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Sources of productivity growth: An empirical analysis with German sectoral data

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Sources of Productivity Growth
An Empirical Analysis with
German Sectoral Data

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Sources of Productivity Growth

An Empirical Analysis with German Sectoral Data

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Abstract:

In the paper, the productivity growth of German sectors is analyzed. Sectoral production functions are estimated with annual national account data of 51 sectors from 1960–1990. Both, the pure Solow growth model and the Solow model augmented with human capital do not account for observed productivity increases. It should be extended by allowing for inter-industry spillovers and scale economies at the aggregate level, as well as for scale economies associated with human capital at the sectoral level. The business cycle affects observed productivity changes both in the short run and in the long run.

Keywords: Endogenous growth, human capital, intersectoral spillovers

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1 Introduction

In the paper, the sources of productivity growth are investigated by an empirical analysis with German sectoral data. The motivation behind this study is the existence of a large residual left after standard procedures of growth accounting. Growth accounting refers to the famous neoclassical growth model of Solow, where output growth is attributed to the increase of the standard production factors labour and capital, and a residual. The residual left after this kind of exercise is above 2 percent, i.e. about 2/3 of every years output growth are left unexplained. This contrasts sharply with the high value of these productivity increases: the present value of one year's total factor productivity growth, calculated with a real interest rate of 4 percent, amounts to about 50 percent of one year's value added!

A convenient way to deal with this discrepancy is to treat the residual as exogenous. However, nearly every information and a priori assessments about the sources of productivity increases would reject this approach. The incentives and the process of introducing productivity enhancements are not at all exogenous to the economic system, but have their origins in the intertemporal optimizing behaviour of competing firms. Nevertheless, in many economic models dealing *not* explicitly with the sources of economic growth, technical change is treated as exogenous, and labour and capital are the only endogenous inputs of the production process.

In the paper, it is tried to relate the productivity increases to those factors emphasized by the theories of endogenous growth. In the past few years, a large number of models dealing with the sources of productivity growth have emerged. Perhaps the slightest methodological change is introduced by models correcting for the quality of the factor inputs or augmenting it with additional factor inputs. As one extension, human capital appears as a third factor input in the production process. In a similar manner, a fourth production factor, namely the stock of knowledge can be introduced. Firms invest in R&D, thereby generating a stock of knowledge which can serve as a substitute to other production factors.

The notion of knowledge as a production factor introduces two methodological changes into the analysis. The first is the idea of scale economies associated with knowledge. It is easy to think about production processes characterized by constant returns to scale of the standard production factors. Increasing standard production inputs by a certain percentage, holding knowledge constant, should increase output by the same percentage. Increasing all inputs then leads to a more than proportional increase of output. Scale economies change the whole procedure of calculating the residual and can also account for endogenous sustainable growth.

The second methodological change introduced by knowledge as a production factor is the idea of knowledge spillovers. Knowledge can be transferred at a cost which is much lower than the cost of originally producing it. This idea has received a lot of attention in recent growth models. It allows to maintain the assumption of constant returns to scale at the level of the individual firm, but increasing returns and endogenous growth at the aggregate level. In addition, large productivity increases can be attributed to low expenses on R&D.

Despite of the enormous policy implications of scale economies and knowledge spillovers, clearcut empirical results are still missing. In the paper, it is tried to shed some light on these arguments by an empirical investigation of the sources of sectoral productivity growth. A general production function is estimated which includes some of the above mentioned arguments. A further theme of the paper is the relation between productivity growth and the business cycle. First, empirical growth model should account for the business cycle to correct for inefficiencies associated with them. Second, the sources of growth are probably not independent from the business cycle.

The data source which is applied for the empirical analysis are the sectoral national accounts of the Federal Republic of Germany. The empirical investigation with sectoral data has several advantages. Compared with aggregate data, the number of observations is enormously increased. On the other hand, compared with cross-country data sets, inconsistencies of data measurement and inhomogeneity with respect to omitted variables appear to be much less of a problem.

2 Growth accounting

The starting point for standard growth accounting and for the empirical approach applied here is an aggregate production function. This relates to the famous neoclassical growth model of Solow (1956, 1957).

$$Y = Y(K, L, \text{residual}) \quad (1)$$

with: Y : real output
 K : physical capital
 L : labour input

Output is produced with capital and labour as inputs. The residual refers to technical efficiency which may increase over time. Growth accounting usually relies on the assumption of constant returns to scale for labour and capital. Then, output growth is determined by the growth of the two factor inputs weighted by their respective output elasticities, and a residual. The elasticity of output with respect to employment is estimated from the labour share.

Table 1: Growth accounting

	1961 – 1970	1971 – 1980	1981 – 1990	1960 – 1990
Δy	4.43	2.58	2.18	3.06
Δk	5.93	4.10	2.77	4.27
Δl	-0.11	-0.36	0.35	-0.04
Δh	-1.01	-1.08	-0.74	-0.94
sl	69.7	71.7	69.2	70.2
$\Delta k \cdot (1 - sl)$	1.79	1.16	0.85	1.27
$(\Delta l + \Delta h) \cdot sl$	-0.79	-1.04	-0.29	-0.71
residual	3.42	2.46	1.62	2.50
real interest rate	3.08	3.08	4.75	3.64

Small case letters denote logs. Annual averages in percent.

Private sector of the German economy.

Empirical post-war data for most of the developed countries show an average output growth of about 3 percent. The capital stock increases slightly faster. Employment remains fairly stable, but one can observe a reduction of the working time per employee and consequently a decrease of the labour input. The labour share is about 0.7. Then, the increase of capital accounts for slightly more than 1 percentage point of economic growth. Together with the significant decrease of the working time, the residual left after this kind of growth accounting exercise is above 2 percent. This contrasts sharply with the high value of these productivity increases. With a real interest rate of about 4 percent, the present value of one year's total factor productivity growth amounts to about 50 percent of one year's value added.

The results of this kind of growth accounting exercise for data of the Federal Republic of Germany are contained in [table 1](#). Average output growth Δy for the last 30 years amounts to about 3 percent per year, and the increase of the capital stock Δk is slightly above 4 percent. The labour share sl is about 70 percent. Calculating the elasticity of output with respect to the capital stock as 1 minus the labour share yields a contribution of capital to growth of about 1.3 percentage points.¹ The change of the labour input is documented for its

¹Calculating the capital share from the user costs of capital yields an even lower capital share and consequently a lower contribution of capital to growth. The real interest rate is about 4 percent, depreciation amounts to about 6 percent, and the net capital-output ratio calculated for German data is about 1.4. This would imply an even larger residual.

two components, total employment L and average worked hours per employee H . Employment remained fairly stable, but the working time was reduced by nearly 1 percent per year. Therefore, the labour input reduced also by about 1 percent per year. The residual left after accounting for labour and capital inputs, i.e. total factor productivity growth, is calculated as 2.5 percent. This can be compared with the real interest rate displayed at the bottom line of table 1. It is calculated as the long term bonds yield minus the average rate of inflation and amounts to about 3.6 percent on average. The resulting average present value of one years total factor productivity growth is therefore much above half of GDP. It is difficult to believe that these productivity increases were exogenous. That would imply either an enormous outcome of the low R&D investments of the public, or an enormous, costless gift.²

Figure 1 gives a visual impression of the development of output, factor inputs, and the residual for the German data from 1960 to 1990. One can see the long-run decrease of the growth rates of output, capital, and the residual, and also the cyclical variability of these series. Output changes fluctuated more than labour and capital input changes, therefore total factor productivity is strongly procyclical. One explanation for the procyclical behaviour of the factor productivities are adjustment costs for labour and capital and consequently underutilization of capital and labour hoarding during recessions. This will be taken into account for the empirical analysis presented below.

This standard growth accounting approach is often extended by allowing for quality changes of the factor inputs,³ or by introducing additional production factors. A drawback of this method is its reliance on factor income shares which are difficult to measure. An alternative method of growth accounting consists in estimating the output elasticities of the factors from the production function instead of calculating them from factor income shares. This kind of growth accounting has become very popular with the availability of new data sets,⁴ and is also applied in the work here.

Mankiw, Romer, Weil (1992) provide an example about the relative success that can be achieved by this kind of analysis.⁵ They analyzed economic growth in a cross-section of countries by a Solow model augmented with human capital, and could explain a much greater part of the variance than in the standard model. Their estimated elasticity of output with respect to human capital was as high as the respective elasticities for labour and physical capital. The importance of this third production factor becomes also visible when looking for investments in and returns from human capital. In the developed countries,

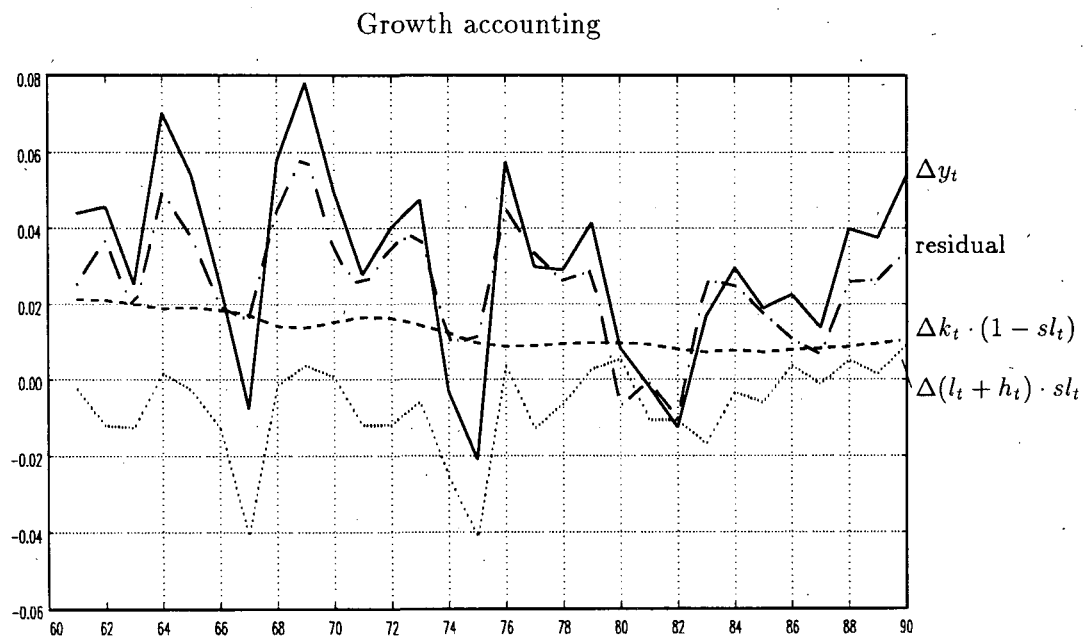
²For instance, Benhabib, Jovanovic (1991), p.86, argue that "...some knowledge comes for free from abroad, and in addition, some knowledge is generated for free domestically as a by-product of everyday economic activity."

³See Maddison (1982, 1987) and the literature cited there.

⁴For instance, the Penn world tables, see Summers, Heston (1991).

⁵See also Romer (1989), Barro (1991), and Levine, Renelt (1992) for an overview.

Figure 1: Growth accounting



outlays for better qualification of the work force are about as high as the costs of investments in physical capital. Measures of the returns on human capital give a similar impression. The wage of an unqualified workers, for instance approximated by the wage of a worker in the lowest wage group, is about one half of the average wage. A similar value results from estimation of usual Becker/Mincer type earnings functions when comparing average earnings with the earnings of a person without human capital. This implies returns to human capital in the dimension of the returns to simple labour.⁶

The augmented production function which captures this approach and which also accounts for efficiency changes during the business cycle can be written as:

$$Y = Y(K, L, HK, U, \text{residual}) \quad (2)$$

with: HK : human capital per worker

U : indicator of the business cycle, factor utilization

However, the importance of human capital as a third production factor should not be misunderstood as an explanation of the whole residual. An increase of human capital input during the last 30 years is visible, but it is difficult to imagine that the better qualification of the work force is the only or even the most important difference between production processes today and before 30 years.

3 The accumulation of knowledge

In the same way, a fourth production factor, namely the stock of knowledge, can be introduced. One may start with a simple model, where knowledge is produced by investments in R&D. The accumulation of R&D constitutes an stock of knowledge which increases the productivity of the other input factors.⁷ A specification of a sectoral production function in growth rates which captures this approach can be written as:

$$\Delta y_{i,t} = \Delta y(\Delta k_{i,t}, \Delta l_{i,t}, \Delta hk_{i,t}, \Delta u_{i,t}, \Delta k_{i,t}^n, \text{residual}) \quad (3)$$

with: K^n : knowledge

i is the sector index, and small case letters represent logarithms of the variable. However, it is difficult to think about knowledge produced by R&D as the only modification which is necessary to explain the residual. Conventional measures of R&D amount to about 2 percent of GDP. Then it would require a very high

⁶Therefore, the introduction of human capital as a production factor also brings growth models which rely on high output elasticities of reproducible capital more in accordance with income distribution, i.e. the observed 70 percent labour share.

⁷This idea dates back at least to Uzawa (1965).

productivity of R&D to explain a large proportion of the 2 percent productivity growth by it. It would also provoke the question, why R&D expenditures are so low.

On the other hand, the consideration of knowledge as a production factor introduces two methodological changes into the analysis. The first is the idea of scale economies. Assuming linear homogeneity of the production function in the *physical* input factors, a proportional increase of *all* factors increases output more than proportionally. In addition, the outlays for innovations probably constitute more or less a fixed cost which is independent from the level of production. This strengthens the case of scale economies associated with knowledge. However, economies of scale at the firm level imply an incentive for firms to become larger, and markets should become more concentrated. A tendency towards monopolization can be found for some markets but not for the aggregate. Especially if one wants to attribute a large part of the observed productivity increases to increasing returns, this view is not supported by data about firm concentration. This does not imply that scale economies at the firm level should be neglected. For instance, they may be very important for some industries, and scale economies may also arise due to specialization.⁸ Finally, scale economies of a smaller extent are compatible with constant firm size, if the market is characterized by monopolistic competition with specialized products.

Probably the most important methodological innovation which is introduced by knowledge as a production factor is the idea of knowledge spillovers. This concept was already introduced by Arrows (1962) notion of "learning by doing" and has received a lot of attention in recent models of endogenous growth.⁹ The idea is that an innovation which is produced by one firm *may* also be used by another firm, without incurring very much additional cost. Second, an innovation which is produced by one firm *can* also be used by another firm. To some extent, firms can imitate others' innovations without paying a price for it.¹⁰

This spillover constitutes the major mechanism by which sustained growth in those models is driven. It allows to maintain the assumption of constant returns to scale and competition at the firm level, but increasing returns to scale and endogenous growth for the aggregate economy. However, there remains a logical difficulty in the argument. External effects create an inefficiency, because firms do not receive full compensation for their research effort. Equilibrium R&D would be below the social optimum. The pure amount of the present value of productivity increases then implies an enormous incentive for

⁸See Romer (1987b).

⁹Much of the recent work was inspired by the models of Romer (1986) and Lucas (1988).

¹⁰Arrows (1962) model accentuated the importance of aggregate gross investment, Romer (1986) emphasized R&D, and Lucas (1988) analyzed the role of external effect associated with human capital.

firms to exploit some of the social value of the spillovers. To some extent, patents have this function, but their value is low compared with the value of productivity growth. Nevertheless, spillovers deserve a prominent role for the explanation of endogenous growth.

A final theme of the paper is the relation between growth and the business cycle. The sources of growth are probably not independent from the business cycle but its impact on long-run productivity growth cannot be determined without ambiguity from theoretical arguments.¹¹ The arguments of learning by doing suggest a complementarity between productivity growth and economic activity. In addition, R&D can be more easily financed from retained profits and is more profitable during expansions.¹² In other models, it is argued with opportunity costs and intertemporal substitution, thereby stating a positive influence of recessions on long-run growth.¹³ Productivity enhancements require the reorganization of production processes which is less costly during periods of slack demand and underutilization of labour and capital. The undertaking of internal R&D activities in recessions can be understood as the reallocation of idle resources. This argument is also consistent with the measured procyclical development of total factor productivity. In both cases, the effect of the business cycle stands for unobserved components of R&D activities. The answer, which effect dominates, and whether productivity growth and production activity are substitutes or complements, is left to the empirical work.

For an empirical application, the measurement of knowledge constitutes a major problem. Conventionally measured R&D outlays do not capture all expenditures related to improving production processes or the quality of goods.¹⁴ Therefore, for the empirical estimation, the stock of knowledge is determined by introducing the concept of a knowledge production function.

Arguments of learning by doing suggest that knowledge may be acquired through investments in physical capital. First, process innovations are often embodied in new investment goods. Second, improving production processes or the quality of goods often implies the reorganization of production processes which may require capital investment. In this sense, capital accumulation and technical progress are complements. In this case, the estimated effect of investment on productivity growth captures not only the production elasticity of (homogeneous) capital, but also those externalities associated with the increase of knowledge.¹⁵

¹¹See Aghion, Saint-Paul (1993) for a discussion.

¹²See Stiglitz (1993).

¹³See Bean (1990), Saint-Paul (1993), and Bean, Pissarides (1993).

¹⁴In addition, R&D outlays were not available at the sectoral level for the investigated time period. Therefore, estimating the effect of R&D outlays on the stock of knowledge is left to future work.

¹⁵See also Romer (1987a).

Another specification of learning by doing which is the spirit of the work by Romer (1986, 1989) and Lucas (1988) is related to human capital. Knowledge may arise as a not necessarily costless by-product of the daily work of qualified workers. Qualified employees are doing not only their production activities but are also searching for process and product improvements. Formal R&D requires that people are paid just for this activity. Another part of R&D is probably more implicate and not included in those data. This argument implies that *increases of knowledge* are associated with the *level of human capital*.

Summarizing these arguments, it is tested whether the change of knowledge depends positively on the accumulation of physical capital and the amount of human capital. The spillover is approximated by allowing for effects of aggregate labour productivity increases on the sectors' productivity growth. A specification of a knowledge production function, which captures these arguments and allows also for effects of the business cycle, is given by:

$$\Delta k_{i,t}^n = \Delta k^n[\Delta k_{i,t}, hk_{i,t-1}, \Delta(y-l)_t, u_{i,t-1}, \varepsilon_{i,t}] \quad (4)$$

$\varepsilon_{i,t}$ is the error term. Inserting eq. (4) into the production function eq. (3) and assuming constant returns to scale for the standard production factors yields the following equation for the sectoral labour productivity growth:

$$\begin{aligned} \Delta(y-l)_{i,t} = & \Delta y[\Delta(k-l)_{i,t}, \Delta hk_{i,t}, \Delta u_{i,t}, \varepsilon'_{i,t}, \\ & \Delta k_{i,t}, hk_{i,t-1}, \Delta(y-l)_t, u_{i,t-1}] \end{aligned} \quad (5)$$

A log-linearized form of eq. (5) is the base for the empirical investigations which are discussed in the next section.

4 Data and empirical specification

The basic data source which is employed are the sectoral national accounts of the Federal Republic of Germany. The empirical analysis is performed with annual data from 1960–1990 for the private sector excluding agriculture.¹⁶ That leaves, in total, 51 sectors of industry, trade and traffic, and services, and conforms to the 2-digit level for industry.

This sectoral approach for the determination of the sources of growth has several advantages. As compared with the estimation of cross-country growth regressions, as performed by many other authors,¹⁷ the cross-sectoral data set exhibits a much greater homogeneity. For instance, inconsistencies of data measurement and the omission of unobserved differences appears much less

¹⁶The public sector and agriculture are deliberately excluded from the analysis, because the construction of those data does not allow an interpretation in terms of the model. For some sectors, the data start in 1970.

¹⁷For an overview, see Levine, Renelt (1992) and Sala-i-Martin (1994).

a problem in the cross-sectoral approach. On the other hand, if the cross-country analysis is confined to a more homogeneous group, for instance the OECD-countries, less observations and much less variance is left as for the disaggregated approach.¹⁸ This holds even more for a pure time series analysis with aggregate data for one country.

The analysis with sectoral data has also some advantages compared with micro data for firms. First, micro data panels for firms often capture only a short time period and are usually not available since the sixties, as sectoral data are. Second, firm data sets do not include informations about important variables, as for instance price indices which are necessary to calculate real values. Third, firm data are mostly confined to industry, while sectoral data capture the whole economy.

The main data which are taken from the national accounts are the real value added, total employment, and the gross capital stock. The values of the capital stock are taken for the beginning of year. This represents something like a time-to-build assumption, as it implies that it takes some time before new investment goods become productive.¹⁹ A shortcoming of the data set is that no sectoral data for the working time and for R&D expenditures were available. In figure 2, some measures of the data are shown. In the first figure, the aggregate labour productivity change is depicted together with its cross-sectoral standard deviation σ . σ is calculated for each year as the unweighted standard deviation of the sectoral growth rates. It can be seen that the data are characterized by a large sectoral variance, while the short-run time series variance is mainly due to the business cycle.

The second figure depicts the labour productivity growth of the more aggregated sectors industry, trade and traffic, and services. It can be seen that the labour productivity growth of these sectors is highly correlated. This is partly due to the common effects of the business cycle; but they also share the same common trend which is not obvious. The data for the business cycle indicator which stand for the factor utilization are taken from the business survey of the ifo-institute.²⁰ For the empirical investigation, u is measured as the difference of the shares of firms reporting a good and a bad business cycle situation, respectively.

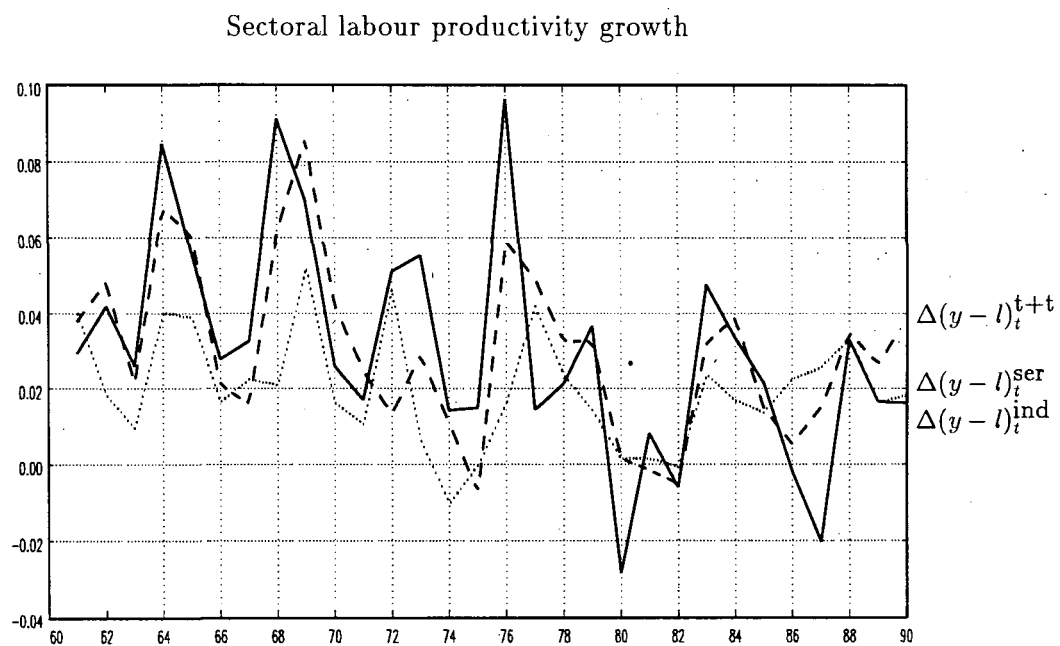
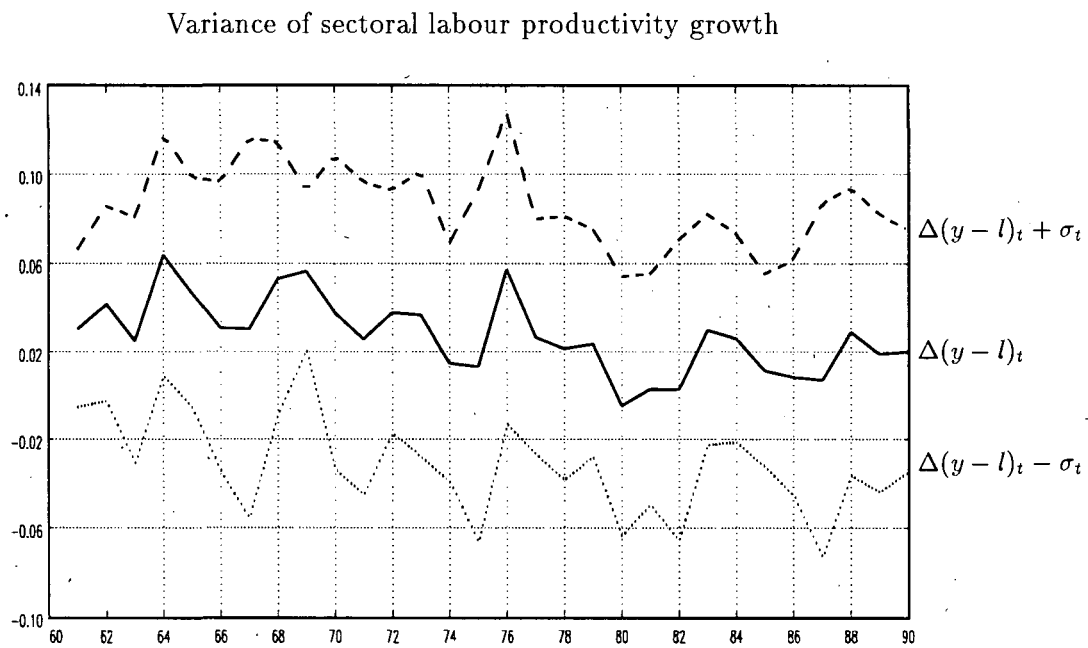
Some remarks are necessary with respect to the construction of an index of sectoral human capital. The human capital per employee may be measured

¹⁸See also figure 2.

¹⁹It was tested, whether another specification, i.e. the average value of the beginning and end of year capital stock outperforms those results. This was not the case. In addition, it was tested, whether different coefficients result for equipment and structures, but the results were inferior to those presented.

²⁰Special thanks are due to the ifo-institute for providing me with those data. These data are available only for the industry sectors and from 1961 or 1967 onwards. The values for aggregate industry were also used to approximate the business cycle effects for the other sectors which may be excusable in view of their high sectoral correlation.

Figure 2: Sectoral labour productivity growth



σ : standard deviation of sectoral growth rates
ind: industry, t+t: trade+traffic, ser: services

by the real cost of obtaining it, for instance approximated by the years of schooling and formal apprenticeship training. However, this measure does not take into account those qualifications which are acquired by informal training and experience. In addition, these data were not available at the sectoral level. Another indicator for human capital can be constructed from its returns. The average wage paid in a sector, in relation to the wage for unqualified work, can be used as a measure for the quality of its work force. Why should higher wages be paid in a sector, if not for better qualified work? This procedure has some resemblance to the calculation of the real capital input. Nominal market values are deflated by an appropriate price index.

Here, a two-step procedure is applied to capture this argument. First, the average sectoral wage is set in relation to the average aggregate wage. This gives a measure of the relative qualification of the worker for the sectors. Second, an indicator for aggregate human capital is calculated as the ratio of the average aggregate wage and the wage for unqualified work.²¹ Of course, one can argue that sectoral wages are also determined by other factors than human capital. However, a substantial part of interindustry wage differentials can be attributed to observable, human capital related characteristics of the work force.²² In addition, the remaining differences are mainly attributed to efficiency wage arguments.²³ This is consistent with the interpretation that wage differentials can serve as an indicator of the quality of the work force.

The empirical specification of the production function is always estimated for the first differences of the endogenous variable. The economic theory behind the model suggests the non-stationarity of most of the variables which was also confirmed by a time series investigation.²⁴ In addition, it is everything but obvious that there should be cointegration between the variables. The measurement of physical capital, human capital, and the determinants of knowledge are probably subject to measurement errors and omitted (non-stationary) variables which would lead to spurious regression results.²⁵ In addition, the levels of real labour productivity are not comparable across sectors due to the different development of prices. It is not easy to account for

²¹ The definition of unqualified work may have changed during the time period under consideration. Therefore the wage for unqualified work was also substituted by the wage of a rather homogeneous group, i.e. blue collar workers with completed vocational training. In addition, it was tested whether the human capital can be approximated by the share of workers in the high qualification groups.

²² See, for instance, Krueger, Summers (1988).

²³ See again Krueger, Summers (1988). These authors also mention union density as a cause of interindustry wage differentials which, however, hardly plays a role for Germany.

²⁴ Non-stationarity of the level of the logarithm of labour productivity could not be rejected for nearly all of the sectors, while for the corresponding growth rates, non-stationarity could be rejected for nearly all of the sectors.

²⁵ In addition, an estimation in levels would have to rely on poorly measured initial values of capital and knowledge.

the change of efficiency, and it appears inadequate to try to explain the levels of labour productivity and knowledge. It is also allowed for a constant and a time trend in the estimated equations to account for omitted variables and to capture the general development of declining growth rates.

5 Estimation results

The estimation results are contained in table 2 and 3 on the following pages. A log-linear specification of eq. (5) is chosen which implies constant output elasticities of the factors. The growth regressions are performed both for the private sector excluding agriculture (table 2) and for a more restricted data set, i.e. the (more homogeneous) production industries (table 3).

Model (1) corresponds to the simple Solow model with constant returns to scale, where the exogenous technical change is approximated by a constant and a time trend. The results surprisingly yield a quite reasonable estimate for the elasticity of output with respect to capital. The estimated coefficient is close to the share of capital (or residual) income in value added. This gives an impression about the advantages of cross-sectoral data as compared with a pure time series analysis, where the effect of the trend increase of the capital-labour ratio often cannot be distinguished statistically from simple deterministic or stochastic time trends. It shows also the relative advantage against a cross-country growth analysis, where the capital intensity is correlated with many other determinants of growth, and stands more or less for the general state of development of the country.

The estimated equation in the next row accounts also for changes in the utilization of the input factors, and it can be seen that changes in utilization are a very important determinant of the Solow-residual in the short run. The coefficient associated with the business cycle indicator is highly significant, and the inclusion of this variable results in a reduction of the standard error of the coefficient of the capital-labour ratio. Omitting the effects of the business cycle leads to an underestimation of the effect of capital.

In the next two rows, the Solow model is augmented with human capital. The relative human capital of the sectors, approximated by the relative wage, is included as an additional variable, and it can be seen that it is as important for the determination of the productivity growth as the physical capital. Both coefficients are of the same order of magnitude. The significance of the human capital variable indicates also the appropriateness of approximating labour quality by its real returns, i.e. a relative wage. It should be noted that the relative wage does not stand for substitution effects. This is taken into account by the capital-labour ratio. The estimated coefficient of the capital-labour ratio is of plausible magnitude and does not change with the inclusion of the relative wage. It was also tried to include an indicator for the average

Table 2: Sources of productivity growth: private sector

endogenous variable: $\Delta(y-l)_{i,t}$

exogenous variables:

	constant	trend	$\Delta(k-l)_{i,t}$	$\Delta hk_{i,t}$	$\Delta u_{i,t}$	$\Delta(y-l)_t$	$hk_{i,t-1}$	$u_{i,t-1}$	R^2
Solow model									
(1)	0.031 (6.4)	-0.0008 (-3.6)	0.267 (6.8)						0.063
(2)	0.032 (6.2)	-0.0010 (-4.7)	0.360 (9.3)		0.099 (14.8)				0.196
Augmented Solow model									
(3)	0.030 (6.2)	-0.0008 (-4.0)	0.280 (7.4)	0.572 (8.0)					0.104
(4)	0.031 (6.1)	-0.0011 (-4.9)	0.366 (9.5)	0.378 (5.2)	0.092 (13.6)				0.213
The impact of the aggregate productivity									
(5)	-0.006 (-0.6)	-0.0001 (-0.2)	0.364 (9.6)	0.391 (5.4)	0.068 (8.1)	0.714 (4.8)			0.226
Level effects									
(6)	0.027 (5.2)	-0.0009 (-4.3)	0.405 (10.3)	0.378 (5.2)	0.104 (14.1)		0.024 (3.7)	0.022 (3.7)	0.228
(7)	-0.004 (-0.5)	-0.0001 (-0.4)	0.397 (10.2)	0.388 (5.4)	0.080 (8.7)	0.627 (4.2)	0.024 (3.6)	0.018 (2.8)	0.239
Time dummies									
(8)			0.402 (9.9)	0.387 (5.3)	0.073 (6.4)		0.023 (3.5)	0.009 (1.0)	0.258
Sectoral dummies									
(9)		-0.0000 (-0.1)	0.384 (9.4)	0.330 (4.4)	0.085 (8.9)	0.613 (4.1)	-0.052 (-1.4)	0.024 (3.2)	0.288
Time and sectoral dummies									
(10)			0.383 (9.0)	0.329 (4.3)	0.076 (6.2)		-0.047 (-1.3)	0.010 (0.9)	0.306

Annual data (1960 – 1990) of 51 sectors, private sector excluding agriculture.

1422 (1283) observations. t -values in parentheses.

Table 3: Sources of productivity growth: industry

endogenous variable: $\Delta(y-l)_{i,t}$

exogenous variables:

	constant	trend	$\Delta(k-l)_{i,t}$	$\Delta hk_{i,t}$	$\Delta u_{i,t}$	$\Delta(y-l)_t$	$hk_{i,t-1}$	$u_{i,t-1}$	R^2
Solow model									
(1)	0.043 (7.4)	-0.0011 (-4.1)	0.167 (3.7)						0.054
(2)	0.040 (6.7)	-0.0012 (-4.8)	0.296 (6.5)		0.101 (14.3)				0.240
Augmented Solow model									
(3)	0.043 (7.7)	-0.0012 (-5.0)	0.163 (3.7)	0.740 (8.9)					0.127
(4)	0.041 (7.0)	-0.0013 (-5.3)	0.277 (6.1)	0.396 (4.5)	0.090 (12.1)				0.259
The impact of the aggregate productivity									
(5)	-0.006 (-0.5)	-0.0001 (-0.2)	0.280 (6.3)	0.391 (4.5)	0.065 (7.6)	0.925 (5.6)			0.286
Level effects									
(6)	0.040 (6.5)	-0.0014 (-5.1)	0.316 (6.7)	0.375 (4.3)	0.099 (12.0)		0.035 (3.9)	0.013 (1.9)	0.274
(7)	-0.003 (-0.3)	-0.0002 (-0.6)	0.306 (6.6)	0.372 (4.3)	0.072 (7.4)	0.884 (5.3)	0.033 (3.8)	0.006 (1.0)	0.299
Time dummies									
(8)			0.278 (5.4)	0.415 (4.5)	0.071 (6.4)		0.033 (3.7)	0.008 (1.0)	0.328
Sectoral dummies									
(9)		-0.0001 (-0.4)	0.268 (5.4)	0.320 (3.6)	0.070 (6.9)	0.914 (5.5)	-0.039 (-0.8)	0.004 (0.5)	0.343
Time and sectoral dummies									
(10)			0.237 (4.3)	0.378 (3.9)	0.067 (5.6)		-0.023 (-0.5)	0.001 (0.1)	0.370

Annual data (1960 – 1990) of 32 industry sectors. 950 (820) observations.

t -values in parentheses.

aggregate human capital input, measured either by the relation of the aggregate wage to the wage of non-qualified workers, or by the shares of the groups of employees with high qualifications. However, these variables never had a significant impact on labour productivity growth. This may be due to the low variance of these variables, the time series of the variables can be described appropriately by a smooth trend.²⁶ In addition, the aggregate working time never proved significant in the estimates which is probably due to the same reasons. Therefore, these results are not included in the tables.

The results so far show that the increase of the capital-labour ratio, the change of human capital input, and the business cycle effects cannot account for the long-run trend of labour productivity growth in the German economy. This can be seen from the high and significant coefficients of the constant and the time trend. These estimates have about the same implications for the long-run development of the Solow-residual as are shown in table 1 in section 2 above. A large share of the long-run total factor productivity growth cannot be related to these variables. In model (5), (6), and (7), it is tested for an impact of those variables which stand for the increase of knowledge as proposed by the models of endogenous growth. Model (5) tests for the impact of the aggregate productivity growth on the productivity growth of the individual sectors which stands for inter-sectoral knowledge spillovers. The results indicate a really strong impact of aggregate productivity changes on sectoral productivity changes. The estimated coefficient is quite significant, and its value implies a strong association of the variables. In addition, the constant and the trend nearly drop out of the equation!

This result, first of all, is consistent with a strong inter-sectoral spillover, strong enough to account for endogenous growth. Second, it cannot be attributed simply to a simultaneous equation bias: the aggregate growth rate is calculated excluding the sector under consideration. However, it cannot be proven that it is caused by knowledge spillovers. For instance, the correlation may also be caused by common, unobserved business cycle effects. It is tried to control for them in the equation with different business cycle indicators, but something may be left. Another explanation would be an exogenous increase of knowledge which is important in most or all of the sectors. The sectoral specification allows to look for inter-sectoral correlation of productivity enhancements which may indicate spillovers. It does not allow to discriminate between common productivity shocks and causation between aggregate and sectoral productivity developments.

Finally, the investment rate, the level of sectoral human capital, and the level of the business cycle situation are included as determinants of the change of knowledge. The investment rate never appears significant in the estimates

²⁶The relation of the average wage and the wage of an unqualified worker increases steadily by about 15 percent during the observation period.

and is dropped for the reported results. This standard version of sectoral economies of scale is not supported by the data. However, human capital and the business cycle situation appear with positive and significant coefficients. Therefore, endogenous growth model which rely on scale economies and spillovers associated with human capital receive some support from the estimates. Boom periods also significantly increase productivity growth in the long run,²⁷ apart from their short-run impact on factor productivity via factor utilization. The inclusion of those two variables reduces the spillover coefficient of the aggregate productivity slightly, which is an expected result: if it is allowed for sectoral scale economies, the estimated inter-sectoral spillover becomes smaller.

The pooled cross-section/time series analysis allows also to control for unobserved differences over time or between sectors by including dummy variables.²⁸ The respective results are included at the bottom lines in tables 2 and 3. The following results are worth to be noted: first, the coefficients of the change of the capital-labour ratio, the human capital indicator and the business cycle are very robust and remain nearly unchanged. This enhances the reliability of the results and indicates the appropriateness of the approximation of labour quality by wages. Second, the spillover is nearly unaffected by the inclusion of sectoral dummy variables. Third, the coefficient associated with the level of human capital remains unaffected by time dummies but loses significance and even changes sign with the inclusion of sectoral dummies. This implies that the significance of this effect depends on the cross-sectional variance of this variable and can also explain the lack of significance of the aggregate human capital indicator. Fourth, the effect of the level of the business cycle remains unchanged by inclusion of sectoral dummies, but loses significance together with the time dummies. Here the time series dimension of the data series appears to be more important, while the cross-sectoral correlation of the series is very high. Finally, the inclusion of time and sectoral dummies increases the fit of the estimated equation, but not by as much that the pooling of time series and cross-sectoral data would be completely rejected. In general, the R^2 of all reported equations is remarkably low. Even the most sophisticated model can account for less than a third of the observed variance of the sectoral labour productivity growth of the private sector.²⁹ This indicates that more work is necessary to account for the sources of productivity growth.

²⁷ This effect is not significant for the constrained sample of industry sectors.

²⁸ It was also tested for autocorrelation and dynamic adjustment processes. There was no significant autocorrelation of the residuals, and the lagged endogenous variable never had a significant impact. In addition, the cross sectoral correlation of the residuals was low.

²⁹ The R^2 is only slightly higher for the more homogeneous industry sectors.

6 Conclusions

Several shortcomings limit the scope of the empirical results. No sectoral measure of the working time was included despite its importance for the productivity development. In addition, no sectoral measure of R&D expenditures was available, and the aggregate impact of human capital could not be determined. Therefore, it was not tried to obtain a reduced form by substituting the aggregate productivity growth by the aggregate determinants of knowledge.

Nevertheless, some results of the study appear to be rather robust. First, the time series/cross-sectoral dataset yields a well determined and reasonable estimate of the impact of physical capital. Second, the results exemplify the prominent role of human capital as a production factor. The relative sectoral human capital can be approximated by relative wages. Third, the business cycle affects productivity growth both in the short run and in the long run. Fourth, the sectoral total factor productivity changes are highly correlated which can be interpreted as evidence for inter-sectoral spillovers. This would allow for endogenous growth. Finally, the level effects of human capital and the business cycle indicate scale economies even at the sectoral level.

These results, if they are reliable, would have important policy implications. Every year's technical change has an enormous social value. Most probably, it is generated endogenously by the economic system. However, if it is distributed for free, as the spillover model suggests, firms have low incentives to engage in R&D, and the market outcome would be below the social optimum. Further empirical work is necessary to investigate this issue. A cross-sectoral/time series data set provides a useful basis for further empirical investigations of technical spillovers. In addition to inter-sectoral spillovers within a country, one can look for across border spillovers between the sectors and test for convergence towards "best practice" technology.³⁰ This provides a framework to analyze the impact of economic integration through trade and foreign direct investment. The empirical work with sectoral data can be supplemented with the analysis of disaggregated firm data sets to investigate scale economies at the micro level and their consequences for market behaviour.

³⁰See Grossman, Helpman (1991).

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