not yet set on its long run growth path.

Growth of domestic technology pool In contrast, the growth of the domestic technology pool appears to be less often of importance. For food and textiles, the parameter estimation of β^D is not significant. The negative sign for chemicals is counterintuitive within the context of the growth model. Apparently, the technology growth path in chemicals strongly diverges from that of the domestic technology pool.

Table 5.6: WLS estimation technology growth function, 1973-1993 (t -values between brackets)

	EE	OC	CH	RP	FO	TL
<i>$\hat{\beta}$, impact of the growth of...</i>						
... leading industry	0.63	0.16	1.08	0.56	1.04	0.54
technology pool A^{hF}	(11.41)	(1.82)	(14.69)	(3.91)	(4.40)	(2.07)
... domestic technology	0.55	1.09	-0.24	0.28	-0.10	0.43
pool A^D	(6.48)	(10.14)	(-2.82)	(1.73)	(-0.25)	(1.39)
<i>\hat{z}, long run gap with leading industry technology pool A^{hF}</i>						
France	-2.52		-2.19	-0.12	-2.21	-0.01
	(-7.36)		(-3.93)	(-0.16)	(-4.00)	(-0.01)
Germany	-2.64	12.13	-0.67	-0.27	-2.02	0.04
	(-3.58)	(0.72)	(-1.58)	(-1.61)	(-3.88)	(0.06)
UK	-2.07	12.89	-2.19	-0.85	-1.25	-0.50
	(-6.52)	(0.72)	(-3.08)	(-5.85)	(-4.32)	(-0.94)
<i>\hat{z}, long run gap with domestic technology pool A^D</i>						
France	-0.96		-1.37	-2.27	-3.46	-5.17
	(-3.93)		(-4.73)	(-6.81)	(-20.61)	(-2.23)
Germany	-2.02	-16.74	-1.16	-2.44	-4.55	-4.56
	(-3.95)	(-0.93)	(-3.36)	(-11.81)	(-10.70)	(-3.48)
UK	-0.74	-18.25	-1.59	-2.27	-3.06	-4.12
	(-3.67)	(-0.95)	(-6.59)	(-8.98)	(-14.87)	(-3.51)
<i>$\hat{\chi}$, impact interaction of the two technology gaps $\hat{\Theta}$</i>						
France	-5.71		-14.17	22.84	-9.45	38.11
	(-0.89)		(-1.43)	(1.55)	(-1.70)	(2.40)
Germany	4.04	-73.87	-34.73	22.34	-6.77	43.58
	(0.70)	(-4.59)	(-2.31)	(1.33)	(-1.12)	(2.29)
UK	-10.30	-59.57	-10.26	18.23	-13.40	38.19
	(-1.44)	(-3.51)	(-0.98)	(1.19)	(-2.09)	(2.27)
<i>$\hat{\gamma}$, impact R&D intensity on speed of diffusion from...</i>						
... leading industry	22.57	-36.55	1.83	16.84	48.22	-2.08
technology pool A^{hF}	(2.05)	(-2.28)	(0.90)	(1.57)	(2.40)	(-0.23)
... domestic technology	-33.62	-41.47	61.29	-46.73	-46.03	13.53
pool A^D	(-2.39)	(-2.34)	(3.88)	(-1.53)	(-1.68)	(1.22)
<i>$\hat{\psi}$, impact of constant on speed of diffusion from...</i>						
... leading industry	-99.99	472.26	53.86	-144.84	-192.82	-186.99
technology pool A^{hF}	(-2.03)	(4.75)	(0.82)	(-1.89)	(-2.00)	(-1.88)
... domestic technology	213.12	480.82	-234.34	184.50	295.36	-153.59
pool A^D	(2.72)	(4.56)	(-2.84)	(1.28)	(2.18)	(-2.43)

EE = electronic equipment, OC = office and computing, CH = chemicals, RP = rubber and plastics, FO = food, TL = textiles. Estimations for office and computing do not include data for France. These are covered in the French data for electronic equipment.

Table 5.7: WLS estimation technology growth function, 1973-1993, continued

	EE	OC	CH	RP	FO	TL
<i>Observations</i>	63	42	60	60	63	63
<i>Mean dependent variable</i>						
France	3.61		2.13	1.86	9.63	3.39
Germany	3.38	3.26	2.91	4.24	5.29	2.38
UK	-0.27	2.00	1.61	0.18	3.20	-1.27
<i>Standard error regression</i>						
France	0.88		0.97	2.60	4.04	3.79
Germany	1.34	1.20	0.98	1.14	2.83	3.07
UK	1.26	2.14	1.13	1.71	6.21	3.40
<i>Durbin Watson</i>						
France	2.34		2.79	1.59	1.84	2.75
Germany	0.93	2.31	1.73	1.75	1.80	1.66
UK	2.32	2.65	2.04	1.23	1.23	2.85

EE = electronic equipment, OC = office and computing, CH = chemicals, RP = rubber and plastics, FO = food, TL = textiles. Estimations for office and computing do not include data for France. These are covered in the French data for electronic equipment.

Furthermore, the estimated parameter value for office and computing is about one. This suggests that the industry follows the growth path of the domestic technology pool. However, the office and computing industry and also the electronic equipment industry are technologically progressive industries with a high patenting productivity, actually affecting the growth of the domestic technology pool. An explanation of the high estimated values for these industries might be that the technology pools of the two industries interact with the domestic technology pool. They produce parts of the ICT, a breakthrough technology. The reaction of other sectors to ICT may learn the two industries about underdeveloped or new technology areas in ICT. This in turn drives developments in the technology pool of the electronic equipment and office and computing industries.

Long run technology gaps The country-specific long run technology gaps z^{hF} and z^D often reveal statistically significant estimates which have negative sign (as to be expected). Particularly the technology gap of an industry with the domestic technology pool A^D appears to be often significant, except for office and computing. This gap is smallest for electronic equipment and largest for food and textiles, with chemicals and rubber between these industries. This logically follows from the fact

that the electronic equipment industry has a relatively large technology pool.

In contrast, the long run technology gap with the leading industry technology pool A_t^{hF} is larger for the electronic equipment industry than for the other industries. In the high tech electronic equipment industry, the leading technology pool A_t^{hF} is relatively large, thereby increasing opportunities for technology diffusion to followers.

Taking into account the short estimation period and the estimated low values of β^{hF} and β^D , it might well be the case that the estimators for the long run technology gaps are not or only approximately the actual long run values in all industries.

Interaction between the two technology diffusion channels The Wald test reveals that a country-specific coefficient χ for the interaction term is a better specification than a common coefficient. These coefficients are significant for office and computing and textiles, and in some cases also for chemicals (Germany) and food (France and the UK). Except for the textiles industry, the signs of the interaction parameter estimates are negative. This implies that the interaction of the two diffusion channels has a negative effect on the growth rate of technology of these industries. Particularly for office and computing and textiles, the impact is large.

R&D and speed of diffusion The signs of the estimated coefficients for the R&D intensity γ and the constant ψ change across industries, and they are not in all cases statistically significant.¹⁵ Generally, if the coefficient γ has a positive sign, the constant ψ has a negative sign, and reversely.

The electronic equipment industry and food industry show the same pattern of negative and positive signs for the various parameters. There is a positive sign for the R&D parameter γ^{hF} for the technology gap with the leading industry technology pool A_t^{hF} , and a negative sign for the constant ψ^{hF} . These parameter signs are similar to those in the macro-economic model estimation in Chapter 4.

¹⁵Estimations of country-specific coefficients for the speed of diffusion γ and ψ are not reported. Apart from the focus of the current chapter (industry differences instead of international differences), the time series are short and the degrees of freedom too low.

But the reverse holds for the technology gap with the domestic technology pool: a negative sign for the R&D coefficient γ^D , and a positive sign for the constant ψ^D . A negative influence of R&D in a technologically progressive industry like electronic equipment on the speed of absorption of technologies is counterintuitive. A possible explanation is that the data do not measure what they should do. Alternatively, one might speculate that the positive effects of R&D will come with a delay. However, it might be more likely that the electronic equipment industry does not invest in R&D in order to absorb technologies from the domestic technology pool, being one of the most technologically progressive industries in the domestic economy. The positive signs for the constant ψ^D might be explained by that the two industries are embedded well in the domestic economy and its institutions.

On the other hand, the chemicals and textiles industries show positive signs for the R&D parameter γ^D and negative signs for the constant ψ^D . This indicates that if these industries invest in R&D, given their technology gaps, they will speed up absorption of technologies from the domestic technology pool, and if they do not invest in R&D, they will lag further behind. The textiles industry also shows a negative sign for the constant ψ^{hF} which affects the speed of absorption of leading technologies from abroad.

The office and computing industry seems to be an exception, with negative signs for the R&D coefficients and positive signs for the constants. This industry is as technologically progressive as the electronic equipment industry. I would expect a positive sign for the R&D parameter γ^{hF} , but the estimated sign is negative. However, as discussed earlier (Section 5.4.2), the estimations for the office and equipment industry are less reliable because of data problems. For the rubber industry, no statistically significant estimates are obtained.

I carefully conclude that the electronic equipment industry and food industry have to invest in R&D to absorb foreign leading technologies. However, the three industries (and the office and computing industry) seem to be well-embedded in the domestic economy, as they are not in large need of R&D investment to absorb technologies from the domestic technology pool. In contrast, the chemicals and textiles industries have to invest in R&D to absorb technologies from the domestic technology pool.

5.6 Conclusions

The current chapter presented estimations of an industry model, in which two technology diffusion channels exist. First, general purpose technology is transferred from the domestic technology pool to the follower industry. Second, industry purpose technology flows from a leading industry technology pool into the follower industry.

The model was estimated with data for six manufacturing industries in France, Germany and the UK in the period 1973-1993, with the data for the three countries pooled for each industry. These industries range from high-tech to low-tech industries: electronic equipment, office and computing, chemicals, rubber and plastics, food, and textiles. The US is not considered to be the leader in all industries. It is used as a benchmark for the European economies. The comparative developments in labour productivity, capital intensity, technology and R&D effort show differences across industries and countries.

The model seems to be able to discriminate across industries with respect to the two technology diffusion channels. Several estimation problems (such as panel data problems and the quality of the data), the short estimation period and the low aggregation level (with a large heterogeneity in economy and institutions) indicate that alternative model specifications and data might be considered in the future. Conditional on the current estimation problems, the estimations of the industry growth model lead to the following careful conclusions.

First, the estimations of the productivity growth function show that in electronic equipment, office and computing, chemicals and textiles, both capital and technology play a (statistically) significant role. Due to a high patenting productivity, the role of capital is somewhat suppressed in chemicals. The role of technology is relatively largest for the electronic equipment industry.

The estimations for the technology growth function suggest that it depends on the industry under consideration which technology diffusion channel is more important and whether its impact is negative or positive: diffusion of industry purpose technology from the leading industry technology pool or diffusion of general purpose from the domestic technology pool.

For a high tech industry like electronic equipment, and the food industry, the absorption of industry purpose technology from the leading industry abroad seems to be of importance. Investment in R&D has a

positive impact on their speed of absorption. Stronger, without R&D, they would fall further behind the technology frontier.

For chemicals, and the low tech textiles industry, R&D investment has a positive impact on the speed of absorption of general purpose technology from the domestic technology pool. Without R&D, they fall behind the domestic technology frontier. The reverse holds for electronic equipment and food. These two industries (and the office and computing industry) seem to be well-embedded in the domestic economy, suggesting they are not in large need of R&D investment in order to absorb technologies from elsewhere in the domestic economy.

Furthermore, the growth of the leading industry technology pool is exerting substantial influence on the technology growth of the follower industries. The growth rate of a domestic technology pool does matter less often. But probably for high technology industries like electronic equipment and office and computing, interaction with the rest of the economy is of importance in order to learn about new niche markets (in ICT).

The long run technology gap with the domestic technology frontier of general purpose technologies is of particular importance for the low tech food and textiles. The technology gap with the leading technology pool abroad is important for the high tech electronic equipment.

Interaction between the two technology diffusion channels appears to be of importance for particularly office and computing (with a negative effect on technology growth) and textiles (with a positive effect).

In sum, there seem to exist differences across industries in the extent to which diffusion of GPTs and IPTs are important to the industry technology growth rates. As GPTs are transferred from the national level to the industry, this indicates that for industries to which GPTs are important, a properly working national innovation system with a certain social capability is crucial to absorb GPTs and transfer them to the industry under consideration. To industries for which IPTs are important, own R&D efforts are necessary to adjust foreign IPTs to local circumstances, given the international differences in technology systems. Given the historical experience, it is likely that the industry also has to adopt and adapt accompanying institutions, though this is more difficult and takes more time.

