# Sources of Productivity Growth at the Firm Level
# A Production Function Approach

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**Abstract:**

In the paper, the sources of productivity growth are investigated by an empirical analysis with micro data for West-German manufacturing firms. The theoretical framework corresponds to an augmented growth accounting approach based on a production function. The empirical results reveal that innovative firms exhibit more productivity increases. Large firms exhibit more productivity increases as compared with small firms, ceteris paribus, which hints towards scale economies at the firm level. However, innovations seem to be more productive in small firms. Scale economies at the sectoral level are indicated by positive spillover effects from others productivity changes.

Keywords: Growth accounting, innovations

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# 1 Introduction

The recent development of endogenous growth theories has renewed the interest into the sources of productivity growth of the advanced industrialized economies. In this paper, the sources of productivity growth are investigated by an empirical analysis with micro data for West-German manufacturing firms. The starting point of the study is the large residual left after standard procedures of growth accounting, i.e. standard growth models leave most of observed growth unexplained. 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 exogenous to the economic system, but have their origins in the intertemporal optimizing behaviour of competing firms; i.e. technological change evolves endogeneously within the economic system.

In the analysis, productivity increases are explained by those factors emphasized by endogenous growth theories. 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 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. In a similar manner, a fourth production factor, namely the stock of knowledge is introduced. Firms invest in R&D and introduce innovations, thereby generating a stock of knowledge which serves as a substitute to other production factors. One aim of the study is to estimate the impact of innovations on the productivity growth of West-German firms.

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 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.

The contribution of this paper is to shed some light on these arguments by an empirical investigation based on a production function framework, i.e. the theoretical model corresponds to an augmented growth accounting approach. Since scale economies and spillovers are *per se* properties of the production function, this framework can capture many of the arguments of endogenous growth theory. Former work with sectoral data has shown that inter-sectoral spillovers within the country and intra-sectoral spillovers between countries contribute significantly to the explanation of sectoral productivity growth.[1] The novelty of the study here is the empirical investigation of this subject on the base of a broad panel of micro data for West-German manufacturing firms.

The model is estimated with a unique data-set of firm-level data for West-German manufacturing, the ifo firm panel. The data set contains informations for 2405 firms for the period from 1980 to 1992 from the business survey, the innovation survey, and the investment survey of the ifo institute.[2] From the business survey, qualitative monthly data for output changes, and quarterly data for employment changes and capacity utilization are available. Since 1980, the business survey also contains an annual question on innovations.[3] The data-set contains the qualitative information, whether a firm has implemented product and/or process innovations. These data were matched with quantitative annual data on investment, employment, and sales from the investment survey.

In the empirical model, the contribution of employment changes and capital investment to firm-level output growth is estimated. Second, it is tested, to what extent productivity growth can be attributed to innovations. Third, it is tested for scale economies related to firm size and innovations. Finally, it is tested for productivity spillovers from other firms in the sector. Innovations, scale economies, and knowledge spillovers are important concepts in growth theory. From a theoretical perspective, they allow to understand technical progress as endogenously determined within the economic system. In addition, every year's productivity increases exhibit an enormous social value. Therefore, the analysis of innovations, scale economies, and knowledge spillovers has important implications which enhances the interest into empirical investigations of these issues.

# 2 Theoretical framework

## 2.1 Growth accounting

The starting point for standard growth accounting and for the empirical approach applied here is a firm-level production function. This relates to the

[1] See Smolny (1995a,b).

[2] See Schneeweis, Smolny (1996), Smolny, Schneeweis (1996), and Smolny (1996a,b).

[3] See Oppenländer, Poser (1989) and Penzkofer, Schmalholz, Scholz (1989).

famous neoclassical growth model of Solow.[4]

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

$Y$ is real output, $K$ is physical capital, and $L$ is employment. Output is produced with capital and labour as inputs. The residual refers to technical 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 output elasticities can be calculated from factor income shares; alternatively, they can be estimated from a production function. This second approach is chosen here.

This standard growth accounting approach is often extended by allowing for quality changes of the factor inputs,[5] or by introducing additional production factors. Mankiw, Romer, Weil (1992) provide an example about the relative success which can by achieved by this kind of analysis. 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 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. 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. 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 percent labour share.

A second aspect of growth accounting within the framework of a production function are short-run effects of the business cycle on factor utilization.[6] Investment and employment adjust only slowly with respect to demand shocks. Consequently, output changes fluctuate more than labour and capital input changes, and total factor productivity is strongly procyclical.[7] The augmented production function which captures human capital and which accounts also for

[4] See Solow (1956,1957).

[5] See e.g. Maddison (1982,1987).

[6] See Flaig, Steiner (1993), Burnside, Eichenbaum, Rebelo (1995), Hart, Malley (1996), and Burnside (1996).

[7] See Smolny (1995a).

efficiency changes during the business cycle can be written as:

$$Y = Y(K, L, \mathrm{HK}, U, \mathrm{residual}) \tag{2}$$

HK is human capital per worker, and $U$ is factor utilization. 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. The accumulation of R&D constitutes a stock of knowledge which increases the productivity of the other input factors. A specification of a production function in growth rates which captures this approach can be written as:

$$\Delta y = \Delta y(\Delta k, \Delta l, \Delta \mathrm{hk}, \Delta u, \Delta k^n) \tag{3}$$

$K^n$ is knowledge, and small case letters represent logarithms of the variables. In eq. (3), the residual of the standard growth accounting approach, i.e. total factor productivity growth, is attributed to changes in knowledge.

## 2.2 The model of the firm

In Smolny (1996a,b), a model of an endogenous innovation and investment behaviour of the firm was developed. In the analysis, it was distinguished between product and process innovations. It was assumed that process innovations increase the efficiency of labour and capital and reduce production costs. In addition, process innovations were distinguished from capital investment. It was assumed that capital investment stands for the quantity effects of (homogeneous) capital, while process innovations capture the quality effects.[8] It was found that both process innovations and investment increase output and employment.

Product innovations affect the demand curve. A successful product innovation implies that the quality of the product increases, and demand increases. In the model, four effects were distinguished: product innovations can affect the level of demand, the price elasticity of demand, the uncertainty about demand, and/or production costs. It was found, that product innovations increase the level of demand and reduce competition, i.e. reduce the absolute value of the price elasticity of demand: on average, product innovating firms set higher prices and increase output and employment, which implies that the demand increasing effect exceeds the output decreasing effect of higher prices due to a lower price elasticity of demand.[9]

In the model, it was assumed that investment and innovations adjust with a delay with respect to short-run demand and cost shocks. The decision on innovation and investment must be met under uncertainty of demand. This

[8] It is difficult to disentangle process innovations and investment in quantitative data due to double-counting. See Schankerman (1981). The problem does not occur for our specification of the data, i.e. a dummy for process innovations and quantitative data for investment.
[9] See Smolny (1996a).

assumption allows to separate the short-run (and medium-run) decisions on output, prices, and employment from the long-run decision on innovations and investment.[10] Innovations are treated as investments in knowledge. In the short run, output supply $YS$ is determined by a limitational production function with capital and labour as inputs:

$$YS = \min(YC, YL) = \min(\pi_k \cdot K, \pi_l \cdot L) \tag{4}$$

$YC$ are capacities, $YL$ is the employment constraint of the short-run limitational production function, and $\pi_l$, $\pi_k$ are the productivities of labour and capital. The factor productivities depend on the capital-labour ratio and production efficiency. Production efficiency depends on predetermined process innovations and productivity spillovers. Demand $YD$ is determined within a model of monopolistic competition from a log-linear demand curve. It depends on the price and predetermined product innovations. In addition, it depends on the market structure and the behaviour of other firms. Output is given be the minimum of supply and demand:

$$Y = \min(YS, YD) \tag{5}$$

The assumption of a delayed adjustment of investment and innovations extends the standard deterministic model by introducing uncertainty and allows to analyze the resulting inefficiencies:

- Ex ante, the firm must decide on innovations and investment before knowing the location of the demand curve. The immediate adjustment is contained as a special case. As compared with this model, optimal capacities are chosen lower due to the additional costs of underutilization of capacities.

- Ex post, different regimes on the goods market and underutilization of capacities are possible. In case of a positive demand shock, the firm cannot satisfy demand and/or increases the price; in case of a negative demand shock, underutilization of capacities occurs, since variable costs and the finite price elasticity of demand imply a lower bound on optimal prices.

  In the model, short-run demand shocks can be identified from the utilization of capacities.

## 2.3 The knowledge production function

The delayed adjustment structure provides a consistent framework to discuss business cycle induced effects on factor productivities. In addition, the model

[10] A assumption of a delayed adjustment was made common by Kydland, Prescott (1982). In Smolny (1996a), the medium-run adjustment of prices and employment was analyzed under uncertainty of demand, with predetermined capacities and innovations. In Smolny (1996b), the long-run determination of capacities and innovations was analyzed under uncertainty of demand (and output, prices, and employment).

allows to analyze endogenous innovations under uncertainty of demand. Innovations can be treated like capital investment. However, it is difficult to think about knowledge produced by innovations as the only modification which is necessary to explain the residual. Conventional measures of R&D amount to about 2 percent of GDP, and the average share of innovation expenditures in sales in the ifo firm panel is about 3 percent.[11] Then it would require a very high productivity of R&D or innovations to explain a large proportion of the 2 percent productivity growth by it. It would also provoke the question, why innovation 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 associated with innovations. 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. Finally, innovations increase production efficiency and the quality of the product permanently. One aim of the study here is to test for scale economies associated with innovations.

Probably the most important methodological change 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.[12] 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 second major mechanism by which sustained growth in endogenous growth 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, external effects create an inefficiency, because firms do not receive full compensation for their research efforts. Equilibrium R&D would be below the social optimum, and the test for knowledge spillovers can provide important informations for economic policy evaluations.

For an empirical application, the measurement of knowledge constitutes a major problem. Here, the stock of knowledge is determined by introducing the concept of a knowledge production function.[13] First, it is assumed that knowledge is aquired through investments in R&D and innovations. Second, 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

[11] See Smolny (1996b).
[12] Much of the recent work was inspired by the models of Romer (1986) and Lucas (1988).
[13] See Nadiri (1993).

the quality of goods often implies the reorganization of production processes which may also require capital investment. In this sense, capital accumulation and technical 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.[14]

Third, scale economies at the micro level imply that large firms exhibit a higher total factor productivity. In addition, it can be argued that large firms exhibit more productivity growth, given the development of factor inputs and innovations. Large firms can build on a larger pool of knowledge, accumulated through innovations or learning by doing in the past, which is thought to exhibit a positive effect on productivity growth. On the other hand, it was argued that the productivity of R&D declines with firm size.[15] One argument is that large firm undertake more R&D; in case of decreasing marginal returns to R&D, the average productivity will be lower. In addition, the benefits of individual effort and the efficiency of control diminishes with firm size.[16]

Fourth, the possibility to imitate others' new products increases the productivity of own product innovations, and technology spillovers increase the productivity of own process innovations and investment.[17] Therefore, the innovations of other firms should exhibit a positive effect on productivity growth. Alternatively, it is tested for productivity spillovers between firms. An indirect measure of knowledge can be derived from the production function framework: knowledge changes are given by the residuals of a standard growth accounting exercise, i.e. total factor productivity growth. Knowledge spillovers than imply a positive effect of total factor productivity growth on other firms' productivity increases, i.e. the micro level specification of the production function allows to look for inter-firm spillovers through the correlation of firm-level total factor productivity changes.

Summarizing these arguments, it is tested whether the change of knowledge depends positively on innovations, the accumulation of physical capital, and firm size. The spillover is approximated by allowing for an effect of other firms' innovations or other firms' total factor productivity growth on the productivity growth of the individual firm. A specification of a knowledge production function which captures these arguments is given by:

$$\Delta k^n = \Delta k^n[\Delta k, \text{proc}, \text{prod}, \text{firm size}, \text{proc}^s, \text{prod}^s, \Delta tfp^s, \varepsilon] \tag{6}$$

The index $^s$ refers to aggregate (sectoral) variables, non-indexed variables refer to firm specific values. prod are product innovations, proc are process inno-

[14]See also Romer (1987). Knowledge might also arise as a not necessarily costless by-product of the daily work of qualified employees. See Romer (1986,1989), Lucas (1988), and Smolny (1995a).

[15]See Cohen, Klepper (1996).

[16]See Cohen, Levin (1989) and Smolny (1996b).

[17]See Bernstein, Nadiri (1986), Jaffee (1986,1988), Levin, Reiss (1988), Cohen, Levinthal (1989), Segerstrom (1991), Nadiri (1993), and Coe, Helpman (1995).

vations, and $\Delta tfp$ is total factor productivity growth. $\varepsilon$ is the error term, i.e. the residual from this augmented growth accounting approach. Inserting eq. (6) into the production function, eq. (3), yields the basic specification for the empirical investigations which are discussed below.

# 3 Data and empirical specification

## 3.1 Data

The data base for the empirical application consists of a panel of West German manufacturing firms for 13 years (1980–92), the ifo firm panel.[18] The data stem from two sources:

- the business survey (Konjunkturtest) of the ifo institute which contains detailed monthly informations on the short-run demand and supply conditions. Once a year, the questionaire includes a question on innovation activities. The answers in the business survey are related to a specific product or product group, i.e. not necessarily to the whole firm. Some firms have different products (groups) in the panel; the panel consists of 2405 observation units from 1982 firms.[19] Most of the data from the business survey are qualitative.

- the investment survey (Investitionstest) of the ifo institute which contains detailed data on investment activities at the firm level. From this survey, the quantitative data on investment, employment, and sales were used.[20] These data are available annually.

The business survey contains monthly data on output changes: every month, the firms are asked whether they had increased, decreased, or left their output constant. On average, 14.0 percent report an increase of output ($y^+$) and 17.6 percent report a reduction of output ($y^-$) (see table 1).[21] The business survey also contains quarterly data about employment changes, again for the narrow definition of the product or the product group. In four months, the firms are asked, whether the number of employees (seasonally adjusted) will increase, decrease, or stay constant within the next 3 months. On average, 6.7 percent of firms report an increase of employment ($l^+$), 13.7 percent report a decrease ($l^-$), i.e. about 80 percent of the firms report that employment will not change (see table 2).[22]

[18] For a detailed description of the data, see Schneeweis, Smolny (1996) and Smolny (1996a,b). The surveys are described in Oppenländer, Poser (1989). I like to thank the ifo Institut, München, for providing the data.

[19] Note that for most firms, the product level corresponds to the whole firm.

[20] The matching of the data was part ot the research project "Growth and Innovations". Until recently, most empirical work on innovations with the ifo data base was constrained to the business survey data.

[21] The corresponding sectoral data are contained in table 8 in the appendix. A sector list is contained in table 7 in the appendix.

[22] The corresponding sectoral data are contained in table 9 in the appendix.

**Table 1: Prices, output, and sales**

| year | $p^+$ | $p^-$ | $\Delta p$ | $\sigma_{\Delta p}$ | $y^+$ | $y^-$ | $\Delta y$ | $\sigma_{\Delta y}$ | $\Delta \ln y$ | $\sigma_{\Delta \ln y}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1980 | 0.163 | 0.034 | 0.129 | 0.199 | 0.121 | 0.181 | -0.060 | 0.256 | | |
| 1981 | 0.146 | 0.047 | 0.099 | 0.231 | 0.100 | 0.248 | -0.148 | 0.276 | 0.012 | 0.134 |
| 1982 | 0.096 | 0.082 | 0.014 | 0.237 | 0.098 | 0.276 | -0.179 | 0.270 | -0.002 | 0.142 |
| 1983 | 0.086 | 0.054 | 0.033 | 0.191 | 0.153 | 0.184 | -0.031 | 0.267 | 0.022 | 0.134 |
| 1984 | 0.123 | 0.044 | 0.078 | 0.230 | 0.164 | 0.163 | 0.001 | 0.254 | 0.048 | 0.135 |
| 1985 | 0.095 | 0.044 | 0.051 | 0.190 | 0.160 | 0.145 | 0.015 | 0.252 | 0.045 | 0.137 |
| 1986 | 0.074 | 0.055 | 0.019 | 0.189 | 0.147 | 0.150 | -0.003 | 0.245 | 0.030 | 0.135 |
| 1987 | 0.072 | 0.054 | 0.018 | 0.187 | 0.125 | 0.175 | -0.050 | 0.249 | 0.004 | 0.126 |
| 1988 | 0.117 | 0.030 | 0.087 | 0.211 | 0.166 | 0.133 | 0.034 | 0.259 | 0.042 | 0.128 |
| 1989 | 0.146 | 0.022 | 0.124 | 0.223 | 0.179 | 0.104 | 0.075 | 0.256 | 0.068 | 0.131 |
| 1990 | 0.136 | 0.031 | 0.105 | 0.212 | 0.176 | 0.097 | 0.079 | 0.256 | 0.070 | 0.143 |
| 1991 | 0.115 | 0.048 | 0.067 | 0.222 | 0.129 | 0.172 | -0.043 | 0.283 | 0.045 | 0.156 |
| 1992 | 0.076 | 0.090 | -0.014 | 0.229 | 0.091 | 0.267 | -0.176 | 0.286 | -0.008 | 0.142 |
| total | 0.111 | 0.049 | 0.062 | 0.216 | 0.140 | 0.176 | -0.036 | 0.274 | 0.031 | 0.139 |

**Table 2: Employment, capacity utilization, and innovations**

| year | $l^+$ | $l^-$ | $\Delta l$ | $\sigma_{\Delta l}$ | $\Delta \ln l$ | $\sigma_{\Delta \ln l}$ | prod | proc | $\Delta \ln DUC$ | $\sigma_{\Delta \ln DUC}$ | $i/l$ | $\sigma_{i/l}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1980 | 0.069 | 0.085 | -0.016 | 0.279 | | | 0.506 | 0.496 | | | 5.559 | 8.921 |
| 1981 | 0.025 | 0.195 | -0.170 | 0.319 | -0.021 | 0.105 | 0.427 | 0.396 | -0.047 | 0.113 | 5.133 | 7.153 |
| 1982 | 0.015 | 0.267 | -0.253 | 0.338 | -0.044 | 0.109 | 0.471 | 0.411 | -0.037 | 0.120 | 5.145 | 8.265 |
| 1983 | 0.030 | 0.190 | -0.160 | 0.319 | -0.033 | 0.100 | 0.464 | 0.415 | 0.019 | 0.126 | 5.743 | 9.527 |
| 1984 | 0.058 | 0.123 | -0.065 | 0.304 | -0.010 | 0.103 | 0.494 | 0.442 | 0.026 | 0.124 | 5.825 | 7.512 |
| 1985 | 0.093 | 0.093 | -0.001 | 0.326 | 0.002 | 0.106 | 0.498 | 0.449 | 0.021 | 0.120 | 6.774 | 10.746 |
| 1986 | 0.083 | 0.088 | -0.005 | 0.300 | 0.010 | 0.096 | 0.493 | 0.469 | 0.005 | 0.107 | 7.139 | 9.256 |
| 1987 | 0.042 | 0.136 | -0.093 | 0.301 | -0.012 | 0.101 | 0.506 | 0.463 | -0.017 | 0.112 | 7.690 | 10.486 |
| 1988 | 0.064 | 0.107 | -0.043 | 0.303 | -0.004 | 0.096 | 0.521 | 0.494 | 0.021 | 0.108 | 8.496 | 11.932 |
| 1989 | 0.133 | 0.066 | 0.067 | 0.336 | 0.021 | 0.093 | 0.542 | 0.519 | 0.024 | 0.107 | 9.616 | 12.804 |
| 1990 | 0.150 | 0.052 | 0.098 | 0.320 | 0.023 | 0.102 | 0.512 | 0.492 | 0.013 | 0.097 | 10.998 | 20.368 |
| 1991 | 0.091 | 0.118 | -0.027 | 0.350 | 0.012 | 0.093 | 0.533 | 0.482 | -0.028 | 0.108 | 11.597 | 22.675 |
| 1992 | 0.026 | 0.270 | -0.243 | 0.371 | -0.030 | 0.106 | 0.518 | 0.479 | -0.056 | 0.112 | 10.391 | 13.458 |
| total | 0.067 | 0.137 | -0.070 | 0.337 | -0.008 | 0.103 | 0.497 | 0.459 | -0.004 | 0.117 | 7.489 | 12.388 |

Source: ifo firm panel, 2405 firms, 13 years

The investment survey contains a corresponding quantitative information on employment. These data are available annually and only for the firm level. Therefore they cannot be compared directly with the information from the business survey, but they can give some information about the reliability of the qualitative data. Table 2 contains the average employment change ($\Delta \ln l$) as well as its cross-sectional standard deviation $\sigma$ from the investment survey. It can be seen that the year with the largest employment decreases (1982) is also the year, where the most firms report an employment decrease, and the least firms report an employment increase. Correspondingly, in the years with the largest employment increases (1989 and 1990), the most firms report an employment increase and the least firms report an employment decrease. The data for total manufacturing depict the same development.[23] That means, at the aggregate level the qualitative and the quantitative data are consistent.

For real output, no quantitative data are available at either the firm or the product level. However, the investment survey contains annual data on nominal sales. In addition, the business survey contains a monthly information on price changes. It corresponds to those on output changes: every month, the firms are asked whether they had increased, decreased, or left unchanged their prices (net prices) as compared with the last month.[24] Therefore, it is possible to test to what extent the qualitative monthly price and output information together correspond to the annual data on sales. In table 3, some results of least squares regressions of quantitative sales changes $\Delta \ln s$ on qualitative price and output changes are reported. The table also includes the corresponding regression results for employment. For the estimates, only those firms are included were product level employment is at least half of firm-level employment, i.e. where the product level corresponds roughly to the firm level.

In the first row, the logarithmic change of employment $\Delta \ln l$ is regressed on the relative number of employment increases $l^+$ and the relative number of employment decreases $l^-$ within the year. Both variables are highly significant with the expected sign. In addition, the absolute value of both coefficients is nearly identical. Therefore, net employment changes were calculated as $\Delta l = l^+ - l^-$. The regression results are depicted below. The coefficients imply that

- the growth rate of employment for a firm that reported an employment increase (decrease) in each quarter is about 10 percentage points higher (lower) than those of a firm that reported no employment changes,

[23] See Smolny (1996a).

[24] On average, 11.1 percent report that they have increased their prices ($p^+$), 4.9 percent report that they have decreased their prices ($p^-$). That means, on average there is about one price increase each year for each product, and about one price decrease every second year. However, the distribution is quite uneven: nearly 1000 firms never reported falling prices during the observation period, and a large number of firms do not report any price change during some years. See table 10 in the appendix.

**Table 3: Correlation between qualitative and quantitative data**

endogenous variable: employment changes $\Delta \ln l$

| | const. | $l^+$ | $l^-$ | $\Delta l$ | SEE | $\overline{R}^2$ | obs |
|---|---|---|---|---|---|---|---|
| OLS | 0.001 | 0.102 | −0.109 | | 0.096 | 0.127 | 11990 |
| | (0.7) | (21.0) | (-32.1) | | | | |
| OLS | 0.000 | | | 0.106 | 0.096 | 0.127 | 11990 |
| | (0.2) | | | (41.8) | | | |
| FE | | 0.087 | −0.111 | | 0.096 | 0.135 | 11990 |
| | | (16.6) | (-29.6) | | | | |
| FE | | | | 0.102 | 0.096 | 0.134 | 11990 |
| | | | | (37.6) | | | |
| FE-TD | | 0.076 | −0.101 | | 0.095 | 0.143 | 11990 |
| | | (14.2) | (-26.1) | | | | |
| FE-TD | | | | 0.092 | 0.095 | 0.143 | 11990 |
| | | | | (31.7) | | | |

endogenous variable: sales changes $\Delta \ln s$

| | const. | $y^+$ | $y^-$ | $\Delta y$ | $p^+$ | $p^-$ | $\Delta p$ | SEE | $\overline{R}^2$ | obs |
|---|---|---|---|---|---|---|---|---|---|---|
| OLS | 0.048 | 0.109 | −0.177 | | 0.061 | −0.082 | | 0.133 | 0.105 | 12105 |
| | (22.6) | (15.3) | (-27.9) | | (7.4) | (-9.0) | | | | |
| OLS | 0.036 | | | 0.148 | | | 0.072 | 0.133 | 0.101 | 12105 |
| | (28.2) | | | (31.3) | | | (12.3) | | | |
| FE | | 0.106 | −0.189 | | 0.083 | −0.107 | | 0.130 | 0.147 | 12105 |
| | | (11.6) | (-25.0) | | (8.6) | (-9.3) | | | | |
| FE | | | | 0.155 | | | 0.095 | 0.130 | 0.144 | 12105 |
| | | | | (29.5) | | | (14.9) | | | |
| FE-TD | | 0.097 | −0.175 | | 0.069 | −0.102 | | 0.129 | 0.155 | 12105 |
| | | (10.5) | (-22.3) | | (7.1) | (-8.9) | | | | |
| FE-TD | | | | 0.143 | | | 0.086 | 0.129 | 0.152 | 12105 |
| | | | | (25.5) | | | (13.2) | | | |

OLS: OLS–estimates, FE: Fixed effects, FE-TD: Fixed effects and time dummies, sample 1981–1992, $t$-values in prantheses.

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– i.e. each reported employment increase implies an about 2.5 percentage point higher growth rate of employment, each reported employment reduction implies a 2.5 percentage points lower growth rate of employment.

In the versions below, the regressions were performed with fixed firm effects (FE), and with additional time dummies (FE-TD). The results are roughly the same. The results for sales are similar: qualitative output and price changes are significantly correlated to quantitative sales changes with the expected sign. Each monthly reported output change corresponds to an about one percentage point change of sales, each monthly reported price change corresponds to an about 0.5 percentage point change of sales.[25] Therefore it can be concluded that the balanced qualitative data capture the quantitative development of the

[25] Note that the sectoral inflation rate does not contribute significantly to the explanation of the growth rate of sales, if it is controlled for firm specific price changes.

respective variable quite accurately.

For the estimates of the production function, two different sets of variables were calculated:

- In a first set of estimates, the net output changes from the business survey ($\Delta y = y^{+} - y^{-}$) are related to the net employment changes from the same survey ($\Delta l$).[26]

- Second, a measure of the change of real sales is calculated as the nominal sales change minus the price effect ($\Delta \ln y = \Delta \ln s - 0.072 \cdot \Delta p$). The corresponding average rate of change ($\Delta \ln y$) and its cross-sectional standard deviation are reported in table 1. This measure is related to the rate of change of employment from the investment survey ($\Delta \ln l$).

  Since these data on output are related to sales (instead of net production or value added) a sectoral measure of the change of material inputs ($\Delta \ln m^{s}$) is used as an additional regressor.

A complete list of variables and definitions is contained in table 6 in the appendix. The business survey also contains quarterly information on the degree of capacity utilization *DUC*. The average rate of change and its cross-sectional standard deviations are reported in table 2.[27] The average capacity utilization is about 83 percent (not reported). This low utilization is consistent with a slow adjustment of capacities and underlines the importance to control for short-run demand induced effects on factor productivities.

In figure 1 in the appendix, time-series plots of the data on prices, output, employment, and capacity utilization are depicted. In the first three figures, the solid line represents the share of firms reporting an increase of the respective variable, the dotted line represents a decrease. In the figure at the bottom, capacity utilization (solid line) is plotted together with +/– one standard deviation (dotted lines). It can be seen that the observation period captures slightly more than one business cycle. 1980 was the first year of a beginning downturn, 1990 was about the last year of the following upswing. The sample ends with the deep recession in 1992; the short downswing in 1987 is hardly visible in the data.

In table 2, a measure of investment from the investment survey is reported. The data-set does not contain capital stock data, therefore firm-level investment is normalized with employment. $i/l$ is equipment investment per employee in 1000 of DM. Equipment investment is chosen instead of total investment, because the specification of the production function in first differences

[26] This kind of balancing is not without problems; relevant information may be lost. However, the estimation results above give some confidence into this proceeding.

[27] The data for capacity utilization are classified in steps of 5 percent from 30 percent to 100 percent. For about 15 percent of the observations, the degree of utilization of capacities is 100 percent. The firms can also report a capacity utilization rate above 100 percent. This is the case for 2 percent of the observations. For the estimations, the data were truncated at 100 percent.

captures mainly the short-run effects. Notable is both the cyclical variance, but also the much higher cross-sectional variance of this variable.[28] However, investment is in nominal values; in addition, the capital-labour ratio is rather different in the sectors. Therefore, for the estimation of the model, the firm specific investment per employee is divided by the sectoral nominal capital-labour ratio $(k/l)^s$. The resulting variable $\frac{i}{l} \cdot \left(\frac{l}{k}\right)^s$ is a measure of the gross growth rate of the capital stock.

Once a year, in december, the business survey contains the information, whether within the year for the respective product an innovation was implemented. Innovations are defined as novelties or essential improvements of the product or the production technique. The answers are distinguished for product and process innovations. The business survey does not contain informations about the number or the relative importance of these innovations.[29] Table 2 contains annual averages of the data. Apart from the first year, this is the starting year of the question, the share of both product and process innovators is slightly increasing over time.[30] The relative frequency of product and process innovations for the firms is quite evenly distributed within the range $\{0, 1\}$ (not reported),[31] the average probability of each, product and process innovations is about 0.5.

Some remarks are necessary with respect to the construction of an index of human capital. First, the data-set does not include any information about the qualification of the employees within the firm. Therefore, the estimates had to rely on sectoral data. The human capital per employee at the sectoral level 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.[32] 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 wage differentials is related to the qualification of the work force. One may argue that sectoral wages are also determined by other factors than qualification, and there

[28] Sectoral data are contained in table 9 in the appendix.

[29] The ifo firm panel contains, in addition, detailed information on innovation activities from the innovation survey (Innovationstest) of the ifo institute. See Penzkofer, Schmalholz, Scholz (1989). These data were not employed for the current study; they are available only for a subset of the data base, the response rate of this survey is about 50 percent.

[30] In table 9 in the appendix, the sectoral shares of innovators are reported. It can be seen that the sectoral variance of the shares exceeds the time series variance.

[31] See Smolny (1996a,b).

[32] A similar procedure is proposed in a recent working paper by Mulligan, Sala-i-Martin (1995). See also Smolny (1995a).

is a large literature on inter-industry wage differentials. However, one result from this literature is that a substantial part of inter-industry wage differentials can be attributed to observable, human-capital related characteristics of the work force.[33] In addition, the remaining differences are mainly attributed to efficiency wage arguments.[34] This confirms that cross-sectoral wage differentials can serve as an indicator of the quality of the work force. 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. Aggregate human capital is captured by time dummies.

### 3.2 Empirical specification

In the empirical model, it is tested to what extend the arguments of the theoretical model can be related to the observed productivity changes of West-German manufacturing firms. The empirical model of the production function is always estimated in first differences: from theoretical arguments, it is expected that productivity shocks have long (ever) lasting effects on productivity; second, for most variables, only data for (relative) changes are available from the data-set.

The endogenous variable of the empirical model are either the net output changes from the business survey ($\Delta y$), or the deflated sales from the investment survey ($\Delta \ln y$). The development of employment is approximated in the first case by the net employment changes from the business survey ($\Delta l$); in the second case, the rate of change of employment from the investment survey is used ($\Delta \ln l$). The equations for real sales include a sectoral measure of material inputs as an additional regressor ($\Delta \ln m^s$). These regressions are performed for a restricted sample of firms, where product level employment is at least half of firm-level employment. Sectoral human capital is approximated by the relation of the average sectoral wage to the aggregate wage ($\mathrm{hk}^s$).

The development of physical capital is approximated by the firm-specific equipment investment per employee, normalized with the sectoral capital-labour ratio, $\frac{i}{l} \cdot \left(\frac{l}{k}\right)^s$. This variable is taken from the preceding year, which implies a time-to-build assumption: investment increases capacities only in the following year.[35] The innovation behaviour is specified by dummies for the implementation of process (proc) and product (proc) innovations. The observations on innovations were also taken from the preceding year. Capacity utilization is specified as the logarithmic change of the average capacity utilization rate ($\Delta \ln DUC$).

[33] See, for instance, Krueger, Summers (1988) and Katz, Summers (1989).

[34] See again 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). 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 the quality of the work force, i.e. it includes for instance also workers' effort and unobserved ability.

[35] This specification outperformed other specifications with contemporary investment.

The test for scale economies at the firm level is performed by including two size dummies for firms with less than 50 employees ($\bar{l} < 50$) and for firms with more than 1000 employees ($\bar{l} > 1000$), on average, i.e. medium-size firms with 50 to 1000 employees are the reference group. Firm size is related to the respective product for the business survey data, and to the firm level for the investment survey data. In order to test whether the productivity of innovations is different in small and large firms, these dummies were also interacted with the innovation behaviour.

Knowledge spillovers were specified by firstly testing for an effect of others innovation and investment behaviour on firm-level productivity growth. In addition, different interaction terms between product and process innovations, process innovations and investment, and own and others innovations were included to test for complementarities. These variables are also taken from the preceding year. Sectoral values are always calculated excluding the respective firm. Alternatively, it is tested for productivity spillovers from other firms in the sector. For this purpose, the average labour productivity of the other firms in the sector from the investment survey is included as an additional variable. In addition, the sectoral change of capacity utilization is included to disentangle short-run changes of factor utilization. The sectoral change of employment and the sectoral investment rate are added to obtain a measure of total factor productivity growth.

Finally, a complete set of 11 time dummies is always included (not reported). These dummies shall capture effects of aggregate human capital and other omitted aggregate variables, e.g. spillovers from other sectors. The robustness of the results is tested with 27 sector dummies and with a fixed effects model.

A random effects model was not estimated, since the required assumption of uncorrelatedness of the random effects and the explanatory variables does not appear plausible for theoretical arguments. Note also that the endogenous variables are already specified as changes.

### 3.3 Attrition

An important topic when dealing with panel-data is attrition.[36] Since the panel covers a rather long period, a large number of firms left the panel during the observation period: in 1980, 2156 firms (products) participated in the panel. Since then, 243 firms entered the panel, while 548 firms left it. The annual attrition rate since 1985 is about 3.5 percent.

Attrition is not random. For instance, every year about 2 percent of all firms in manufacturing were closed due to insolvency.[37] Other firms were liq-

[36] See Heckman (1979). Other possible sources of sample selection bias are that the firms in the panel are not representative for the whole population, or that the probability of missing data for specific variables is correlated with the variables of the model. See Smolny (1996a) for a discussion and tests about this subject.

[37] See Winker (1996).

uidated or they stopped producing specific products. Of course, not all exits out of the panel are also exits out of the market; some firms probably left the panel for other reasons. Nevertheless, the possible endogeneity of attrition should be taken into account. In former work with the data from the ifo firm panel, selection equations were estimated.[38] It was found that a high degree of capacity utilization, output increases in the past, and an expected increase of demand significantly reduces the probability of leaving the panel. In addition, implementing an innovation reduces the probability of leaving the panel, and large firms leave the panel less often. This indictates that at least some firms leave the panel due to exit out of the market.

One possibility to deal with endogenous attrition for the estimation of the model is to estimate the economic model with a sample selection correction. However, in our case a serious identification problem arises, since selection is affected by the same factors as the endogenous variables of the economic model. Selection can be seen like a kind of truncation for the endogeous variable: at some stage, it is not profitable to stay in the market.

Another possible test for the impact of attrition on the model parameters is to include a dummy variable for future leavers of the panel. This corresponds to the view that selection (attrition) can be treated like a fixed effect, e.g. general bad business prospects of the product, or a bad management. Since dealing with endogenous attrition within a simultaneous equation context does not appear feasible due to the identification problem, the second procedure is chosen here: dummy variables for future leavers and exits are included in all model equations. The results are discussed below. Note that this procedure does not solve the selection problem entirely. It does not yield unbiased parameters for the model, since attrition is an endogenous variable.[39] Nevertheless, it gives an impression about the importance of the sample selection problem for the model parameters.

## 4 Estimation results

The estimation results are contained in table 4 and table 5. The growth regressions are performed both for the specification of output and employment changes from the business survey data (table 4) and for the specification of the quantitative data from the investment survey (table 5). Since the investment survey is related to the whole firm, while the data on innovations are related to a specific product or product group, the second set of estimates is performed for the restricted sample of firms, where the product level corresponds roughly to the firm level. Note the smaller number of observations in this case.

In the first columns in both tables, the results for a simple Solow model with exogenous technical progress are reported. Output changes are explained with labour input changes and the gross growth rate of the capital stock. A

[38] See Smolny (1996a,b).
[39] See Heckman, Hotz (1989).

log-linear specification is chosen which implies constant output elasticities of the factors. Exogenous technical progress is taken into account with a constant and time dummies for each period (not reported).

The results reveal that employment changes are more important for the explanation of short-run output changes than the equipment investment rate. The coefficients in table 5 can be interpreted as the short-run output elasticities of the factors, i.e. the estimated elasticity of output with respect to employment is about 0.5, the elasticity with respect to capital is only about 0.05. The estimated elasticity of capital is rather low, but note that the specification in differences captures only the short-run effect, and investment refers to equipment only.[40] The coefficient of changes of material inputs is also significant for the specification of real sales growth from the investment survey. The respective variable did not contribute significantly to the explanation of output changes from the business survey (not reported). This indicates that those data correspond to net production.[41] The estimated coefficients in table 4 cannot be interpreted directly as production elasticities. However, if the estimated relation between the business survey data and quantitative investment survey data from table 3 is taken into account, the implied elasticities are in the same order of magnitude.

Column (2) corresponds to an augmented Solow model. The estimated equation accounts also for changes of (sectoral) human capital and changes in the utilization of the input factors. It can be seen that the relative change of human capital in the sectors, approximated by the relative change of wages, is very important for the determination of output growth. The estimated output elasticity is in the dimension of the elasticity with respect to employment. The significance of this variable also confirms the appropriateness of approximating labour quality by its real returns, i.e. relative wages. Note that the relative wage does not stand for substitution effects; those are taken into account by explicitely accounting for capital and labour input changes. The estimated coefficients of those variables are of plausible magnitude, the coefficient of the investment rate becomes even larger. The results also reveal that changes of capacity utilization are a very important determinant of the Solow-residual in the short run. The coefficient is highly significant, and the inclusion of this variable results in an increase of the coefficient and the $t$-value of the investment rate. Omitting capacity utilization leads to an underestimation of the output elasticity of capital. This confirms the assumption of a delayed capacity adjustment which was applied in the model.

The results so far correspond to an augmented neoclassical growth accounting approach based on a production function; the residuals of the equation define cyclically adjusted total factor productivity growth. In the next versions, total factor productivity growth is explained by those variables which stand

[40] Investments in structures did not exhibit a significant effect on output growth (not reported). Therefore, this variable is skipped for the reported results.

[41] The question in the survey is not explicite; it refers to "changes of production".

**Table 4: Sources of productivity growth at the product level**

endogenous variable: $\Delta y$

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| $\Delta l$ | 0.298 | 0.265 | 0.265 | 0.264 | 0.269 | 0.269 | 0.264 | 0.263 |
| | ( 56.5) | ( 50.6) | ( 47.4) | ( 47.4) | ( 48.2) | ( 48.2) | ( 45.4) | ( 45.0) |
| $\frac{i}{l} \cdot \left(\frac{l}{k}\right)^s$ | 0.109 | 0.124 | 0.096 | 0.099 | 0.092 | 0.090 | 0.093 | 0.084 |
| | ( 6.9) | ( 7.9) | ( 5.7) | ( 5.8) | ( 5.4) | ( 5.3) | ( 5.1) | ( 4.6) |
| $\Delta \ln \mathrm{hk}^s$ | | 0.303 | 0.396 | 0.367 | 0.334 | 0.335 | 0.249 | 0.263 |
| | | ( 2.8) | ( 3.4) | ( 3.2) | ( 2.9) | ( 2.9) | ( 2.0) | ( 2.1) |
| $\Delta \ln DUC$ | | 0.523 | 0.537 | 0.538 | 0.533 | 0.533 | 0.513 | 0.514 |
| | | ( 35.2) | ( 33.2) | ( 33.3) | ( 33.1) | ( 33.1) | ( 30.3) | ( 30.3) |
| proc | | | 0.038 | 0.025 | 0.019 | 0.016 | 0.015 | 0.015 |
| | | | ( 10.7) | ( 6.5) | ( 4.9) | ( 3.6) | ( 3.2) | ( 3.3) |
| prod | | | | 0.031 | 0.022 | 0.024 | 0.026 | 0.026 |
| | | | | ( 8.2) | ( 5.7) | ( 5.4) | ( 5.5) | ( 5.5) |
| $\bar{l} < 50$ | | | | | −0.043 | −0.048 | −0.045 | −0.046 |
| | | | | | ( -9.3) | ( -8.2) | ( -7.4) | ( -7.6) |
| $\bar{l} > 1000$ | | | | | 0.027 | 0.042 | 0.039 | 0.040 |
| | | | | | ( 4.6) | ( 3.4) | ( 3.1) | ( 3.2) |
| $(\bar{l} < 50)\cdot$proc | | | | | | 0.031 | 0.031 | 0.030 |
| | | | | | | ( 3.0) | ( 2.9) | ( 2.8) |
| $(\bar{l} > 1000)\cdot$proc | | | | | | −0.026 | −0.026 | −0.027 |
| | | | | | | ( -1.9) | ( -1.8) | ( -1.9) |
| $(\bar{l} < 50)\cdot$prod | | | | | | −0.011 | −0.015 | −0.015 |
| | | | | | | ( -1.1) | ( -1.4) | ( -1.4) |
| $(\bar{l} > 1000)\cdot$prod | | | | | | 0.006 | 0.007 | 0.006 |
| | | | | | | ( 0.4) | ( 0.5) | ( 0.4) |
| $\Delta \ln(y-l)^s$ | | | | | | | 0.135 | 0.172 |
| | | | | | | | ( 2.6) | ( 3.2) |
| $\Delta \ln DUC^s$ | | | | | | | 0.479 | 0.426 |
| | | | | | | | ( 5.6) | ( 4.9) |
| $\Delta \ln l^s$ | | | | | | | | 0.179 |
| | | | | | | | | ( 2.8) |
| $\left(\frac{i}{l}\right)^s \cdot \left(\frac{l}{k}\right)^s$ | | | | | | | | 0.109 |
| | | | | | | | | ( 1.9) |
| SEE | 0.232 | 0.223 | 0.219 | 0.218 | 0.217 | 0.217 | 0.216 | 0.216 |
| $\overline{R}^2$ | 0.228 | 0.279 | 0.294 | 0.297 | 0.303 | 0.303 | 0.302 | 0.303 |
| obs | 19508 | 18825 | 15827 | 15827 | 15801 | 15801 | 14538 | 14538 |

Sample 1981–1992, time dummies were always included. $t$-values in parantheses.

**Table 5: Sources of productivity growth at the firm level**

endogenous variable: $\Delta \ln y$

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| $\Delta \ln l$ | 0.524 | 0.497 | 0.497 | 0.496 | 0.495 | 0.495 | 0.494 | 0.489 |
| | ( 45.8) | ( 42.7) | ( 39.0) | ( 38.9) | ( 38.8) | ( 38.8) | ( 38.9) | ( 38.4) |
| $\frac{i}{l} \cdot \left(\frac{l}{k}\right)^s$ | 0.055 | 0.068 | 0.058 | 0.059 | 0.057 | 0.055 | 0.055 | 0.049 |
| | ( 5.3) | ( 6.4) | ( 4.9) | ( 5.0) | ( 4.8) | ( 4.7) | ( 4.7) | ( 4.2) |
| $\Delta \ln m^s$ | 0.266 | 0.266 | 0.276 | 0.272 | 0.262 | 0.264 | 0.202 | 0.194 |
| | ( 6.7) | ( 6.7) | ( 6.2) | ( 6.1) | ( 5.9) | ( 6.0) | ( 4.5) | ( 4.3) |
| $\Delta \ln \mathrm{hk}^s$ | | 0.422 | 0.476 | 0.468 | 0.466 | 0.460 | 0.310 | 0.328 |
| | | ( 5.5) | ( 5.7) | ( 5.6) | ( 5.6) | ( 5.5) | ( 3.6) | ( 3.8) |
| $\Delta \ln DUC$ | | 0.212 | 0.223 | 0.224 | 0.224 | 0.224 | 0.219 | 0.218 |
| | | ( 19.0) | ( 17.9) | ( 17.9) | ( 18.0) | ( 18.0) | ( 17.4) | ( 17.4) |
| proc | | | 0.005 | 0.002 | 0.001 | 0.000 | 0.000 | 0.000 |
| | | | ( 2.0) | ( 0.8) | ( 0.3) | ( 0.0) | ( 0.0) | ( 0.2) |
| prod | | | | 0.007 | 0.004 | 0.004 | 0.004 | 0.004 |
| | | | | ( 2.7) | ( 1.6) | ( 1.1) | ( 1.1) | ( 1.2) |
| $\bar{l} < 50$ | | | | | −0.013 | −0.023 | −0.022 | −0.023 |
| | | | | | ( -3.5) | ( -5.0) | ( -4.9) | ( -5.0) |
| $\bar{l} > 1000$ | | | | | 0.006 | 0.018 | 0.017 | 0.018 |
| | | | | | ( 1.8) | ( 2.6) | ( 2.5) | ( 2.7) |
| $(\bar{l} < 50) \cdot \mathrm{proc}$ | | | | | | 0.018 | 0.018 | 0.018 |
| | | | | | | ( 2.3) | ( 2.3) | ( 2.2) |
| $(\bar{l} > 1000) \cdot \mathrm{proc}$ | | | | | | −0.007 | −0.007 | −0.008 |
| | | | | | | ( -0.9) | ( -0.9) | ( -1.0) |
| $(\bar{l} < 50) \cdot \mathrm{prod}$ | | | | | | 0.021 | 0.020 | 0.020 |
| | | | | | | ( 2.4) | ( 2.3) | ( 2.3) |
| $(\bar{l} > 1000) \cdot \mathrm{prod}$ | | | | | | −0.008 | −0.008 | −0.010 |
| | | | | | | ( -1.0) | ( -1.0) | ( -1.2) |
| $\Delta \ln(y - l)^s$ | | | | | | | 0.311 | 0.354 |
| | | | | | | | ( 8.3) | ( 9.2) |
| $\Delta \ln DUC^s$ | | | | | | | 0.155 | 0.093 |
| | | | | | | | ( 2.6) | ( 1.5) |
| $\Delta \ln l^s$ | | | | | | | | 0.205 |
| | | | | | | | | ( 4.5) |
| $\left(\frac{i}{l}\right)^s \cdot \left(\frac{l}{k}\right)^s$ | | | | | | | | 0.078 |
| | | | | | | | | ( 2.0) |
| SEE | 0.125 | 0.123 | 0.123 | 0.123 | 0.123 | 0.123 | 0.123 | 0.122 |
| $\overline{R}^2$ | 0.184 | 0.210 | 0.211 | 0.212 | 0.213 | 0.214 | 0.221 | 0.223 |
| obs | 12053 | 11620 | 9835 | 9835 | 9835 | 9835 | 9835 | 9835 |

Sample 1981–1992, time dummies were always included. $t$-values in parantheses.

for the increase of knowledge as proposed by endogenous growth models.

In version (3) and (4), it is tested for an impact of innovation activities on productivity growth. The results reveal that both, process and product innovations exhibit a significant effect on the net output changes from the business survey. That means, endogenous growth models which rely on (endogenous) innovations are supported by these estimates. The coefficients of process innovations are not or only weakly significant in the specification of output changes from the investment survey. This can be caused by the lower number of observations for those estimates. For instance, in the restricted sample, many of the large firms are excluded, because they produce many different products, and the firm level does not correspond to the product level. Another reason for the inconclusive result for process innovations can be that investment at the firm level is a better indicator for the intensity of process innovations at the firm level than innovations at the level of a specific product. Third, the output measure is based on nominal sales, deflated with qualitative price informations. If the deflation procedure is not fully appropriate, the coefficient could depict a combination of a positive productivity effect and a negative price effect. Therefore, it is difficult to obtain a precise estimate of the quantitative impact of innovations on productivity growth. Taken the estimated coefficients at face value, version (4) implies that the productivity growth of a firm which implemented both, a product and a process innovation is about 1 percentage point higher than those of a firm that did not implement an innovation.[42]

In version (5), it is tested for scale economies associated with firm size. The theoretical argument for an effect of firm size on productivity growth is that large firms can build on a larger pool of knowledge. For this purpose, two size dummies for firms with less than 50 employees ($\bar{l} < 50$) and for firms with more than 1000 employees ($\bar{l} > 1000$), on average, are included; i.e. medium-size firms with 50 to 1000 employees are the reference group.[43] Employment is related to the respective product for the business survey data, and to firm-level employment for the investment survey data. The results for the investment survey data reveal that large firms exhibit about 0.6 percentage points more productivity growth than the reference group, ceteris paribus; small firms, on the other hand exhibit 1.3 percentage points less productivity growth. The results achieved with the business survey data indicate effects in the same order of magnitude. Note that these coefficients refer to the effects of firm size on productivity <u>growth</u>, i.e. the estimation results imply strong scale economies.

In order to test whether the productivity of innovations is different in small and large firms, these dummies were also interacted with the innovation behaviour. The results of version (6) reveal that the productivity of process innovations is higher in small firms and lower in large firms than in medium-

[42] In addition, different interaction terms between product and process innovations, and process innovations and investment were included to test for complementarities. Those variables never exhibit a significant effect in the estimates.

[43] A more detailled classification of firm-size dummies did not prove significant.

size firms. This can reflect the higher prospensity to innovate in large firms: in case of decreasing marginal returns to innovations, the average productivity will be lower. It can also indicate that the effort of individual researchers diminishes with firm size. The corresponding results for product innovations are inconclusive: for the business survey data, small firms exhibit a lower productivity of product innovations, ceteris paribus; for the investment survey data, small firms exhibit a higher productivity of product innovations; in both cases, the effect are hardly significant. Nevertheless, the total firm size effect on productivity growth is positive. The effect of the size dummies outweighs thoose of the size-innovation interaction terms. In addition, about 75 percent of the large firms but only 25 percent of the small firm innovate.[44]

Next, it was tested for knowledge spillovers between firms. First, knowledge spillovers were specified by testing for an effect of others innovation behaviour on firm-level productivity growth. In addition, different interaction terms between own and others innovations were included. These variables never exhibit a significant effect on productivity growth (not reported); this standard version of innovation spillovers is not supported by the estimates.[45]

Alternatively, knowledge spillovers are specified by introducing the average labour productivity of the other firms in the sector. In addition, the sectoral change of capacity utilization is included to disentangle short-run changes of factor utilization. The results are depicted in version (7). The sectoral capacity utilization rate exhibits a positive coefficient which can be interpreted as sectoral common demand shocks which affect all firms. The sectoral labour productivity also exhibits a significantly positive impact which indicates spillover effects. Note that this result cannot be attributed simply to a simultaneous equation bias: the variables are calculated excluding the firm under consideration. It should also not be attributed to exogenous growth factors. Exogenous technical progess does not appear as a reasonable concept, and it is difficult to find plausible arguments in favour of exogenous productivity shocks which affect all firms in the sector equally.

In the last version in the tables, the sectoral change of employment and the sectoral investment rate are included to obtain a measure of total factor productivity growth. The coefficient of employment changes is positive which is consistent with an effect of total factor productivity changes instead of labour productivity changes: if sectoral labour productivity increases despite an increase of employment, the effect is stronger. The coefficient associated with the sectoral gross investment rate is positive which indicates additional positive spillovers associated with capital investment.

Finally, the robustness of these results was tested. In table 11 in the ap-

[44] This result is also consistent with the explanation that large firm perform a continuous innovation policy; in this case, productivity growth does not depend that much on year to year innovations.

[45] Note however that others innovations effect own innovations positively. See Smolny (1996). One reason for the insignificance of others innovations could therefore be the multicollinearity between own and others innovations.

pendix, the results of the test for a bias due to endogenous attrition are reported. For this purpose, the model was estimated with a dummy which is equal to one for those firms that leave the business survey during the observation period (leaver). The equations reveal that firms which leave the panel exhibit an about 1.4 percentage points lower productivity growth. This implies that firms which left the panel performed worse, even given the development of the explanatory variables of the model.[46] It indicates that at least some firms left the panel due to exit out of the market. However, and most important, all coefficients and $t$–values of the model variables remain nearly unchanged. The pooled cross-section/time-series analysis also allows to control for unobserved differences between firms or sectors by including dummy variables. The fixed effects results are also depicted in table 11. Again, most of the coefficients remain nearly unchanges; only the coefficents of firm-specific investment and process innovations became insignificant in these estimates. These results are comfortable, i.e. they do not destroy the confidence into the estimates of the economic model.

## 5 Conclusions

In this paper, the sources of productivity growth are investigated by an empirical analysis with micro data for West-German manufacturing firms from the ifo firm panel. The theoretical framework corresponds to an augmented growth accounting approach based on a production function. Output growth is attributed to the change of conventional factor inputs; the residual, i.e. total factor productivity growth, is attributed to variables which stand for arguments from endogenous growth models.

- First, the time-series/cross-section data-set yields a well determined and reasonable estimate of the (short-run) impact of employment and physical capital on output growth. The coefficents are highly significant; their quantitative values are consistent with factor income shares.

- Second, 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.

  In the short run, the Solow residual is significantly related to capacity utilization. It is important to allow for business cycle induced changes of utilization to obtain a well determined estimate of the output elasticity of capital.

- Third, innovative firms exhibit significantly more productivity growth. The quantitative impact could not be determined very precisely, but the

[46] This confirms the results in Smolny (1996a,b) which revealed that leavers exhibit less output, and employment growth, and innovate and invest less.

point estimates indicate an about one percentage point higher productivity growth of innovative firms, ceteris paribus.

- Fourth, scale economies at the micro level are indicated by the higher productivity growth of large firms. On the other hand, the productivity of process innovations tends to be higher in small firms. The overall effect of firm size on productivity is positive.

- Finally, scale economies at the sectoral level are indicated by positive spillover effects from others productivity changes and others investment. Significant spillover related to others innovations were not found.

The growth accounting approach provides a useful framework to test for knowledge spillovers and scale economies. In former work (Smolny (1995a,b)), inter- and intra-sectoral spillovers, and scale economies at the sectoral and aggregate level were found on the base of industry data. In this study, spillovers and scale economies at the firm level were found.

Innovations increase the quality of goods and reduce the input requirement. In a previous paper (Smolny (1996a)), the effects of innovations on output, employment, and prices were analyzed. It was found that innovative firms are more successful; they exhibit a higher capacity utilization and more output and employment growth.

Innovations, scale economies, and productivity spillovers are important concepts for the theory of endogenous technical progress. In addition, every year's productivity increases have 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 innovations, scale economies and spillovers has important policy implications which enhances the interest into further empirical investigations.

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# Appendix

**Table 6: List of variables**

| | |
|---|---|
| $y^+, (y^-)$: | relative number of output increases (decreases) |
| $\Delta y$: | net output increases, $\Delta y = y^+ - y^-$ |
| $p^+, (p^-)$: | relative number of price increases (decreases) |
| $\Delta p$: | net price increases, $\Delta p = p^+ - p^-$ |
| $\Delta \ln s$: | rate of change of sales |
| $\Delta \ln y$: | rate of change of sales deflated |
| | $\Delta \ln y = \Delta \ln s - 0.072 \cdot \Delta p$ |
| $l^+, (l^-)$: | relative number of employment increases (decreases) |
| $\Delta l$: | net employment increases$\Delta l = l^+ - l^-$ |
| $\Delta \ln l$: | rate of change of employment |
| $DUC$: | capacity utilization, $0.3 \leq DUC \leq 1.0$ |
| $\Delta \ln DUC$: | rate of change of capacity utilization |
| $i/l$: | equipment investment per employee, in 1000 of DM |
| $(k/l)^s$: | sectoral capital-labour ratio, equipment, in 1000 of DM |
| $\mathrm{hk}^s$ | indicator of human capital, relative sectoral wage |
| $\Delta \ln m^s$ | indicator of material inputs, |
| | $m$ is the ratio of gross production to gross value added |
| prod: | dummy variable, 1 for product innovation |
| proc: | dummy variable, 1 for product innovation |
| $\bar{l} < 50$: | dummy variable, 1 for firms with less than 50 employees |
| $\bar{l} > 1000$: | dummy variable, 1 for firms with more than 1000 employees |
| leaver: | dummy variable, 1 for leavers of the panel |

**Table 7: Manufacturing sectors**

| ifo | Sypro | sector | sample | total |
|---|---|---|---|---|
| 21 | 25 | stone, clay | 0.042 | 0.079 |
| 22 | 27/30 | drawing, cold-rolling mills | 0.012 | 0.010 |
| 23 | 28/29 | foundry | 0.016 | 0.016 |
| 24 | 22 | mineral oil | 0.004 | 0.002 |
| 25 | 24/40 | chemicals | 0.015 | 0.035 |
| 26 | 53 | wood | 0.037 | 0.043 |
| 27 | 55 | paper | 0.018 | 0.004 |
| 28 | 59 | rubber | 0.007 | 0.006 |
| 31 | 31 | steel products | 0.030 | 0.034 |
| 32 | 32/50 | machinery | 0.141 | 0.125 |
| 33 | 33/34/35 | car manufacturing | 0.034 | 0.062 |
| 34 | 36 | electrical products | 0.052 | 0.077 |
| 35 | 37 | precision and optical goods | 0.033 | 0.031 |
| 37 | 30 | steel | 0.041 | 0.033 |
| 38 | 38 | ironware | 0.050 | 0.054 |
| 411 | 51 | fine ceramics | 0.012 | 0.004 |
| 412 | 52 | glass | 0.023 | 0.008 |
| 42 | 54 | furniture | 0.053 | 0.052 |
| 43 | 39 | musical instruments, toys, etc. | 0.014 | 0.015 |
| 441 | 56 | paper products | 0.044 | 0.019 |
| 442 | 57 | printing | 0.090 | 0.044 |
| 45 | 58 | plastic | 0.038 | 0.047 |
| 46 | 61/62 | leather | 0.022 | 0.014 |
| 471 | 63 | textiles | 0.060 | 0.038 |
| 472 | 64 | clothing | 0.026 | 0.053 |
| 51 | 68/69 | food, beverages | 0.083 | 0.098 |
| 52 | 68/69 | tobacco | 0.005 | 0.001 |

Notes: *ifo* is the sector classification of the ifo institute,
*Sypro* is the classification according to the German Statistical Office.
*Sample* denotes the share of firms in the ifo firm panel,
*total* denotes the shares in total manufacturing.

**Table 8: Prices, output, and sales**

| sector | $p^+$ | $p^-$ | $\Delta p$ | $\sigma_{\Delta p}$ | $y^+$ | $y^-$ | $\Delta y$ | $\sigma_{\Delta y}$ | $\Delta \ln y$ | $\sigma_{\Delta \ln y}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 0.081 | 0.068 | 0.013 | 0.219 | 0.134 | 0.209 | -0.075 | 0.256 | 0.027 | 0.125 |
| 22 | 0.147 | 0.035 | 0.112 | 0.224 | 0.199 | 0.202 | -0.004 | 0.332 | 0.024 | 0.166 |
| 23 | 0.180 | 0.167 | 0.013 | 0.352 | 0.114 | 0.177 | -0.062 | 0.263 | 0.015 | 0.160 |
| 24 | 0.286 | 0.283 | 0.004 | 0.252 | 0.095 | 0.128 | -0.034 | 0.204 | -0.029 | 0.214 |
| 25 | 0.099 | 0.068 | 0.031 | 0.242 | 0.128 | 0.177 | -0.049 | 0.244 | -0.002 | 0.126 |
| 26 | 0.133 | 0.138 | -0.005 | 0.326 | 0.082 | 0.181 | -0.099 | 0.242 | 0.013 | 0.139 |
| 27 | 0.170 | 0.117 | 0.052 | 0.325 | 0.106 | 0.142 | -0.036 | 0.248 | 0.036 | 0.109 |
| 28 | 0.086 | 0.088 | -0.002 | 0.253 | 0.066 | 0.115 | -0.049 | 0.227 | 0.033 | 0.145 |
| 31 | 0.080 | 0.066 | 0.013 | 0.222 | 0.109 | 0.161 | -0.051 | 0.289 | 0.034 | 0.203 |
| 32 | 0.087 | 0.018 | 0.069 | 0.135 | 0.116 | 0.156 | -0.040 | 0.270 | 0.038 | 0.176 |
| 33 | 0.102 | 0.023 | 0.080 | 0.173 | 0.141 | 0.155 | -0.014 | 0.260 | 0.041 | 0.225 |
| 34 | 0.097 | 0.022 | 0.075 | 0.154 | 0.146 | 0.154 | -0.008 | 0.271 | 0.043 | 0.113 |
| 35 | 0.100 | 0.012 | 0.088 | 0.138 | 0.121 | 0.168 | -0.047 | 0.285 | 0.029 | 0.129 |
| 37 | 0.143 | 0.052 | 0.091 | 0.249 | 0.150 | 0.188 | -0.037 | 0.294 | 0.024 | 0.128 |
| 38 | 0.094 | 0.017 | 0.077 | 0.130 | 0.145 | 0.173 | -0.028 | 0.253 | 0.021 | 0.111 |
| 411 | 0.115 | 0.019 | 0.096 | 0.160 | 0.102 | 0.159 | -0.057 | 0.241 | 0.018 | 0.081 |
| 412 | 0.106 | 0.024 | 0.082 | 0.169 | 0.129 | 0.189 | -0.060 | 0.281 | 0.027 | 0.151 |
| 42 | 0.101 | 0.025 | 0.076 | 0.161 | 0.163 | 0.172 | -0.009 | 0.287 | 0.027 | 0.135 |
| 43 | 0.125 | 0.028 | 0.098 | 0.225 | 0.122 | 0.153 | -0.031 | 0.253 | 0.029 | 0.110 |
| 441 | 0.213 | 0.076 | 0.137 | 0.359 | 0.176 | 0.181 | -0.005 | 0.320 | 0.032 | 0.101 |
| 442 | 0.096 | 0.061 | 0.036 | 0.220 | 0.189 | 0.209 | -0.020 | 0.273 | 0.049 | 0.103 |
| 45 | 0.134 | 0.068 | 0.067 | 0.227 | 0.152 | 0.210 | -0.058 | 0.291 | 0.039 | 0.113 |
| 46 | 0.104 | 0.029 | 0.075 | 0.173 | 0.093 | 0.154 | -0.061 | 0.240 | 0.001 | 0.119 |
| 471 | 0.099 | 0.049 | 0.051 | 0.214 | 0.116 | 0.175 | -0.059 | 0.278 | 0.017 | 0.130 |
| 472 | 0.087 | 0.021 | 0.066 | 0.150 | 0.099 | 0.159 | -0.060 | 0.262 | 0.013 | 0.131 |
| 51 | 0.115 | 0.064 | 0.051 | 0.237 | 0.198 | 0.202 | -0.004 | 0.276 | 0.037 | 0.117 |
| 52 | 0.069 | 0.023 | 0.046 | 0.104 | 0.309 | 0.252 | 0.057 | 0.284 | 0.040 | 0.141 |
| total | 0.111 | 0.049 | 0.062 | 0.216 | 0.140 | 0.176 | -0.036 | 0.274 | 0.031 | 0.139 |

Source: ifo firm panel, 2405 firms, 13 years

**Table 9: Employment, capacity utilization, and innovations**

| year | $l^+$ | $l^-$ | $\Delta l$ | $\sigma_{Deltal}$ | $\Delta \ln l$ | $\sigma_{\Delta \ln l}$ | prod | proc | $\Delta \ln DUC$ | $\sigma_{\Delta \ln DUC}$ | $i/l$ | $\sigma_{i/l}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 0.034 | 0.116 | -0.082 | 0.276 | -0.010 | 0.082 | 0.330 | 0.358 | -0.001 | 0.139 | 19.472 | 27.089 |
| 22 | 0.113 | 0.138 | -0.026 | 0.377 | -0.011 | 0.100 | 0.405 | 0.409 | 0.003 | 0.159 | 6.288 | 7.929 |
| 23 | 0.037 | 0.124 | -0.087 | 0.282 | -0.002 | 0.079 | 0.368 | 0.465 | 0.000 | 0.086 | 8.671 | 7.031 |
| 24 | 0.044 | 0.235 | -0.192 | 0.390 | -0.051 | 0.076 | 0.379 | 0.466 | 0.022 | 0.114 | 39.152 | 34.581 |
| 25 | 0.022 | 0.090 | -0.069 | 0.249 | -0.039 | 0.158 | 0.450 | 0.413 | -0.002 | 0.145 | 10.929 | 14.172 |
| 26 | 0.035 | 0.090 | -0.055 | 0.238 | -0.010 | 0.117 | 0.206 | 0.300 | 0.002 | 0.111 | 10.963 | 17.253 |
| 27 | 0.028 | 0.062 | -0.034 | 0.212 | 0.009 | 0.067 | 0.324 | 0.427 | -0.003 | 0.074 | 20.096 | 42.020 |
| 28 | 0.068 | 0.161 | -0.093 | 0.360 | -0.026 | 0.090 | 0.677 | 0.496 | -0.007 | 0.100 | 6.254 | 4.382 |
| 31 | 0.079 | 0.134 | -0.055 | 0.347 | -0.019 | 0.095 | 0.404 | 0.356 | -0.007 | 0.138 | 3.711 | 2.961 |
| 32 | 0.093 | 0.160 | -0.067 | 0.395 | -0.006 | 0.096 | 0.647 | 0.510 | -0.007 | 0.129 | 4.877 | 5.211 |
| 33 | 0.079 | 0.215 | -0.135 | 0.404 | -0.011 | 0.093 | 0.670 | 0.572 | 0.000 | 0.142 | 6.252 | 5.463 |
| 34 | 0.097 | 0.165 | -0.068 | 0.379 | 0.002 | 0.088 | 0.684 | 0.625 | -0.005 | 0.119 | 5.763 | 3.777 |
| 35 | 0.071 | 0.166 | -0.095 | 0.365 | -0.011 | 0.107 | 0.612 | 0.447 | -0.001 | 0.115 | 3.842 | 3.234 |
| 37 | 0.077 | 0.134 | -0.057 | 0.339 | -0.001 | 0.102 | 0.408 | 0.487 | -0.007 | 0.120 | 6.411 | 5.561 |
| 38 | 0.065 | 0.120 | -0.054 | 0.312 | -0.013 | 0.111 | 0.494 | 0.487 | -0.003 | 0.109 | 4.679 | 5.127 |
| 411 | 0.037 | 0.217 | -0.180 | 0.354 | -0.015 | 0.079 | 0.670 | 0.628 | -0.002 | 0.086 | 4.334 | 5.550 |
| 412 | 0.055 | 0.166 | -0.111 | 0.344 | -0.001 | 0.118 | 0.578 | 0.509 | -0.010 | 0.109 | 7.375 | 8.058 |
| 42 | 0.089 | 0.121 | -0.032 | 0.343 | 0.000 | 0.108 | 0.590 | 0.447 | -0.002 | 0.112 | 4.257 | 5.593 |
| 43 | 0.061 | 0.165 | -0.104 | 0.347 | -0.015 | 0.129 | 0.570 | 0.480 | 0.003 | 0.137 | 5.982 | 6.489 |
| 441 | 0.087 | 0.094 | -0.007 | 0.314 | -0.005 | 0.097 | 0.342 | 0.383 | -0.001 | 0.097 | 7.147 | 8.067 |
| 442 | 0.080 | 0.096 | -0.016 | 0.316 | 0.004 | 0.097 | 0.238 | 0.409 | 0.001 | 0.098 | 8.638 | 11.436 |
| 45 | 0.063 | 0.122 | -0.058 | 0.319 | 0.005 | 0.100 | 0.472 | 0.440 | -0.001 | 0.128 | 7.808 | 7.528 |
| 46 | 0.024 | 0.152 | -0.129 | 0.291 | -0.045 | 0.137 | 0.490 | 0.378 | -0.012 | 0.116 | 2.687 | 3.309 |
| 471 | 0.033 | 0.158 | -0.126 | 0.303 | -0.023 | 0.095 | 0.583 | 0.492 | -0.008 | 0.120 | 4.915 | 4.857 |
| 472 | 0.036 | 0.154 | -0.117 | 0.310 | -0.037 | 0.126 | 0.495 | 0.392 | -0.009 | 0.114 | 1.706 | 3.077 |
| 51 | 0.049 | 0.127 | -0.078 | 0.303 | -0.001 | 0.120 | 0.416 | 0.365 | -0.003 | 0.093 | 11.765 | 13.375 |
| 52 | 0.067 | 0.125 | -0.058 | 0.295 | 0.003 | 0.101 | 0.511 | 0.522 | -0.008 | 0.099 | 14.515 | 17.470 |
| total | 0.067 | 0.137 | -0.070 | 0.337 | -0.008 | 0.103 | 0.497 | 0.459 | -0.004 | 0.117 | 7.489 | 12.388 |

Source: ifo firm panel, 2405 firms, 13 years

**Table 10: Frequency of price, output, and employment changes**

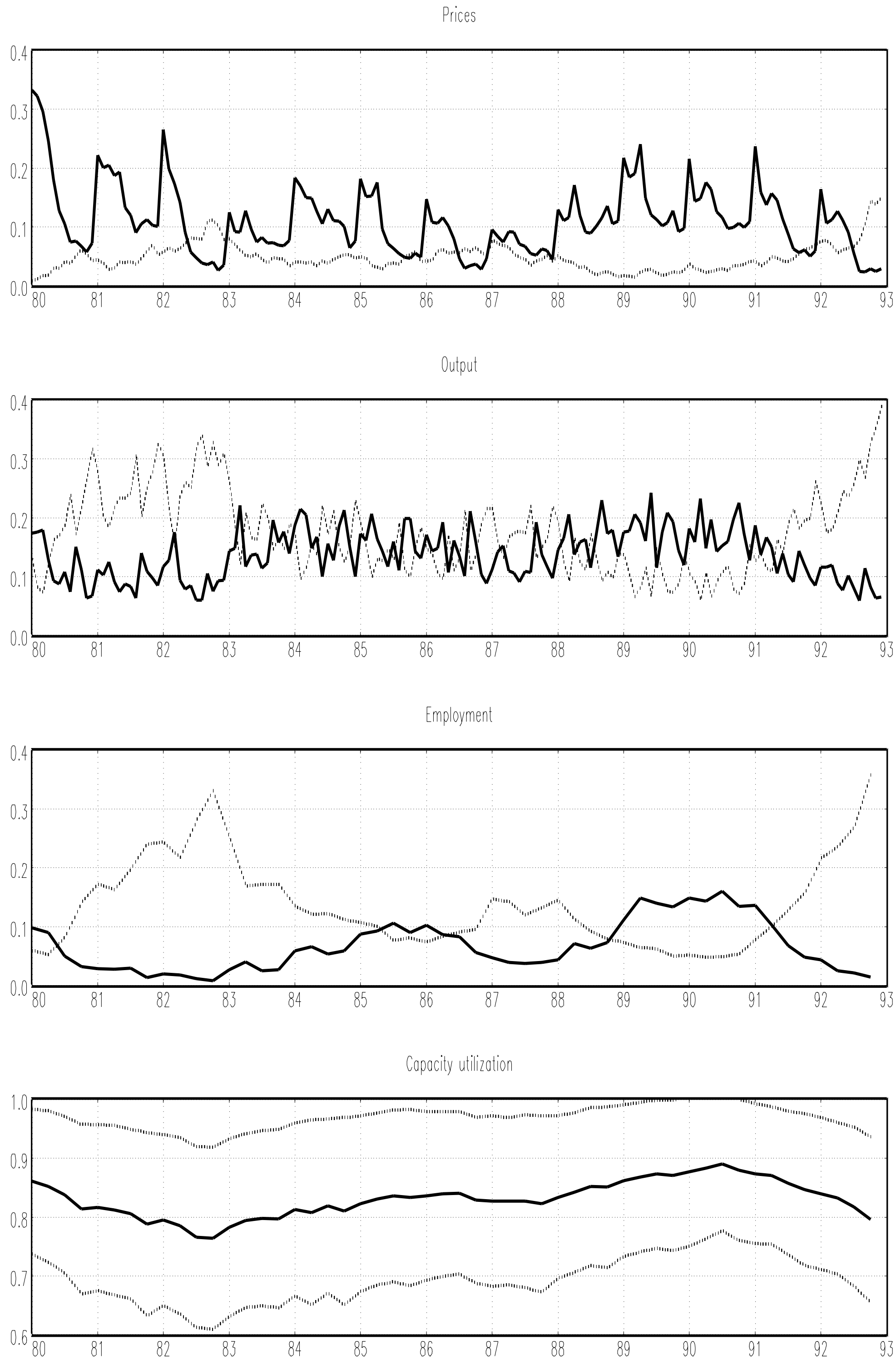
| freq | increase | decrease | no change | change | obs |
|---|---|---|---|---|---|
| **prices** | | | | | |
| 0 | 11468 | 22807 | 201 | 8406 | 3196 |
| 1 | 9017 | 2088 | 371 | 9087 | 172 |
| 2 | 3849 | 1045 | 471 | 4429 | 168 |
| 3 | 1535 | 662 | 566 | 2092 | 219 |
| 4 | 831 | 435 | 707 | 1215 | 268 |
| 5 | 458 | 339 | 925 | 856 | 301 |
| 6 | 305 | 222 | 1144 | 606 | 412 |
| 7 | 190 | 180 | 1492 | 436 | 472 |
| 8 | 131 | 113 | 1993 | 301 | 612 |
| 9 | 105 | 89 | 3007 | 262 | 995 |
| 10 | 85 | 52 | 4814 | 195 | 1796 |
| 11 | 48 | 25 | 7282 | 109 | 4140 |
| 12 | 47 | 12 | 5096 | 75 | 18514 |
| **output** | | | | | |
| 0 | 12369 | 10290 | 447 | 5400 | 3196 |
| 1 | 5212 | 5079 | 744 | 3780 | 172 |
| 2 | 3586 | 3924 | 1053 | 3482 | 168 |
| 3 | 2548 | 2937 | 1496 | 3184 | 221 |
| 4 | 1771 | 2143 | 1752 | 2901 | 263 |
| 5 | 1225 | 1497 | 2198 | 2585 | 305 |
| 6 | 677 | 951 | 2397 | 2038 | 409 |
| 7 | 363 | 575 | 2760 | 1669 | 468 |
| 8 | 164 | 280 | 2891 | 1210 | 612 |
| 9 | 79 | 196 | 2833 | 878 | 1001 |
| 10 | 44 | 92 | 2942 | 507 | 1779 |
| 11 | 23 | 53 | 2944 | 299 | 4104 |
| 12 | 8 | 52 | 3612 | 136 | 18567 |
| **employment** | | | | | |
| 0 | 23307 | 19833 | 1341 | 15956 | 3586 |
| 1 | 2770 | 4184 | 2939 | 6168 | 869 |
| 2 | 1012 | 1950 | 4404 | 3089 | 1397 |
| 3 | 432 | 1111 | 7099 | 1667 | 4144 |
| 4 | 158 | 601 | 11896 | 799 | 21269 |

**net increases**

| | $\Delta p$ | $\Delta y$ | $\Delta l$ |
|---|---|---|---|
| -12 | 12 | 52 | |
| -11 | 24 | 52 | |
| -10 | 45 | 84 | |
| -9 | 78 | 157 | |
| -8 | 97 | 220 | |
| -7 | 142 | 380 | |
| -6 | 186 | 588 | |
| -5 | 272 | 804 | |
| -4 | 330 | 1169 | 601 |
| -3 | 517 | 1697 | 1094 |
| -2 | 779 | 2540 | 1881 |
| -1 | 1373 | 3723 | 3867 |
| 0 | 9049 | 7634 | 16269 |
| 1 | 8348 | 3358 | 2454 |
| 2 | 3523 | 2121 | 935 |
| 3 | 1373 | 1397 | 420 |
| 4 | 695 | 844 | 158 |
| 5 | 400 | 552 | |
| 6 | 264 | 279 | |
| 7 | 168 | 196 | |
| 8 | 116 | 94 | |
| 9 | 100 | 59 | |
| 10 | 84 | 41 | |
| 11 | 47 | 20 | |
| 12 | 47 | 8 | |

Source: ifo firm panel

**Figure 1: Prices, output, employment, and capacity utilization**




Source: ifo firm panel

**Table 11: Attrition and fixed effects**

| | $\Delta y$ | $\Delta y$ | | $\Delta \ln y$ | $\Delta \ln y$ |
|---|---|---|---|---|---|
| | attrition | fixed effects | | attrition | fixed effects |
| $\Delta l$ | 0.263 | 0.223 | $\Delta \ln l$ | 0.488 | 0.426 |
| | ( 44.9) | ( 39.0) | | ( 38.2) | ( 32.0) |
| $\frac{i}{l} \cdot \left(\frac{l}{k}\right)^s$ | 0.082 | $-0.022$ | $\frac{i}{l} \cdot \left(\frac{l}{k}\right)^s$ | 0.048 | 0.022 |
| | ( 4.5) | ( -1.1) | | ( 4.1) | ( 1.5) |
| | | | $\Delta \ln m^s$ | 0.196 | 0.199 |
| | | | | ( 4.3) | ( 4.5) |
| $\Delta \ln \text{hk}^s$ | 0.265 | 0.284 | $\Delta \ln \text{hk}^s$ | 0.333 | 0.377 |
| | ( 2.2) | ( 2.6) | | ( 3.9) | ( 4.4) |
| $\Delta \ln DUC$ | 0.514 | 0.507 | $\Delta \ln DUC$ | 0.218 | 0.219 |
| | ( 30.3) | ( 34.9) | | ( 17.4) | ( 17.8) |
| proc | 0.015 | 0.000 | proc | 0.000 | $-0.002$ |
| | ( 3.2) | ( 0.0) | | ( 0.0) | ( -0.7) |
| prod | 0.025 | 0.011 | prod | 0.004 | 0.006 |
| | ( 5.4) | ( 2.6) | | ( 1.1) | ( 1.8) |
| $\bar{l} < 50$ | $-0.044$ | | $\bar{l} < 50$ | $-0.022$ | |
| | ( -7.1) | | | ( -4.8) | |
| $\bar{l} > 1000$ | 0.037 | | $\bar{l} > 1000$ | 0.017 | |
| | ( 3.0) | | | ( 2.5) | |
| $(\bar{l} < 50) \cdot \text{proc}$ | 0.028 | | $(\bar{l} < 50) \cdot \text{proc}$ | 0.017 | |
| | ( 2.6) | | | ( 2.1) | |
| $(\bar{l} > 1000) \cdot \text{proc}$ | $-0.026$ | | $(\bar{l} > 1000) \cdot \text{proc}$ | $-0.007$ | |
| | ( -1.8) | | | ( -0.9) | |
| $(\bar{l} < 50) \cdot \text{prod}$ | $-0.014$ | | $(\bar{l} < 50) \cdot \text{prod}$ | 0.020 | |
| | ( -1.3) | | | ( 2.3) | |
| $(\bar{l} > 1000) \cdot \text{prod}$ | 0.007 | | $(\bar{l} > 1000) \cdot \text{prod}$ | $-0.010$ | |
| | ( 0.4) | | | ( -1.2) | |
| $\Delta \ln(y-l)^s$ | 0.178 | 0.177 | $\Delta \ln(y-l)^s$ | 0.360 | 0.345 |
| | ( 3.3) | ( 3.7) | | ( 9.3) | ( 8.9) |
| $\Delta \ln DUC^s$ | 0.425 | 0.463 | $\Delta \ln DUC^s$ | 0.085 | 0.093 |
| | ( 4.8) | ( 6.1) | | ( 1.4) | ( 1.5) |
| $\Delta \ln l^s$ | 0.173 | 0.120 | $\Delta \ln l^s$ | 0.204 | 0.225 |
| | ( 2.6) | ( 2.0) | | ( 4.5) | ( 4.7) |
| $\left(\frac{i}{l}\right)^s \cdot \left(\frac{l}{k}\right)^s$ | 0.101 | 0.202 | $\left(\frac{i}{l}\right)^s \cdot \left(\frac{l}{k}\right)^s$ | 0.073 | 0.162 |
| | ( 1.8) | ( 2.5) | | ( 1.8) | ( 2.6) |
| leaver | $-0.019$ | | leaver | $-0.014$ | |
| | ( -3.6) | | | ( -3.7) | |
| SEE | 0.216 | 0.189 | SEE | 0.122 | 0.121 |
| $\overline{R}^2$ | 0.304 | 0.465 | $\overline{R}^2$ | 0.224 | 0.231 |
| obs | 14496 | 14562 | obs | 9798 | 9835 |

Sample 1981–1992, time dummies were always included, 1992 is the reference period. $t$-values in parantheses.