

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

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Many theoretical analyses of the sources of economic growth focus on knowledge spillovers and scale economies to explain growth endogenously. The contribution of this paper is to shed some light on these arguments by an empirical investigation based on a production function framework. Sectoral production functions are estimated with annual German data of 51 sectors from 1960–90. The estimates reveal that both a pure Solow growth model and a Solow model augmented with human capital cannot account for the observed productivity increases. The model 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 in the short run and in the long run.

I. INTRODUCTION

‘Technological advance has probably been the major influence on the nature of the lives that we lead relative to the lives that our forebears had and our children and grandchildren will have’ (Stoneman, 1983, p. 1). In this paper, the sources of productivity growth are investigated by an empirical analysis with German sectoral data. The starting point of this study is the large residual left after standard procedures of growth accounting, i.e. standard growth models leave most of observed growth unexplained. Growth accounting refers to the famous neoclassical growth model of Solow (1956, 1957), where output growth is attributed to the increase of the standard production factors labour and capital, and a residual. For most industrialized countries, this residual is above 2% per year, i.e. about two thirds of every year’s output growth is left unexplained.¹ This contrasts sharply with the high value of these productivity increases: The present value of one year’s total factor pro-

ductivity growth, calculated with a real interest rate of 4%, amounts to one half 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* assessment 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.² Nevertheless, in many economic models dealing not explicitly with the sources of economic growth, technological change is treated as exogenous, and labour and capital are the only endogenous inputs of the production process.

In this paper, productivity increases are explained by those factors emphasized by endogenous growth models. 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

¹ See e.g. Denison (1967), Maddison (1982, 1991) and Dowrick and Nguyen (1989).

² See e.g. Romer (1986), Lucas (1988), Grossman and Helpman (1994), Barro and Sala-i-Martin (1995) and Durlauf and Quah (1998). An early reference is Uzawa (1965).

by models correcting only for the quality of the factor inputs, or by augmenting it with additional ones. As one extension, human capital appears as a third factor input in the production process.³ In a similar manner, a fourth production factor, namely the stock of knowledge is introduced. Firms invest in R&D, thereby generating a stock of knowledge which serves as a substitute to other production factors.⁴

The most important aspect of the notion of knowledge as a production factor is that it introduces two methodological changes into the analysis. The first is the idea of scale economies. 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 change introduced by knowledge is the idea of 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.⁵ It permits 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.

Despite the enormous policy implications of scale economies and spillovers, clearcut empirical results about their extent are still ambiguous.⁶ The main contribution of this paper is to shed some light on these arguments by an empirical investigation based on a production function framework. Since scale economies and spillovers are *per se* properties of the production function, this framework can capture many of the arguments of endogenous growth models. In the empirical analysis, it is tested to what extent sectoral productivity growth can be attributed to scale economies associated with physical/human capital and productivity spillovers from other sectors. A final theme of the paper is the relation between productivity growth and the business cycle.⁷ First, empirical growth models should account for the business cycle to correct for inefficiencies associated with them; second, it is tested to what extent the sources of long-run growth can be related to short-run business cycle induced fluctuations.

A novelty of the study is the empirical investigation of this subject on the base of a broad panel of sectoral

national accounts data for the Federal Republic of Germany 1960–90. The empirical investigation with sectoral data has several advantages:⁸ As compared with aggregate data, the number of observations is enormously increased; as compared with cross-country data sets, inconsistencies of data measurement and inhomogeneity with respect to omitted variables are much less of a problem. Finally, the cross-sectoral data-set permits to construct a measure of human capital based on its returns.

II. THEORETICAL FRAMEWORK

Growth accounting

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

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

where Y is real output; K is physical capital, and L is labour input. Output is produced with capital and labour as inputs; the residual refers to technological efficiency which increases exogenously over time. Standard growth accounting relies on the assumption of constant returns to scale for labour and capital. Then, output growth is determined by the growth of those 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. The results of this kind of growth accounting exercise for data of the Federal Republic of Germany are given by:

Sample	Δy	Δk	Δl	Δh	sl	$\Delta k \cdot (1 - sl)$	$(\Delta l + \Delta h) \cdot sl$	residual
1961–1990	3.06	4.27	-0.04	-0.94	70.2	1.27	-0.71	2.50

Note: Small case letters denote logs. Annual averages in per cent. Private sector excluding housing of the German economy.

Average real output growth Δy for the last 30 years amounts to about 3% per year, and the increase of the capital stock Δk is slightly above 4%. The labour share sl is about 70%. 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

³ See e.g. Mankiw *et al.* (1992).

⁴ See e.g. Levin and Reiss (1988), Nadiri (1993) and Grossman and Helpman (1994).

⁵ This idea was introduced by Romer (1986) and Lucas (1988). For an empirical assessment, see Levin and Reiss (1988), Caballero and Lyons (1990, 1992), Coe and Helpman (1993) and Barro and Sala-i-Martin (1995).

⁶ The mostly cited references are Dowrick and Nguyen (1989), Mankiw *et al.* (1992) and Levine and Renelt (1992).

⁷ See Aghion and Saint-Paul (1993), Saint-Paul (1993) and Flaig and Steiner (1993).

⁸ Most empirical work on the sources of productivity growth are cross-sectional analyses with cross-country data sets. In addition, there is some work with rather short panels with micro data for firms. Time-series/cross-industry data are hardly used for empirical analyses. Examples for time-series analyses are Bernard and Jones (1996) and Durlauf and Quah (1998).

percentage points. The change of the labour input is documented for its 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% per year. The residual left after accounting for labour and capital inputs, i.e. total factor productivity growth, is calculated as 2.5%. This contrasts sharply with the high value of these productivity increases. The average real interest rate during the same period was about 3.6%. That means, the resulting average present value of one year's total factor productivity growth amounts to more than one half of one year's value added!

Empirical post-war data for most of the developed countries reveal a total factor productivity growth in about the same dimension.⁹ 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.¹⁰ The data also reveals a long-run decrease of the growth rates of output, capital, and the residual, and an enormous 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.¹¹ This is taken into account in the empirical analysis below.

This standard growth accounting approach is often extended by allowing for quality changes of the factor inputs,¹² or by introducing additional production factors. A drawback of this method is its reliance on factor income shares which are difficult to measure. Further methodological difficulties are encountered by introducing increasing returns to scale, monopolistic factor or product markets, or productivity spillovers. An alternative method of growth accounting consists in estimating the output elasticities of the factors directly from a production function instead of calculating them from factor income shares. This proceeding is also appropriate in case of scale economies and spillovers and has become very popular with the availability of new data sets. It is also applied in the work here.

Mankiw *et al.* (1992) provide an example about the relative success which can be achieved by this kind of analysis.¹³ They analysed 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 vari-

ance of output growth 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 human capital as a third production factor becomes also visible when looking at investments in and returns from human capital. In the developed countries, outlays for better qualification of the work force are about as high as the outlays for investments in physical capital. Measures of the returns on human capital give a similar impression. The wage of an unqualified worker, for instance approximated by the wage of a worker in the lowest wage group, is about one half of the average wage.¹⁴ This implies returns to human capital in the dimension of the returns to simple labour. Therefore, 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% labour share. The augmented production function which captures this approach and which accounts also for efficiency changes during the business cycle can be written as:

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

where HK is human capital per worker and U is an indicator of the business cycle, factor utilization.

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, or innovations.¹⁵ The accumulation of R&D constitutes a stock of knowledge which increases the productivity of the other input factors. A specification of a sectoral production function in growth rates which captures this approach can be written as:

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

where K^n is knowledge. i is the sector index, and small case letters represent logarithms of the variable. Output growth is attributed to the change of the factor inputs, and a residual which is attributed to knowledge. 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% of GDP which would require a very high pro-

⁹ See e.g. Denison (1967), Maddison (1982, 1991) and Dowrick and Nguyen (1989).

¹⁰ For instance, Benhabib and 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.'

¹¹ See Flaig and Steiner (1993) and Aghion and Saint-Paul (1993).

¹² See Denison (1967) and Maddison (1982, 1991) and the literature cited there.

¹³ See Levine and Renelt (1992), Barro and Sala-i-Martin (1995) and Durlauf and Quah (1998) for recent overviews.

¹⁴ Investments in human capital can be estimated from years of schooling, etc. 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.

¹⁵ This idea dates back at least to Uzawa (1965).

ductivity of R&D to explain a large proportion of 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. 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 Arrow's (1962) notion of 'learning by doing' and has received a lot of attention in recent endogenous growth models.¹⁶ 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. This spillover constitutes the major mechanism by which sustained growth in many growth models is driven. It permits 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, external effects create an inefficiency, because firms do not receive full compensation for their research efforts, and equilibrium R&D would be below the social optimum.

A final theme of the paper is the relation between growth and the business cycle. Endogenous growth models suggest that the sources of long-run growth are not independent from the business cycle, but its impact cannot be determined without ambiguity from theoretical arguments.¹⁷ 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 cash flow and profits and is more profitable during expansions. In other models, it is argued with opportunity costs and intertemporal substitution, thereby stating a positive influence of recessions on long-run growth. 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 then be understood as the reallocation of idle resources. In both cases, the effect of the business cycle on long-run growth stands for unobserved components of R&D activities. The answer, which effect dominates, and whether productivity growth and production activity are substitutes or complements, must be left to 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. Therefore, for the empirical estimation, the stock of knowledge is determined by introducing the concept of a knowledge production function.¹⁸ Arguments of learning by doing suggest that knowledge can be acquired through gross investments in physical capital. Process innovations are often embodied in new investment goods, and improving production processes or the quality of goods often implies the reorganization of production processes which may also require capital investment. In this sense, capital accumulation and technological progress are complements, and 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.

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

Finally it is tested for the importance of knowledge spillovers between sectors. A part of this spillover is captured by allowing for an effect of aggregate R&D outlays on sectoral productivity growth. Alternatively, an indirect measure of knowledge is calculated from the production function framework: With constant return to scale for the standard production factors, knowledge changes are given by the residuals of a standard growth accounting exercise, i.e. total factor productivity growth (see Equation 3). Knowledge spillovers then imply a positive effect of total factor productivity growth on other sectors' productivity increases, i.e. the sectoral specification of the production function permits to look for intersectoral spillovers through the correlation of sectoral total factor productivity changes.

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 R&D outlays or alternatively other sectors' average total factor productivity growth on the productivity

¹⁶ Much of the recent work was inspired by the models of Romer (1986) and Lucas (1988).

¹⁷ See Aghion and Saint-Paul (1993) and Saint-Paul (1993) for a discussion.

¹⁸ See Nadiri (1993).

growth of the individual sectors. A specification of a knowledge production function which captures these arguments, and which captures also long-run effects of the business cycle is given by:

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

where Δk^g is gross investment rate, and Δtfp is total factor productivity growth. Inserting Equation 4 into the production function Equation 3 and assuming constant returns to scale for the standard production factors yields the following equation for the sectoral labour productivity growth:

$$\Delta(y - l)_{i,t} = \Delta y [\Delta(k - l)_{i,t}, \Delta hk_{i,t}, \Delta u_{i,t}, \Delta k_{i,t}^g, hk_{i,t-1}, \Delta tfp_t, u_{i,t-1}, \varepsilon_{i,t}] \quad (5)$$

$\varepsilon_{i,t}$ is the error term, i.e. the residual from this augmented growth accounting approach. A log-linearized form of Equation 5 is the base for the empirical investigations below.

III. DATA AND EMPIRICAL SPECIFICATION

The basic data source which is employed for the empirical investigation are the sectoral national accounts of the Federal Republic of Germany. The empirical analysis is performed with a panel of annual data from 1960–1990 for the private sector excluding agriculture and housing. The public sector and agriculture, housing are deliberately excluded from the analysis, because the construction of those data does not permit an interpretation in terms of the model. 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,¹⁹ 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 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. This holds even more for a pure time-series analysis with aggregate data for one country.²⁰

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. In Fig. 1 some measures of the data are shown. In the upper panel, 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. The data reveal 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 long-run trend which is not obvious from theoretical arguments. The data for the business cycle indicator which stand for the factor utilization are taken from the business survey of the ifo-institute.²¹ 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 can be measured 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. Another indicator of the qualification of the work force 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.²² This procedure has some resemblance to the calculation of the real capital input. Nominal market values (average wages) are deflated by an appropriate price index (the wage for unqualified work).

This procedure relies on the assumption that a large part of sectoral wage differentials is related to the qualification of the work force. One may argue that sectoral wages are also determined by factors other than qualification, and there is a large literature on inter-industry wage differentials. However, one result of this literature is that a substantial part of inter-industry wage differentials can be

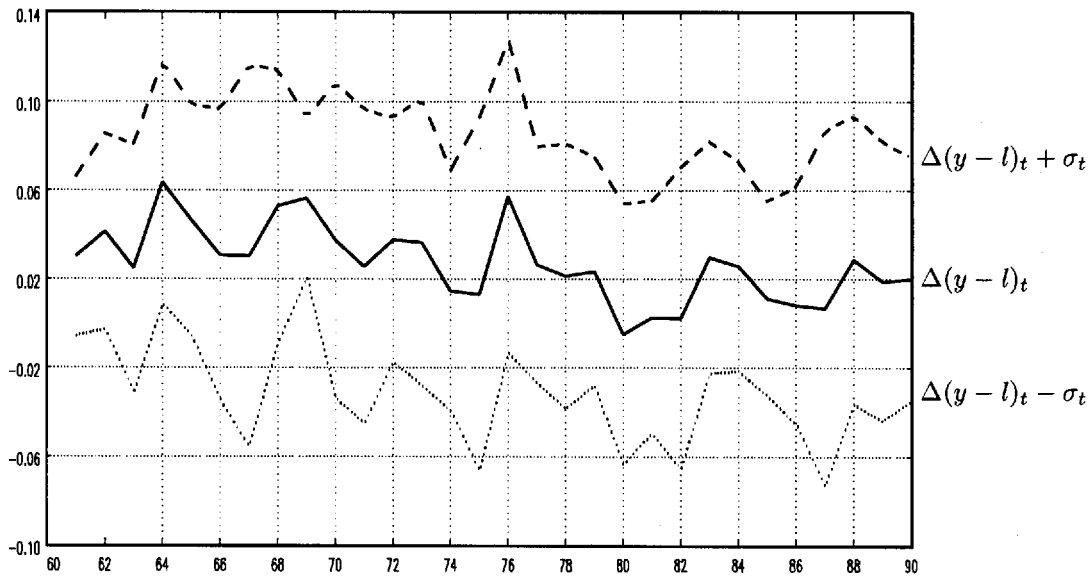
¹⁹ For an overview, see Levine and Renelt (1992), Barro and Sala-i-Martin (1995), and Durlauf and Quah (1998). Cross-industry data are hardly used for empirical analyses.

²⁰ The analysis with sectoral data has also some advantages compared with micro-data for firms. Micro-data firm-panels often capture only a short time period, and firm data sets do not include informations about important variables, e.g. prices.

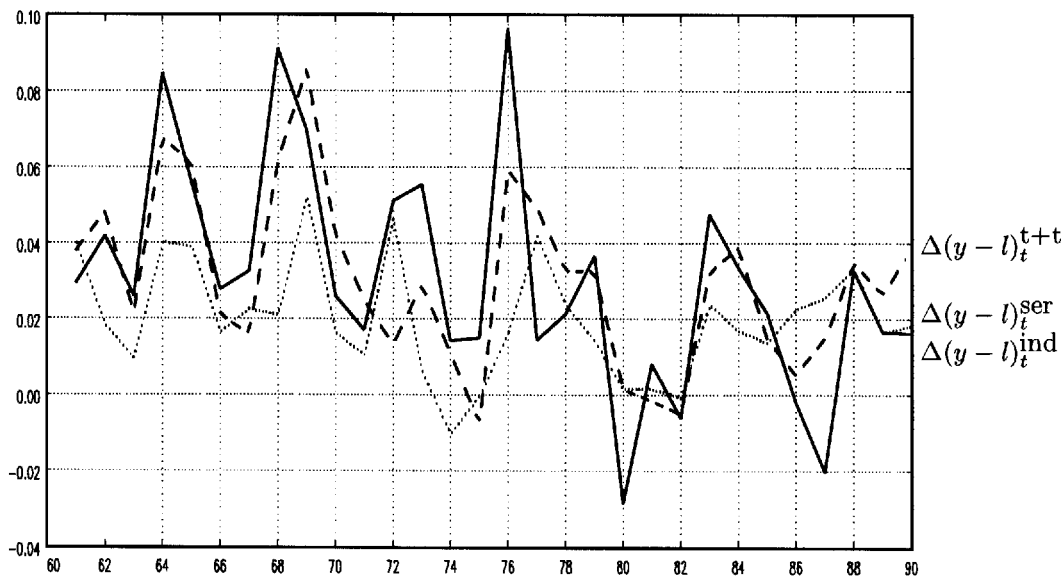
²¹ Special thanks are due to the ifo-institute for providing those data.

²² A similar procedure is proposed in a recent working paper by Mulligan and Sala-i-Martin (1995).

Variance of sectoral labour productivity growth



Sectoral labour productivity growth



σ : standard deviation of sectoral growth rates

ind: industry, t+t: trade+traffic, ser: services

Fig. 1. Sectoral labour productivity growth

attributed to observable, human capital related characteristics of the work force. In addition, the remaining differences are mainly attributed to efficiency wage arguments.²³ This confirms that cross-sectoral wage differentials can

serve as an indicator of the quality of the work force. Note that the usage of the term human capital here is more comprehensive than that of the standard Becker/Mincer human capital model. It captures all aspects of

²³ See Krueger, Summers (1988). These authors also mention union density as another cause of inter-industry wage differentials which, however, hardly plays a role for Germany. See Wagner (1991).

the quality of the work force, i.e. it includes for instance also workers' effort and unobserved ability. For the estimates, the average sectoral wage is set in relation to the average aggregate wage. This yields a measure of the relative qualification of the workers for the sectors.

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: First, from theoretical arguments it is expected that productivity shocks have long (ever) lasting effects on productivity; second, the measurement of physical capital, human capital, and the determinants of knowledge is probably subject to measurement errors and omitted (nonstationary) variables. Both would lead to spurious regression results for an equation in levels. Finally, it is always tested for a constant and a time trend

in the estimated equations to account for non-zero effects of omitted variables.

IV. ESTIMATION RESULTS

The estimation results are contained in Table 1. A log-linear specification of Equation 5 is chosen which implies constant output elasticities of the factors. Model (1) corresponds to a simple Solow model with constant returns to scale, where the exogenous technological change is approximated by a constant and a time trend. Surprisingly, the results yield a quite reasonable estimate of 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

Table 1. Sources of productivity growth

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

Exogenous variables:								
Constant	Trend	$\Delta(k - l)_{i,t}$	$\Delta hk_{i,t}$	$\Delta u_{i,t}$	Δtfp_t	$hk_{i,t-1}$	$u_{i,t-1}$	\bar{R}^2
Solow model								
(1) 0.031 (6.2)	-0.001 (-3.5)	0.269 (6.8)						0.062
(2) 0.030 (5.7)	-0.001 (-4.4)	0.375 (9.4)		0.010 (14.9)				0.196
Augmented Solow model								
(3) 0.029 (5.7)	-0.001 (-4.7)	0.375 (9.5)	0.372 (5.1)	0.093 (13.6)				0.211
Endogenous growth								
(4) 0.013 (2.2)	-0.001 (-2.4)	0.391 (10.0)	0.389 (5.3)	0.065 (7.5)	0.556 (5.2)			0.227
(5) 0.026 (4.9)	-0.001 (-4.1)	0.412 (10.2)	0.373 (5.1)	0.104 (14.0)		0.024 (3.5)	0.022 (3.6)	0.225
(6) 0.013 (2.2)	-0.001 (-2.4)	0.415 (10.4)	0.386 (5.3)	0.077 (7.9)	0.483 (4.4)	0.023 (3.4)	0.015 (2.4)	0.236
Time dummies								
(7)		0.410 (9.8)	0.378 (5.1)	0.074 (6.5)		0.022 (3.4)	0.009 (1.0)	0.239
Sectoral dummies								
(8)	-0.001 (-2.0)	0.404 (9.6)	0.333 (4.4)	0.081 (8.0)	0.467 (4.2)	-0.040 (-1.1)	0.020 (2.7)	0.256
Time and sectoral dummies								
(9)		0.394 (8.8)	0.323 (4.2)	0.078 (6.2)		-0.036 (-1.0)	0.012 (0.9)	0.257

Note: Annual data 1960–1990 of 51 sectors, private sector excluding agriculture and housing. 1407 observations. t -values in parentheses.

²⁴ Nonstationarity 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, nonstationary could be rejected for nearly all of the sectors. See also Smolny (1998) for a more detailed discussion.

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, thus yielding a coefficient of about 1.

Model (2) accounts also for changes in the utilization of the input factors, and it can be seen that changes in utilization are the most 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 model (3), 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. It can be seen that it is as important for the determination of productivity growth as physical capital. Both coefficients are of the same order of magnitude. The significance of the human capital variable confirms also the appropriateness of approximating labour quality by its real returns, i.e. a relative wage. Note that the relative wage does not stand for substitution effects; those are 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.

However, 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 Solow-residual as those of the standard growth accounting approach in Section II above. A large share of the long-run total factor productivity growth cannot be related to these variables. Therefore, in models (4), (5), and (6), it is tested for the impact of those variables which stand for the increase of knowledge as proposed by endogenous growth models.

In model (4), it is tested for intersectoral productivity spillovers by introducing other sectors' total factor productivity growth Δtfp . The estimated coefficient is highly significant, and its value implies a strong association of the variables. In addition, the constant is reduced by about one

half, i.e. a larger part of long-run productivity growth is explained endogenously. This result is consistent with endogenous growth models which place a strong emphasis on technological diffusion and knowledge spillovers at the sectoral level. In a further version (not reported in the table), it was tested whether another spillover stems from other sectors' capital investment. For this purpose, total factor productivity growth was replaced by labour productivity growth and the change of the capital-labour ratio. The resulting coefficients (and t -values) of $\Delta(y - l)^0$ and $\Delta(k - l)^0$ were 0.447 (3.8) and $-0.255 (-1.9)$, respectively. That means, the spillover is related only to total factor productivity growth, not to capital investment. Note also that this result cannot be attributed simply to a simultaneous equation bias: The Δtfp -variable is calculated excluding the sector under consideration.²⁵ It should also not be attributed to exogenous growth factors. Exogenous technological progress does not appear as a reasonable concept, and it is difficult to find plausible arguments in favour of exogenous productivity shocks which affect all sectors equally.

Finally, the gross investment rate, the level of sectoral human capital, and the level of the business cycle indicator were included as determinants of the change of knowledge (models (5) and (6)). The investment rate never appears significant in the estimates and is dropped for the reported results. This standard version of sectoral economies of scale is not supported by the data. The same result was achieved for aggregate R&D outlays which could also approximate spillovers. However, human capital and the business cycle situation both appear with positive and significant coefficients. Therefore, endogenous growth models which rely on scale economies and spillovers associated with human capital receive support from the estimates. Sectors that employ higher qualification workers exhibit more productivity growth in the long run. The business cycle also significantly affects long run productivity growth, apart from its short-run impact on factor productivity via factor utilization, and apart from its effect via capital formation. From the estimates, it can be concluded that recessions reduce productivity also in the long run. The inclusion of those two variables reduces the spillover coefficient of total factor productivity growth slightly: If it is allowed for sectoral scale economies, the estimated intersectoral spillover becomes smaller.

The panel analysis also permits to test the robustness of the results by controlling for unobserved differences over time or between sectors by including dummy variables (fixed effects).²⁶ The respective results are included at the

²⁵ In addition, an instrumental variable estimation yielded a similar result. It was further tested, whether the lagged aggregate total factor productivity growth exhibits a significant effect on sectoral growth. The results reveal that most of the correlation of productivity growth is contemporary. Estimation results are available on request.

²⁶ 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.

bottom lines in Table 1. 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 estimates and confirms the appropriateness of approximating labour quality by its returns. Second, the spillover coefficient is nearly unaffected by the inclusion of sectoral dummy variables. Note that in versions (7) and (9), the Δtfp -variable must be skipped due to multicollinearity with the time dummies. 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. 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 is more important, while the cross-sectoral correlation of the series is very high. 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. Note that the time dummies are hardly significant, and the estimation with dummy variables does not constitute an economic ‘explanation’ of growth. Dummies refer to exogenous growth which does not constitute a meaningful concept. Finally, comparing the results for the whole economy and for the more homogeneous manufacturing sectors reveals hardly any qualitative differences which confirms again the appropriateness of pooling the data (not reported).

V. CONCLUSIONS

Several shortcomings limit the scope of the empirical results. No sectoral measure of R&D expenditures was available, and the aggregate impact of human capital could not be determined. Nevertheless, some results of the study appear robust:

- (1) the time-series/cross-sectoral dataset yields a well determined and reasonable estimate of the impact of physical capital on labour productivity changes. The coefficient of the capital–labour ratio is highly significant and in the magnitude of the capital share in income.
- (2) the results exemplify the prominent role of human capital as a production factor. The relative sectoral human capital can appropriately be approximated by relative sectoral wages.

- (3) the business cycle affects productivity growth both in the short run and in the long run. Changes of factor utilization are the most important determinant of total factor productivity growth in the short run. It is important to allow for business cycle induced changes of factor utilization to get a well determined estimate of the output elasticity of capital.
- (4) the estimates indicate significant inter-sectoral productivity spillovers. This result is consistent with endogenous growth models which place a strong emphasis on technological diffusion. The spillover is related to other sectors’ total factor productivity growth, not to aggregate R&D expenditures or capital investment.
- (5) the level effects of human capital and the business cycle indicate scale economies also at the sectoral level. Scale economies associated with gross investment were not found.

Accounting for those factors leaves a smaller part of productivity growth unexplained: Changes of factor utilization, capital intensity and human capital are the driving forces of short run changes of labour productivity; inter-sectoral spillovers, the level of the business cycle situation and human capital are determinants of long-run growth. The cross-sectoral/time-series data set provides a useful basis for further empirical investigations of technological spillovers and scale economies. 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.²⁷ This provides a framework to analyse the impact of economic integration through trade and foreign direct investment.

Scale economies and productivity spillovers are important concepts for the theory of endogenous technological change. It is evident that technological change evolves endogenously within the economic system. In addition, every year’s productivity increases exhibit an enormous social value. If knowledge is distributed for free, as the spillover model suggests, firms have low incentives to engage in R&D, and the market outcome is below the social optimum. Scale economies, on the other hand, affect the market structure. Therefore, the analysis of scale economies and spillovers has important policy implications which enhances the interest into further empirical investigations.

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²⁷ See Smolny (1999).

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