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The Role of Production Organization, Infrastructure, and R&D in the Catching-up Process of Japanese to German Industries

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Abstract

This paper presents an empirical study of productivity comparison between Japan and Germany with focus on the R&D and infrastructure. By using time-series datasets from auto vehicle industry and electronic engineering industry, the study shows the reversal of productivity advantage from Germany to Japan around 1980. We argue that Japanese productivity gains are from better infrastructure and cost-reducing innovations such as lean production methods. An econometric model determines the causes for the observed differences in the quantities of inputs used. It shows that frequent external procurement among Japanese manufactures has shifted the factor inputs from labor and capital to material, a result which is in line with the philosophy of lean production.

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1. Introduction

Innovations and productivity advances of Japanese manufacturing industries have attracted various scholarly interests to Japanese economy and institutions. Many economists, business leaders, and policy makers in industrialized countries are concerned that their manufacturing industries are losing too much productivity advantage to their Japanese counterparts. This warrants more serious empirical comparisons of manufacturing productivities among Japan and other industrialized countries. In particular, the current debate is whether the Japanese productivity advantages come from the public source such as infrastructure capital or from the private source such as private R&D spending. Previous studies have identified various innovative features of lean production methods, such as manufacturer-supplier networks, automation, team work, and flat hierarchy. Using the examples of these innovations as guidelines, this study investigates the contribution of private innovations (R&D) and public investments (infrastructure) to Japanese production organization and productivity advantage. Japanese and German firms compete world-wide on goods markets for export market shares. Their government compete on international factor markets for mobile capital and mobile know-how. The decline in the cost of communication, the success of the newly developed countries, and the ongoing integration of Eastern Europe and Asia into the international division of labor have resulted in the so-called globalization of markets. On the background that Germany, the richest and most powerful economy in Europe, is in a crisis, it is of interest to analyze the relative development of two industries which are important branches in the Japanese and German manufacturing industries – the motor vehicle industry and the electrical engineering industry. World market shares used to be or are still relatively high for those industries and some of their companies are among the world-wide most active patentees. In 1993, Siemens was ranked top with 1606 patents, Robert Bosch third (1026), Canon eight (728), Mitsubishi nine (606), Sony eleven (478) and Matsushita Electrical Industrial was ranked fourteen (465). The fact that in spite of the high potential for innovation many German firms lose market shares to Japanese firms could be interpreted as a failure of the management. Japanese firms of the motor vehicle industry and of consumer electronic goods were successful with the strategy to fill market gaps. For example, they have achieved their advantages in competition by concentrating on smaller, less powerful compact models. For keeping an once gained competitive advantage, it has to be consequently extended. Therefore, Japanese automobile producers invested in modern large scale technologies to exhaust economies of large scale. Then they renewed their process technique by just in time-production and arrangements to increase quality and productivity (Porter 1990, p. 103 f.). Besides of these private economic R&D efforts, productivity of an economy is also influenced by a modern public infrastructure. An efficient infrastructure is generally seen as a preposition for growth, competitiveness and as a means to reduce high unemployment. Transportation infrastructure, logistics and telecommunication are essential presumptions for the use of new technologies and for the success in international competition. In countries like Japan, Singapore, and Korea the voluminous investment in infrastructure has had advantageous impacts on their economic development (Porter 1991, p. 655). A variety of empirical studies – a prominent example is the world development report of the World Bank in 1994 – support the hypothesis that a good infrastructure is a necessary although not a sufficient condition for economic prosperity.

Infrastructure has two supply effects. As it is production of production provision, it is fundamental for private investment. And second, infrastructure is complementary to private investment and raises its rate of return. Infrastructure, related to the economic performance of an economy, is "core infrastructure", which consists of streets, highways, telecommunication, airports, electricity networks, public transportation, water ways, and sewage disposal plants. In Europe, especially in Germany, traffic congestions make it impossible to estimate travel time. For Germany, the time cost of congestion amounts to 100 billion dollar/a. Therefore, an extension of road infrastructure would improve mobility and raise productivity by lowering average cost of production. Outsourcing, just-in-time production and globalization require a good road infrastructure and transportation system. Therefore, provision of infrastructure for a region or country as a means in strategic interregional competition moved recently in the center of interest. Aschauer (1989) initiated this discussion by pointing out a correlation between the observed decline in expenditure on core infrastructure and between a slowdown in productivity growth in the OECD countries in the 80th.

While empirical work on the quantification of productivity effects of infrastructure (Aschauer 1989, Ford and Poret 1991, Nadiri and Mamuenas 1994, and Conrad and Seitz 1994) up to now has focused on national sectors, in this paper we want to investigate its role in reducing international differences in costs. We take up the issues of innovation and infrastructure from the viewpoint of traditional productivity analyses. Thus, the topic of this paper is a description of international productivity gaps and an econometric analysis of their causes. We analyse the sectoral cost differences, i.e. cost gaps, and their development over time between Japan and Germany for the sectors of electrical engineering and motor vehicles between 1970 and 1990. To explain the catching-up process of the Japanese sectors we do not only use changes in relative prices for labor, capital, and material but also draw into the impacts from the extension of infrastructure, and research and development.

2. Measuring Sectoral Cost Efficiency with Infrastructure and R&D Capital

We start with the dual concept of measuring sectoral cost gaps.[1] Point of departure is the joint variable cost function for both countries:

$$(1) \qquad VC = VC(q, x, KI, KF, D),$$

where q is the vector of factor prices, x the sectoral output, KI the infrastructure capital stock, KF the stock of R&D capital and D a dummy variable. Instead of a time trend variable, in this study R&D capital represents the role of technical change.[2] We assume the variable cost function to be linear homogeneous in x, KI, and KF. Because output levels, capital stocks and factor prices are expressed relative to Germany, the dummy variable takes on the value 0 for Germany (G) and 1 for Japan (J). The dummy variable catches country specific deviations from the joint cost function. It shifts the cost function inwards or outwards. The difference in cost between Japan and Germany at a given point in time is calculated as the total differential of the cost function (1). In form of logarithmic derivatives we get:[3]

$$(2) \qquad \frac{d\ln VC}{dD} = \sum_i s_i \frac{d\ln q_i}{dD} + \frac{\partial \ln VC}{\partial \ln x}\frac{d\ln x}{dD} + \frac{\partial \ln VC}{\partial \ln KI}\frac{d\ln KI}{dD} + \frac{\partial \ln VC}{\partial \ln KF}\frac{d\ln KF}{dD} + \frac{\partial \ln VC}{\partial D},$$

where $s_i = \partial \ln VC / \partial \ln q_i = q_i v_i / VC$ (i = K, L, M) are the cost shares (Shephard's Lemma). In equation (2) the partial derivatives of the variable cost function with respect to the capital stocks KI

and *KF* represent the savings in costs from a marginal increase in those stocks. These savings in costs are the shadow prices of the capital stocks. In logarithmic partial derivatives with respect to *KI* and *KF*, they are the cost shares (multiplied by -1). In case of *KI* e.g. we have:

$$q_{KI} = -\frac{\partial VC}{\partial KI}, \text{ and } \frac{q_{KI} \cdot KI}{VC} = -\frac{\partial \ln VC}{\partial \ln KI}.$$

Under the additional assumption of profit maximizing supply decisions, we have $p = \partial VC / \partial x$. The logarithmic partial derivative with respect to output then corresponds to the revenue cost-share.By rearranging (2) we get:

$$(3) \qquad \frac{\partial \ln VC}{\partial D} = \frac{d \ln VC}{dD} - \sum_i s_i \frac{d \ln q_i}{dD} - \frac{p \cdot x}{VC}\frac{d \ln x}{dD} + \frac{q_{KI} \cdot KI}{VC}\frac{d \ln KI}{dD} + \frac{q_{KF} \cdot KF}{VC}\frac{d \ln KF}{dD}.$$

Equation (3) shows the sectoral difference in costs between Japan and Germany if the costs were adjusted for the differences in the levels of production, capital stock, and factor prices at a given point in time. If there is a disadvantage in costs of a Japanese sector, then $\partial \ln VC / \partial D$ is positive. This means that a hypothetical transfer of resources from Germany to Japan ceteris paribus would result in an increase in variable costs by $(\partial \ln VC / \partial D) \cdot 100$ percent. Therefore, in Germany the resources are used more efficiently. By including infrastructure and the R&D variable, the cost difference between the Japanese and German sector is adjusted for the productivity effects of these variables. A more infrastructure-intensive production in Japan results ceteris paribus in lower Japanese costs so that the difference in costs will be reduced. By a better provision of infrastructure a Japanese disadvantage in costs is reduced, an advantage is expanded. An analogous consideration holds for the R&D capital. A neglect of the last two terms would underestimate a disadvantage in costs and overestimate an advantage in costs.

As a discrete approximation of the Divisia index (3) we use the Törnqvist index. Then the cost gap s_D can be calculated as:

(4)
$$\begin{aligned} s_D = {} & \ln VC(J) - \ln VC(G) - \sum_i \bar{s}_{q_i} \left[\ln q_i(J) - \ln q_i(G) \right] \\ & - \bar{s}_x \left[\ln x(J) - \ln x(G) \right] + \bar{s}_{KI} \left[\ln KI(J) - \ln KI(G) \right] + \bar{s}_{KF} \left[\ln KF(J) - \ln KF(G) \right] \end{aligned}$$

with

$$\bar{s}_j = \frac{1}{2} \left(s_j(J) + s_j(G) \right) \qquad for \;\; j = q_L, q_K, q_M, x, KI, KF.$$

To make the levels of production and of factor quantities comparable we use purchasing power parities (PPPs). The PPPs for capital (K), labor (L), material (M) and output are taken from Conrad (1985). They are expressed in DM per Yen, [4] but were only available until 1979. We extended the PPPs up to 1990 by multiplying the PPPs of inputs and output of the year 1979 by the relative prices.

The assumption of perfect competition permits an economic interpretation (Conrad 1989, p. 1144) of the PPPs. Changes in the PPPs can then be interpreted as changes in the relative marginal productivities of capital, labor and material. This follows from the first order condition for profit maximization. By dividing the first order condition of a Japanese industry by the one of the corresponding German sector we get

(5)
$$\frac{q_i(J)}{q_i(G)} = \frac{p(J)}{p(G)} \cdot \frac{\dfrac{\partial F(v, KI, KF, 1)}{\partial v_i}}{\dfrac{\partial F(v, KI, KF, 0)}{\partial v_i}}, \qquad \text{i = K,L,M.}$$

If we label the relation of the marginal productivities in (5) by RMP_i(J,D) and if we rearrange, we obtain:

$$\mathrm{RMP}_i\left(,G\right)=\frac{PPPv_i}{PPPx}.$$

If the relative marginal product of a factor i is greater (smaller) than 1 because of $PPPv_i/PPPx > 1$, then the marginal product of this factor is in the Japanese industry greater (smaller) than in the German one.

To calculate countrywise differences in costs we employed user cost of capital prices q_{KF} and q_{KI} for R&D and infrastructure capital.[5]

3. Results of Measuring the Sectoral Cost Efficiency

In Table 1 we present the sectoral cost differences s_D and the relative marginal products for the electrical engineering industry. Table 2 shows in addition index numbers for an international comparison in terms of relative output (Japan in relation to Germany), relative variable inputs, and relative capital stocks. RXX is the output ratio, Rii (i = K,L,M) are the input ratios for capital, labor, material, and RKIKI and RKFKF are the ratios for the capital stocks of infrastructure and R&D.

Table 1: Sectoral cost efficiency (production of G produced at location J) and relative marginal productivities (J over G) in the electrical engineering industry.

Year	s_D	RMP_K	RMP_L	RMP_M
1970	0.159	1.230	0.762	0.956
1971	0.132	1.190	0.813	0.976
1972	0.110	1.333	0.834	0.967
1973	*0.105*	1.326	0.874	0.966
1974	0.118	1.100	0.913	1.000
1975	0.111	0.931	0.931	1.042
1976	0.086	1.157	0.931	0.988
1977	0.079	0.953	0.955	1.027
1978	0.057	0.792	0.979	1.052
1979	0.033	1.079	0.881	1.052
1980	0.002	1.225	0.843	1.103
1981	-0.015	1.351	0.883	1.092
1982	-0.035	1.239	0.940	1.128
1983	-0.062	1.353	0.939	1.153
1984	-0.081	1.461	0.934	1.161
1985	-0.075	1.161	*1.015*	1.179
1986	-0.101	1.071	1.060	1.245
1987	-0.140	1.186	1.086	1.290
1988	-0.190	1.445	1.165	1.302
1989	-0.184	1.262	1.206	1.315
1990	-0.185	1.251	1.164	1.302

The comparison of the Japanese and the German industry "electrical engineering" shows that the Japanese sector had a disadvantage in productivity, respectively in costs, from 1970 until 1980 (first column of Table 1). This means that in 1970 the Japanese industry would have produced the German output level at higher costs of about 15%. The difference in costs decreases steadily, and in the eighties it changes its sign into an advantage in costs. The closure of the cost gap is induced by increases in the productivity of the private factors.

If productivity of capital, labor, and material increases, output can be produced at lower costs. The development of relative marginal productivities over time indicates that. It shows that marginal productivity of labor was lower in the Japanese industry until the eighties. However, it increased over the whole period. The same holds for the marginal product of material, whereas the development of the productivity of private capital is ambiguous.

The increases in productivity are in their turn the result of process innovation and of a better provision of infrastructure. This can be concluded from the development of the relative capital stocks of infrastructure and R&D (column 5 and 6 of Table 2). The provision of public infrastructure in Japan was higher in nearly all years. In particular in the eighties this better provision has increased significantly. In contrast, the R&D relation decreased to 1.0 in 1980. However, (after an initial increase) the eighties are characterized by an essentially stronger innovation activity in the Japanese industry.

Table 2: Output and input relations in the industry electrical engineering (J over G).

Year	RXX	RLL	RKK	RMM	RKIKI	RKFKF
1970	1.124	1.610	1.359	1.985	0.906	1.589
1971	1.152	1.597	1.433	1.897	0.936	1.675
1972	1.231	1.639	1.270	1.945	1.076	1.792
1973	1.261	1.663	1.305	1.964	1.101	1.709
1974	1.025	1.592	1.547	1.517	1.068	1.547
1975	0.938	1.579	1.828	1.245	*1.015*	1.390
1976	1.097	1.663	1.424	1.506	1.094	1.335
1977	1.170	1.683	1.883	1.526	1.162	1.280
1978	1.322	1.692	2.392	1.618	1.353	1.321
1979	1.459	1.736	1.904	1.782	1.273	1.092
1980	1.683	1.908	1.858	1.893	1.302	1.006
1981	1.956	2.109	1.869	2.212	1.721	1.246
1982	2.164	2.222	2.325	2.252	1.715	1.191
1983	2.659	2.506	2.463	2.673	1.964	1.331
1984	3.300	2.824	2.739	3.278	2.267	1.531
1985	3.448	2.762	4.098	3.289	2.403	1.605
1986	3.891	2.770	4.950	3.412	2.577	1.730
1987	4.184	2.659	4.716	3.412	2.583	1.675
1988	4.201	2.732	4.310	3.906	3.048	1.862
1989	4.385	2.754	5.405	4.032	3.205	1.897

1990	4.506	2.770	5.291	4.016	3.257	1.926

Technical progress and infrastructure are two sources of explaining regional differences in factor allocation. A further source is (besides factor prices) the quantity of production. The growth of output in the Japanese sector is essentially stronger than in the German sector, particularly in the eighties (column 1 of Table 2). The output relation Japan to Germany decreased initially (1970 until 1975), but has increased considerably from then on. The development of labor and material parallels the output relation. Since about 1980, the relation of the private capital stock is increasing, too.

In Tables 3 and 4 the index numbers for the motor vehicles industry are presented. The development of the cost gap is about the some as in the electrical engineering industry. The disadvantage in productivity in the Japanese industry during the seventies has changed into an advantage in productivity during the eighties.

Table 3: Sectoral cost efficiency (production of G produced at location J) and relative marginal productivities (J over G) in the motor vehicles industry.

Year	s_D	RMP_K	RMP_L	RMP_M
1970	0.247	1.225	0.819	0.975
1971	0.162	1.602	0.675	0.978
1972	0.230	1.869	0.623	0.984
1973	0.137	1.432	0.736	1.018
1974	0.080	1.118	0.821	1.035
1975	0.089	0.615	0.952	1.122
1976	0.053	0.740	0.930	1.100
1977	0.050	0.725	0.896	1.135
1978	0.100	0.953	0.854	1.088
1979	0.118	1.223	0.740	1.096
1980	-0.036	1.388	0.708	1.150
1981	-0.030	1.531	0.741	1.140
1982	0.012	1.402	0.790	1.176
1983	0.005	1.533	0.789	1.201
1984	-0.038	1.655	0.785	1.210
1985	-0.006	1.315	0.852	1.230
1986	0.015	1.213	0.891	1.298
1987	-0.090	1.344	0.913	1.345
1988	-0.150	1.636	0.979	1.358
1989	-0.125	1.430	1.014	1.371
1990	-0.156	1.531	1.007	1.383

This outcome accords with a report by the German Association of the motor vehicles industry. According to this analysis, the competitiveness of the German motor vehicles industry at the world market has worsened continuously since the beginning of the eighties. The reasons are an above the average international increase in labor costs and a lag in productivity progress compared to foreign competitors (Association of the motor vehicles industry e.V., Jahresbericht 93/94, p. 15). The reduction of the Japanese cost disadvantage can be attributed - as shown by the development of the relative marginal productivities - to a raise in the productivity of private capital, labor, and material.

The Japanese R&D capital formation has also contributed to the better performance: its ratio increases as in the electrical engineering industry, though from a lower starting level.

Table 4: output and input relations in the motor vehicles industry (J over G).

Year	RXX	RLL	RKK	RMM	RKIKI	RKFKF
1970	1.223	1.855	1.492	1.390	0.906	1.140
1971	1.369	1.886	1.215	1.597	0.936	1.242
1972	1.497	2.032	1.082	1.745	1.076	1.436
1973	1.557	2.114	1.560	1.663	1.101	1.517
1974	1.589	2.217	1.964	1.628	1.068	1.533
1975	1.733	2.109	4.201	1.661	1.015	1.497
1976	1.552	2.074	3.521	1.438	1.094	1.564
1977	1.592	2.053	3.968	1.466	1.162	1.567
1978	1.470	1.984	2.832	1.436	1.353	1.686
1979	1.459	1.897	2.257	1.396	1.273	1.443
1980	1.730	2.070	2.061	1.564	1.302	1.314
1981	1.845	2.057	1.953	1.712	1.721	1.607
1982	1.886	2.040	2.272	1.706	1.715	1.503
1983	1.976	2.028	2.173	1.730	1.964	1.612
1984	2.192	2.173	2.109	1.901	2.267	1.754
1985	2.309	2.114	3.003	1.968	2.403	1.769
1986	2.481	1.930	3.703	2.016	2.577	1.851
1987	2.659	1.984	3.558	1.988	2.583	1.773
1988	2.985	2.012	3.134	2.178	3.048	1.901
1989	3.225	2.087	3.816	2.375	3.205	1.862
1990	3.086	2.070	3.717	2.283	3.154	1.879

The dynamics of growth of the Japanese motor vehicles industry is expressed by the increasing output ratio RXX, which - apart from a few exceptions - continuously rose. In contrast to the electrical engineering industry, the labor input-ratio RLL increases only slowly in spite of the strong Japanese expansion of output. The input ratios of private capital and of material increase rapidly like in the electrical engineering industry. The process of growth of the Japanese motor vehicles industry is therefore characterized by a bias effect compared to the German sector, namely a relatively labor saving but capital and material using way of production.

To determine the quantitative significance of the productivity effects of infrastructure and R&D capital we calculate the conventional cost gap $\tilde{s}_D$ from the equation

$$\tilde{s}_D = \ln VC(J) - \ln VC(G) - \bar{s}_{q_i}\left[\ln q_i(J) - \ln q_i(G)\right] - \bar{s}_x\left[\ln x(J) - \ln x(G)\right]$$

and compare it with the cost gap in (4). The equations differ by the terms for infrastructure and R&D:

$$(6) \qquad s_D = \tilde{s}_D + \bar{s}_{KI}\left[\ln KI(J) - \ln KI(G)\right] + \bar{s}_{KF}\left[\ln KF(J) - \ln KF(G)\right]$$

As infrastructure and R&D capital result in cost savings, the conventional sectoral cost difference has to be modified by the differences in these variables. Their inclusion implies that a cost disadvantage due to the productivity gap (s_D) turns out to be higher if the level of infrastructure and R&D capital stock is higher in Japan. For R&D capital this is the case over the whole period. The level of infrastructure capital is only in the first two years somewhat higher in Germany. The results for the electrical engineering industry are summarized in Table 5. The cost gap correction is an average value of the difference $s_D - \tilde{s}_D$. It reflects the impact from infrastructure and R&D. The contributions of R&D and infrastructure capital are shown in the rows underneath. They are the averages of the second and third term in equation (6).

Table 5: The impact of infrastructure and R&D capital stocks on cost efficiency in the electrical engineering industry.

	1970 - 1980	1981 - 1990
cost gap correction	0.011	0.020
due to KF	0.010	0.017
due to KI	0.001	0.003

In the first period (1970 - 1980) the Japanese sector shows a disadvantage in costs (see column one in Table 1). By taking infrastructure and R&D capital stocks into account, it appears that the average conventional disadvantage in costs during this period would have been underestimated by 12%.[6] The next two rows show the contribution of infrastructure and R&D to the correction of the cost gap. As can be noticed, the contribution from R&D capital to this cost adjustment term is much higher than the contribution from infrastructure. For the period 1981 to 1990, the inclusion of infrastructure and R&D capital corrects average conventional cost saving by 0.02. Again, the increase in cost saving can be attributed mainly to changes in R&D capital (0.017).

Table 6 presents the adjustments in the motor vehicles industry. The average cost gap in this sector in the first period amounts to 0.114 without KF and KI, and to 0.127 with KF and KI. In the second period the average cost gap is -0.068 and -0.06, respectively. Compared to the electrical engineering industry, the contribution of infrastructure is slightly higher (in percentage terms). Nevertheless, almost the total cost correction is due to R&D capital.

Table 6: The impact of infrastructure and R&D capital stocks on the cost efficiency in the motor vehicles industry.

	1970 -1979	1980 -1990
cost gap correction	0.013	0.008
due to KF	0.011	0.007
due to KI	0.002	0.001

Our decomposition has shown that in the first period the productivity lag in both Japanese sectors was greater than "assumed thus far". Taking into account a better provision of KI and KF, the gap actually was greater. The catching - up process was induced by increases in productivity of the private factors and by an impressive increase in KI and KF. For the second period the conclusion is that the lead in productivity from a superior allocation of K, L, and M has been smaller than "assumed so far". The increase in productivity of K, L, and M to gain the lead has been supported significantly by higher KI and KF.

4. The Significance of Infrastructure and R&D Capital for the Explanation of Cost Gaps

Regional differences in the cost structure of two industries result from differences in the quantities of inputs which in turn are determined by the level of production, by factor prices, provision of infrastructure, and by technical progress. The descriptive analysis of the previous section indicated which components are accountable for the differences in costs but did not determine their contribution in explaining the differences in factor demand. In this section, the causes for the changes in the cost gaps are determined by employing an econometric model. Since the Törnqvist-index is exact with respect to a translog function, we use this flexible functional form to specify our variable cost function in (1).

The empirical model consists of the joint variable cost function for an industry, of the cost shares of the variable factors derived from Shephard's Lemma, i.e.

$$\frac{\partial \ln VC}{\partial \ln q_i} = \frac{q_i v_i}{VC} = s_i \qquad i = K,L,M$$

of the equation for the supply of output,

$$\frac{\partial \ln VC}{\partial \ln x} = \frac{p \cdot x}{VC} = s_x$$

of the cost shares of the capital stocks,

$$\frac{\partial \ln VC}{\partial \ln KI} = -\frac{q_{KI^{KI}}}{VC} = -s_{KI}, \qquad \frac{\partial \ln VC}{\partial \ln KF} = -\frac{q_{KF}{}^{KF-}}{VC} = -s_{KF}$$

and of the equation for the country-wise difference in costs,

$$\frac{\partial \ln VC}{\partial D} = s_D.$$

The translog specification of the variable cost function is

$$
\begin{aligned}
(7)\qquad \ln VC = {} & a_0 + \ln q_K + a_L \ln \tilde{q}_L + a_M \ln \tilde{q}_M + a_x \ln x + a_{KF} \ln KF + a_{KI} \ln KI + a_D D \\
& + \frac{1}{2} \cdot \left(b_{LL} \ln^2 \tilde{q}_L + b_{MM} \ln^2 \tilde{q}_M \right) + b_{xx} \ln^2 x + b_{KFKF} \ln^2 KF + b_{KIKI} \ln^2 KI \\
& + b_{LM} \ln \tilde{q}_L \cdot \ln \tilde{q}_M + b_{Lx} \ln \tilde{q}_L \ln x + b_{L,KF} \ln \tilde{q}_L \ln KF + b_{L,KI} \ln \tilde{q}_L \ln KI \\
& + b_{LD} \ln \tilde{q}_L \cdot D + b_{Mx} \ln \tilde{q}_M \ln x + b_{M,KF} \ln \tilde{q}_M \ln KF + b_{M,KI} \ln \tilde{q}_M \cdot \ln KI \\
& + b_{MD} \ln \tilde{q}_M \cdot D + b_{x,KF} \ln x \ln KF + b_{x,KI} \ln x \ln KI + b_{xD} \ln x \cdot D \\
& + b_{KF,KI} \ln KF \ln KI + b_{KF,D} \ln KF \cdot D + b_{KI,D} \cdot \ln KI \cdot D.
\end{aligned}
$$

It is $\tilde{q}_i = q_i / q_K$, i = L,M, because we have imposed already the parameter restrictions due to the linear homogeneity of the cost function in the input prices. Due to additivity of the cost shares to one for the variable factors, one of the cost share equations must be dropped. Otherwise, the residuals of the econometric model would not be independently distributed. We therefore dropped the equation for the cost of capital. Hence the model consists of the variable cost function (7) and of the following equations:

(8) $s_L = a_L + b_{LL} \ln \tilde{q}_L + b_{LM} \ln \tilde{q}_M + b_{Lx} \ln x + b_{L,KF} \ln KF + b_{L,KI} \ln KI + b_{LD} D,$

(9) $s_M = a_M + b_{MM} \ln \tilde{q}_M + b_{LM} \ln \tilde{q}_L + b_{Mx} \ln x + b_{M,KF} \ln KF + b_{M,KI} \ln KI + b_{MD} D,$

(10) $s_x = a_x + b_{Lx} \ln \tilde{q}_L + b_{Mx} \ln \tilde{q}_M + b_{xx} \ln x + b_{x,KF} \ln KF + b_{x,KI} \ln KI + b_{xD} D,$

(11) $s_{KF} = -\left(a_{KF} + b_{L,KF} \ln \tilde{q}_L + b_{M,KF} \ln \tilde{q}_M + b_{x,KF} \ln x + b_{KFKF} \ln KF + b_{KF,KI} \ln KI + b_{KF,D} D \right),$

(12) $s_D = a_D + b_{LD} \ln \tilde{q}_L + b_{MD} \ln \tilde{q}_M + b_{xD} \ln x + b_{KF,D} \ln KF + b_{KI,D} \ln KI.$

The linear homogeneity of the variable cost function in x, KI and KF implies (Euler's theorem):

$$\frac{\partial VC}{\partial x}x + \frac{\partial VC}{\partial KI}KI + \frac{\partial VC}{\partial KF}KF = VC.$$

Therefore, the following adding-up condition has to be satisfied:

$$\frac{p \cdot x}{VC} - \frac{q_{KI}KI}{VC} - \frac{q_{KF}KF}{VC} = 1.$$

Hence, the residuals of the revenue cost-share and of the cost shares of infrastructure and R&D capital are not distributed independently. We have to exclude one of these equations from the estimation; we dropped the equation for infrastructure. The model (7) - (12) was estimated by the maximum likelihood method under the parameter restrictions

$$\begin{aligned} &b_{ix} + b_{i,KF} + b_{i,KI} = 0, \qquad i = L, M \\ &b_{zx} + b_{z,KF} + b_{z,KI} = 0, \qquad z = x, KF, KI \end{aligned}$$

The parameters of the excluded equations

(13) $\quad s_K = a_K + b_{LK}\ln\tilde{q}_L + b_{KM}\ln\tilde{q}_M + b_{Kx}\ln x + b_{K,KF}\ln KF + b_{K,KI}\ln KI + b_{KD}D$

and

(14) $\quad s_{KI} = -\left(a_{KI} + b_{L,KI}\ln\tilde{q}_L + b_{M,KI}\ln\tilde{q}_M + b_{x,KI}\ln x + b_{KF,KI}\ln KF + b_{KIKI}\ln KI + b_{KI,D}D\right)$

can be determined by the parameter restrictions

$$a_K + a_L + a_M = 1, \qquad a_x + a_{KF} + a_{KI} = 1, \qquad b_{iK} + b_{iL} + b_{iM} = 0, \qquad i = K, L, M$$
$$b_{ij} = b_{ji}, \qquad b_{Kz} + b_{Lz} + b_{Mz} = 0, \qquad z = x, KI, KF.$$

We next interprete the meaning of the parameters of the dummy variable. They represent ceteris paribus the effect of input prices, capital stocks, and production on input quantities, output, and on the sectoral difference in costs. By means of these parameters the catching-up process of the Japanese sectors is to be explained in the next section.

The parameter b_{iD} shows on the one hand the difference in the cost structure of the corresponding sector. If $b_{iD} > 0$, then the cost share of factor i is higher by b_{iD} in Japan. If, however, $b_{LD} < 0$, then the cost share of labor in the Japanese sector is smaller by b_{LD}. Since differences in the cost structure can be attributed to differences in factor prices as well as in factor quantities, we write the cost shares as

$$v_i = \frac{VC}{q_i}\left(a_i + b_{ii}\ln\tilde{q}_i + b_{ij}\ln\tilde{q}_j + b_{ix}\ln x + b_{i,KF}\ln KF + b_{i,KI}\ln KI + b_{iD}D\right)$$

and differentiate logarithmically with respect to D:

$$\frac{\partial \ln v_i}{\partial D} = \frac{b_{iD}}{s_i} + s_D.$$

Therefore, the Parameters b_{iD} also indicate a country bias under a ceteris paribus comparison of the input quantities. Is the country bias factor saving $(b_{iD} < 0)$, then the used quantity of factor i is lower in Japan by the rate b_{iD} / s_i than the overall rate s_D. If there is a cost disadvantage for a Japanese sector $(s_D > 0)$, the use of all inputs will be higher by $s_D \cdot 100\%$, given a neutral country bias $(b_{iD} = 0)$. However, the use of factors is modified by the rate b_{iD} / s_i, so that with a factor i saving (using) country bias the use of this factor is lower (higher) than the rate s_D. If, in contrast, the Japanese sector has an advantage in costs, then it requires from all factors less by $s_D \cdot 100\%$, if the bias is neutral. The factor use is even less in percentage terms if the country bias is factor i saving.

The parameter b_{iD} appears on the other hand also in the regression (12) for the country-wise cost gap. There it indicates the change of the difference in costs caused by an increase in the price of input i. With a factor i saving country bias, a general increase in the price of factor i reduces the difference in costs. Since the Japanese industry uses under a factor saving country bias $(b_{iD} < 0)$ from this input relatively less compared to its competitor, given a cost disadvantage, it is therefore less affected by a general increase in the price of this factor.

The parameter b_{xD} indicates the difference in the revenue cost-share of the corresponding sector. It this parameter is positive, then the revenue cost-share in the Japanese sector is higher than in the German one. Since differences in the profit margin can be attributed to differences on the supply side, we rearrange the revenue cost-share for x and differentiate logarithmically with respect to D. This yields:

$$\frac{\partial \ln x}{\partial D} = -\frac{\dfrac{b_{xD}}{s_x} + s_D}{\dfrac{b_{xx}}{s_x} + s_x - 1}$$

The derivative expresses the rate of change in output if it would be produced in the Japanese sector. For an easier interpretation we assume a homogenous production function, i.e. $b_{ix} = b_{xz} = 0 \ \forall i = x, KI, KF$. Hence the equation of the revenue cost-share is $s_x = a_x + b_{xD} D$. Under this assumption, we get:

$$\frac{\partial \ln x}{\partial D} = -\frac{\frac{b_{xD}}{a_x} + s_D}{a_x - 1}.$$

If this expression is negative, a German firm would supply less in the Japanese environment. Since revenue under a homogeneous production function is a constant share of costs, namely l/r (r - degree of homogeneity), we can also write $a_x + b_{xD} D = 1/r$. Now b_{xD} can be interpreted as a scale parameter. If b_{xD} is positive, the degree of homogeneity is less in the Japanese sector than in the German one. This implies that the Japanese marginal cost function lies above the German one. Therefore, the profit maximizing supply of output is lower than it would have been under German supply conditions. Given a disadvantage in costs $(s_D > 0)$, a positive parameter b_{xD} therefore leads to an additional decrease in supply when production is shifted from the German to Japanese industry.

The parameter $b_{KI,D}$ measures the impact of KI on the sectoral difference in costs:

$$\frac{\partial s_D}{\partial \ln KI} = b_{KI,D}.$$

A negative parameter means that the difference in costs will decrease under a better provision of infrastructure. A better transportation infrastructure and more efficient telecommunication installations increase productivity of the private factors. As a result, the Japanese sector achieves cost savings compared to the German one. In the cost share equation (14) for infrastructure in turn a negative $b_{KI,D}$ implies that the cost share of infrastructure increases when production switches from the German to the Japanese industry. Finally, interpreted as a country bias, it shows the change in the level of infrastructure when production switches from the German to the Japanese sector:

$$\frac{\partial \ln KI}{\partial D} = \frac{-b_{KI,D}}{s_{KI}} + s_D.$$

Given a Japanese disadvantage in costs $(s_D > 0)$ and a neutral country bias, one would need also more infrastructure to produce the German output in the Japanese sector. If the country bias is factor using $(-b_{KI,D} > 0)$, then the Japanese sector needs more than the rate s_D, namely additionally the rate $-b_{KI,D} / s_{KI}$.

For the parameter $b_{KF,D}$, the interpretation is analogous. In the regression (12) for the cost difference it takes into account the impact of the R&D capital. A negative parameter implies a decrease in the cost difference when R&D activities are extended. In the corresponding equation (11) of the cost share s_{KF}, however, it shows the country bias of the R&D activities.

To estimate the model, we add to each equation an additive error term which are assumed to be independently and jointly normally distributed. Altogether, there are 20 parameters to be estimated. The model is estimated simultaneously by the iterative Zellner method. For the endogenous variable of the last equation (s_D) we used the values calculated from the Törnqvist index. For each of the six regression equations we have 42 observations. Therefore, the number of degrees of freedom is 252. In Table 7, we present the values of the estimated parameters of the model [8].

Table 7: Results of the model estimation ((7) - (14)).

	Coefficients			Coefficients	
	EE	MV		EE	MV
a_0	*0.002	-0.076	$b_{L,KI}$	0.042	-0.025
a_L	0.262	0.232	b_{LD}	-0.125	-0.044
a_M	0.626	0.663	b_{MK}	-0.044	-0.038
a_K	0.112	0.105	b_{Mx}	0.062	-0.034
a_x	1.035	1.063	$b_{M,KF}$	*0.001	0.015
a_{KF}	-0.064	-0.065	$b_{M,KI}$	-0.063	0.019
a_{KI}	0.029	0.002	b_{MD}	0.055	0.038
a_D	0.037	0.062	b_{Kx}	-0.036	-0.010
b_{LL}	0.043	0.023	$b_{K,KF}$	0.015	0.004
b_{MM}	0.062	0.040	$b_{K,KI}$	0.021	0.006
b_{KK}	0.069	0.059	b_{KD}	0.070	0.006
b_{xx}	-0.056	-0.066	$b_{x,KF}$	0.019	0.023
b_{KFKF}	-0.013	-0.018	$b_{x,KI}$	0.037	0.043
b_{KIKI}	-0.026	-0.170	b_{xD}	0.105	0.073
b_{LM}	-0.018	-0.002	$b_{KF,KI}$	-0.006	-0.005
b_{LK}	-0.025	-0.021	$b_{KF,D}$	-0.030	-0.016
b_{Lx}	-0.026	0.044	$b_{KI,D}$	-0.075	-0.057
$b_{L,KF}$	-0.016	-0.019			

Parameters marked with * are not significant at a level of significance of 2%.

EE – electrical engineering, MV – motor vehicles.

5. Interpretation of the results

For an additional utilization of the estimated parameters we calculate the impact of the provision of public infrastructure and of R&D capital on private factor demand. The elasticities of factor demand with respect to infrastructure and R&D capital are summarized in Table 8. An extension of infrastructure affects the motor vehicles industry in a labor and capital saving way.and in a material using one. The intuition for this result provides the manufacturer-supplier network: with a better transportation network, part of material input is not produced in the plant but bought from intermediate goods manufacturers. Lean production presumes a good infrastructure since a just-in-time delivery of intermediate goods is important if those parts are not produced within the plant. Infrastructure in the electrical engineering industry is, however, labor and capital using and material saving.

Table 8: Average estimated elasticities of factor demand with respect to infrastructure and R&D capital.

	Electrical Engineering		Motor Vehicles	
	D	J	D	J
$e_{L,KI}$	0.108	0.207	-0.112	-0.130
$e_{L,KF}$	-0.185	-0.345	-0.238	-0.380
$e_{K,KI}$	0.034	0.018	-0.047	-0.030
$e_{K,KF}$	0.025	0.113	0.018	0.056
$e_{M,KI}$	-0.110	-0.093	0.014	0.024
$e_{M,KF}$	0.009	-0.096	0.049	-0.004

As for the effect of technical progress on factor demand, Table 8 shows that R&D is in both sectors labor saving and capital using. Labor saving technical progress can be explained by the characteristics of lean production, that is by short ways of information and decentralization, flat hierarchies, team work, an effort for simplified process organization and perfection, but also by an extensive integration of the producers of intermediate goods. With respect to material input, technical progress has a country specific effect. In the German sectors it is material using, but in the Japanese sectors it is material saving. The German sectors try to set up production processes which are based on assembling intermediate goods within the plant in a better and less costly way. The Japanese sectors, on the other hand, use their R&D activities to switch over to production processes based on roboters and integrated production processes.

A comparison of the countrywise economic development of the sectors can also be carried out by using the parameters of the dummy variable from Table 7. They cover the difference in factor quantities due to technical progress. First, we note that in both Japanese sectors the share of labor costs is lower than in the corresponding German sectors $\left(b_{LD} < 0\right)$. But a negative parameter b_{LD} also indicates, that labor input decreases by the rate b_{LD} / s_L when production is shifted to the Japanese sector. This result can be explained by the Japanese way of organizing work input. In the motor vehicles industry, e.g., the time of production per manufactured vehicle lies evidently below the European effort. Also, the quality of the manufactured products in Japanese plants, measured in terms of 65 defects per 100 vehicles versus 97 defects for the European competitors, is better. Therefore, labor input for expensive repairs can be saved (Daum and Piepel 1992, p. 40). In addition, the Japanese intermediate goods sellers are more included in the planning and production process of the producer and to a greater extent directly responsible for the quality control of their products.

The Japanese sectors produce relatively material intensive $\left(b_{MD} > 0\right)$,i.e., they use in their production process more material in terms of finished intermediate goods instead of producing them within the plant. The lean organization on the producer side is therefore characterized by assigning the production of intermediate goods to the intermediate goods industries. This reduces the vertical stages of production and permits to concentrate only on the core of the production process.

Since $b_{KD} > 0$ for both industries, the shares of capital costs are higher in Japan. Given a neutral effect $\left(b_{KD} = 0\right)$ and a disadvantage in costs, the output is produced with a higher capital input when shifting production to the Japanese industry. Because of the capital using country bias, capital input even increases in addition by the rate b_{KD} / s_K. This result reflects the higher degree of automation in the Japanese sectors.

The parameters $b_{KF,D}$ and $b_{KI,D}$ show that the R&D and infrastructure shares are higher in the Japanese sectors. Their negative values in the regression of the difference in costs, s_D, underline the advantageous effect of a higher stock of infrastructure and R&D capital in the catching-up process of the Japanese industry. In the domain of microelectronics and communication techniques, Japan has overcome its image as a technological imitator and improver and is now a worldwide market leader. One reason for that performance could have been the growth in Japan in the number of persons employed with a degree in technical and natural science. Their number is about three times as high as in Germany. In addition, the number of employees in R&D departments as well as their average working time are significantly higher in Japan's economy.

The ceteris paribus analysis of the difference in input allocation for two spatially separated industries $(\partial \ln v_i / \partial D)$ has only shown one aspect for an explanation of the difference in the level of input demand. A total differentiation of the factor demand with respect to D shows the difference in the input quantities as a weighted sum of their determinants:

(15)
$$\frac{d \ln v_i}{dD} = \sum_j e_{ij} \frac{d \ln q_j}{dD} + e_{ix} \frac{d \ln x}{dD} + e_{i,KI} \frac{d \ln KI}{dD} + e_{i,KF} \frac{d \ln KF}{dD} + \frac{\partial \ln v_i}{\partial D}.$$

We can explain therefore the difference in input deployment by differences in factor prices, in the level of production, in the capital stocks, and by technology. The calculation of each component in (15) should finally shed some light upon which quantitative impact can be attributed to the individual sources in explaining differences in factor deployment. We calculated the average values (1970 - 1990) of the first six components in (15) according to

$$\frac{1}{2}\left\{\left[e_{iz}(\,) + e_{iz}(\,)\right]\left[\ln z(\,) - \ln z(\,)\right]\right\} \qquad z = q_L, q_M, q_K, x, KI, KF$$

and then determined the effect of technology $\partial \ln v_i / \partial D$ as a residual. The figures in Table 9 can be interpreted as follows: if in the Japanese electronically engineering industry German factor prices would have been paid and if no differences in infrastructure, R&D capital stock and technology would exist, then a difference in labor input, e.g., could only be attributed to differences in the level of production (the production effect in Table 9). However, as factor prices, capital stocks and technology differ regionally, the difference in labor input due to production is modified by the quantity effects of the other sources. Due to the higher production level, the average labor input in the Japanese electrical engineering industry is higher by 42%. Because the Japanese wage rate is lower than the German one, the Japanese demand for labor is higher by about 4%. The higher Japanese material prices result in an increased use of labor by 1.4% (a substitute). The difference in capital costs has almost no effect on employment, but the differences in the stock of infrastructure and R&D capital do have a significant impact. The labor using effect of KI is 6.9%, the labor saving effect of KF is 5%. The technology effect finally reveals that the Japanese production process, which concentrates more on the core business, is much more labor saving.

Table 9: Sources of the differences in factor quantities in the electrical engineering industry (average values 1970 - 1990).

	labor input	material input	capital input
difference in input quantities	0.264	0.791	1.092
production effect	0.423	0.799	0.827
wage effect	0.041	-0.017	-0.004
material price effect	0.014	-0.007	0.004

capital price effect	-0.003	-0.005	0.026
KI effect	0.069	-0.049	0.064
KF effect	-0.050	-0.025	0.025
technology effect	-0.230	0.095	0.150

The regional difference in the level of production also explains to a large extent difference in the demand for material and capital. The effect of the factor prices is relatively low, but the effects from infrastructure and R&D are about as important as in the labor demand equation. The technology effect draws attention to the fact that the production process in the Japanese electrical engineering industry is oriented towards material and capital using. As mentioned before, external procurements among Japanese manufactures shift the factor inputs from labor to material and capital.

Table 10 presents the results for the motor vehicles industry. The difference in the level of production is the most important cause for the difference in the input deployment, followed by the technology effect which is material and capital using and labor saving. The lower Japanese wage rate gives rise to a higher labor input by 1.8%. The higher Japanese material price has a labor input increasing effect; the impacts from differences in capital prices are quantitatively minor. Labor saving effects come also from the better provision of infrastructure and from the higher R&D capital stock. The difference in input quantities due to regionally different factor prices is very small in the equation for material demand. In the composition of capital input, the higher Japanese user cost of capital has a quantitatively more important impact on capital input. It results in a by 8% lower Japanese capital usage.

Table 10: Sources of the differences in factor quantities in the motor vehicles industry (average values 1970 - 1990).

	labor input	material input	capital input
difference in input quantity	0.472	0.624	0.576
production effect	0.673	0.539	0.513
wage effect	0.018	-0.003	-0.001
material price effect	0.053	-0.025	0.029
capital price effect	0.004	0.015	-0.088
KI effect	-0.053	-0.010	0.026
KF effect	-0.052	-0.004	0.000
technology effect	-0.171	0.112	0.097

Finally, the technology effects reveals that the Japanese production process is based on external procurements by purchasing material in order to save labor and capital.

6. Conclusions

The reversal of the productivity advantage from Germany to Japan in some key industries is considered to be an empirical fact. The objective of this study was to investigate whether the loss in international competitiveness is caused by an above the average increase in labor costs and by a slow-down in productivity, and whether the productivity effects of infrastructure and R&D has helped Japanese industries to catch-up. According to our measurement concept, the foreign industry has a disadvantage in productivity, or in costs respectively if - given the same prices as in the domestic industry - a lower isoquant is reached with the same input combination. The calculation of cost gaps for the industries electrical engineering and motor vehicles has shown that the Japanese sectors have had a cost disadvantage in the seventies; during the eighties this disadvantage turned into a cost advantage. As the descriptive analysis has shown, the productivity increase in Japan of the private factors capital, labor, and material were supported by a relatively stronger increase in private R&D efforts and in public infrastructure. The conjecture of higher labor coefficients in Japan due to a lower wage level could not be supported by the data analysis. The Japanese process technique focuses on external procurement among manufactures and on assembling product components in a capital using and labor saving way.

The econometric analysis supported this view because technical progress had a country-specific effect with characteristics for Japan that match with lean production. The country bias in the structure of production also shows that output in the Japanese sector is produced with higher infrastructure and R&D provision. Finally, the decomposition of the difference in labor input into differences in factor prices, output level, infrastructure capital, and R&D activity as well as into a technology effect, revealed that differences in factor prices do not explain much compared to the technology effect, and the effects of infrastructure and R&D. Insiders have known this before when visiting Japanese plants. In this paper we have shown that a careful analysis of an international data set permits to reveal differences in technology without visiting foreign plants.

Appendix: Data Description

The national account data for the German industries are taken from the publications of the statistical office (Fachserie 18, Reihe 1.3) and the statistical year books. The period of observation is 1970 - 1990. Under the assumption of linear homogeneity of the variable cost function in x, KI and KF, the price of capital q_K to be calculated from the following equation:

$$p \cdot x = q_K K + q_L L + q_M M + q_{KF} KF + q_{KI} KI.$$

The data for the costs of capital, material and labor from the statistical office contain the costs of R&D. R&D expenditures consist of internal R&D expenditures of the firms and external R&D expenditures (R&D orders placed outside the firm) 9, which are presented in the publications "Forschung und Entwicklung in der Wirtschaft der SV-Gemeinnützige Gesellschaft für Wissenschaftsstatistik mbH".10 Since total R&D expenditures are not separated into capital, material and labor costs, we used for a composition the allocation of the internal R&D expenditures into its categories labor material and capital[11]. The purpose of this procedure was to avoid double counting. From the total internal expenditure for R&D in electrical engineering are 60 % labor expenditure, 27 % material expenditure and 13 % capital expenditure. The figures for motor vehicles are 56%, 34% and 10%, respectively. The variable costs were calculated as

$$VC = \left(q_L L\right)_n + \left(q_M M\right)_n + q_K K - 0{,}2 \cdot R\&D$$

where the subscript n denotes the net costs and R&D the R&D expenditures.

The R&D capital stocks for the German industries have been calculated by accumulation. The source of the German stock of infrastructure are the real public net capital formation figures from the DIW (Stille 1993). We are grateful to Shinichiro Nakamura, Waseda University, Japan for providing us with the Japanese data. Since the Japanese data set is essentially more detailed than the German data set, we have been able to achieve a high degree of comparability with respect to the demarcation of sectors and the comparability of KI and R&D capital stocks.

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Endnotes

[*] We are indebted to the referee for her/his valuable suggestions.

[1] The primal concept to the measurement of productivity gaps was introduced by Jorgenson and Nishimizu (1978) for a two country-comparison. Sectoral cost gaps as dual measure of productivity gaps have been calculated by Denny, Fuss and May (1981), Denny and Fuss (1983), and Conrad (1987, 1989).

[2] Technical progress is included in this model (exogeneously) by the R&D capital. The time variable is therefore neglected when R&D capital is included, see e.g. Mohnen, Nadiri and Prucha (1986, p. 752).

[3] Denny and Fuss (1983) have shown that the discrete variable D can be viewed as continuous by applying Diewert's (1976) Quadratic Lemma.

[4] It is shown in Conrad (1985), that the PPPs of the inputs and of output are not independent of each other in case of a joint cost or production function: the PPP of output has to be a Divisia index of the PPPs of the inputs. Because we didn't have the PPPs to convert the Yen values for KI and KF, we took the exchange rate. The Divisia index of the PPP of output has been modified due to the inclusion of infrastructure and R&D.

[5] These shadow prices were calculated by estimating national translog models analoguously to section 4. They consisted on the one hand on the cost function without KF, and on the other hand on the cost function without KI as well as the corresponding cost shares for K, L, and M. From the partial derivatives of the estimated cost function we then got q_{KI} and q_{KF}, respectively.

[6] The average cost gap (1 970 bis 1979) amounts to 0. 079 without KF and KI and to 09 with KF and KI.

[7] The minus sign results from equation (14).

[8] The data description can be found in the appendix.

[9] See "Forschung und Entwicklung in der Wirtschaft", 1989, p. 87. All of the German R&D data are taken from the publications "Forschung und Entwicklung in der Wirtschaft".

[10] The values for those years for which no figures from the "Stifterverband" were available, had to be calculated by interpolation as in Horn (1993).

[11] This procedure is justifiable because internal R&D efforts include more than 90% of the total expenditures.