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Endogenous innovations in a model of the firm: Theory and empirical application for West-German manufacturing firms

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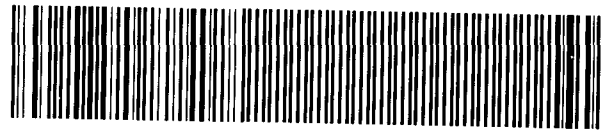
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**Endogenous Innovations in a Model of the Firm
Theory and Empirical Application for
West-German Manufacturing Firms**

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Werner Smolny

February 1997

Abstract:

In the paper, a theoretical model of the determinants of innovation behaviour and investment is developed. The model is estimated with micro-data for West-German manufacturing firms from the ifo firm panel. The empirical results reveal a positive effect from firm size and market power on innovations. In addition, innovations depend positively on others innovations which indicates positive spillover effects. Finally, innovations depend positively on measures of excess demand at the firm level. This implies that temporary demand shocks affect output and productivity in the short run and in the long run. This underlines the importance of financing constraints for innovations and the complementarity of innovations and investment.

Keywords: Endogenous innovations, market structure

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1 Introduction

“... we believe that most technological progress requires, at least at some stage, an intentional investment of resources by profit-seeking firms or entrepreneurs.”¹ The basic premise of most models of endogenous growth is that technological progress is driven by innovations. Firms innovate in order to reduce costs or to increase demand. Since the knowledge incorporated in innovations is non-rival and only partially excludable, the firm size and the market structure are important determinants of innovation behaviour:² large firms on monopolistic markets must fear less imitation from competitors and gain more from scale economies associated with innovations. In addition, monopolistic profits permit an easier finance of risky innovation projects.³ On the other hand, small firms on competitive markets are forced to utilize the best available production technique and to develop better products. Non-innovative firms must fear to be driven out of the market, while firms which successfully introduce an innovation gain from a large increase in the market share.

However, the market structure itself is endogenous.⁴ Innovations of firms change the market structure, and the intended change of the market structure is an important incentive for innovative activities: firms develop differentiated products to earn more profits through a temporary monopolistic situation. In the long run, innovations of other firms destroy the monopolistic situation on the product market, and the process of “creative destruction” is the driving force of technological change.⁵

In this paper, a theoretical model of the determinants of the innovation and investment behaviour of the firm is developed. In the analysis, it is distinguished between product and process innovations, and process innovations are distinguished from capital investment. It is assumed that product innovations change the demand curve, and process innovations change costs through the efficiency of labour and capital. Capital investment stands for the quantity aspects of physical capital. The innovation decision is treated analogously to the investment decision, but in a less formal framework to keep the analysis tractable. In addition, the model is confined to partial analysis, i.e. it is abstracted from strategic interaction among firms. A first topic is the discussion of the effects of the market structure on innovations. Besides firm size, a measure of market power is derived from the price-setting behaviour of the firm, i.e. an information about the market structure is deduced from the market behaviour.

A second topic is the analysis of the relation between innovations and the business cycle. In the theoretical model, the complementarity of innovations and

¹Grossman, Helpman (1994), p. 24.

²See Kamien, Schwarz (1975), Acs, Audretsch (1987,1988), Cohen, Levin (1989), and Scherer, Ross (1990).

³See Stiglitz (1993), Himmelberg, Peterson (1994), and Winker (1996).

⁴See Dasgupta, Stiglitz (1980a,b), Vickers (1986), Geroski, Pomroy (1990), Pohlmeier (1992), and Geroski (1995).

⁵See Aghion, Howitt (1992).

capital investment is explicitly taken into account. This provides a first argument for an effect of the business cycle on long-run growth. A second argument results from capital market imperfections and constraints on the borrowing which drive a wedge between market interest rates and the internal interest rate, and which imply a positive effect of cash flow and retained profits on innovations. Third, growing markets favour innovations. These arguments stand against procyclical opportunity costs and the motive of intertemporal substitution which implies a positive effect from recessions on innovations and long-run growth. A final topic are knowledge spillovers and the appropriability of the returns from innovations.

In the model, a delayed adjustment of innovations, investment and capital-labour substitution with respect to demand and cost shocks is assumed. In the short run, the firm sets output, prices, and employment; capacities, the factor productivities, and innovations are treated as predetermined for the short-run decision. In the long run, the firm decides on investment, capital-labour substitution, and innovations under uncertainty of demand, output, and prices.

The advantage of the assumption of a dynamic decision structure is that it permits to discuss business cycle induced effects consistently within the framework of the theoretical model: an excess demand on the goods market induces capital investment which reduces the costs of innovations; extra profits from higher prices due to unexpected demand shocks permit an easier finance of innovation projects and investment; on the other hand, the lower opportunity costs of reorganizations of the production process in recessions imply an argument in favour of innovations in periods of slack demand. The specification of dynamics in terms of adjustment delays simplifies the formal solution of the model: it allows to reduce the dynamic decision problem of the firm to a sequence of static problems: the short-run decision can be analysed with predetermined capacities, and the long-run decision takes place under uncertainty of demand.

The model is estimated with firm-level data for West-German manufacturing from 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.⁶ From the business survey, qualitative monthly data on price and output changes, and quarterly data on capacity utilization are available. Since 1980, the business survey also contains an annual question on innovation.⁷ The data-set contains the qualitative information, whether a firm plans or has implemented product and/or process innovations. In addition, the annual innovation survey contains qualitative data on innovation activities and impediments, and quantitative data on innovation expenditures. These data were matched with quantitative annual data on investment, employment, and sales from the investment survey.

⁶See Schneeweis, Smolny (1996), Smolny, Schneeweis (1996), and Smolny (1996).

⁷See Oppenländer, Poser (1989) and Penzkofer, Schmalholz, Scholz (1989).

2 Theoretical framework

In the analysis, it is distinguished between the implementation of product and process innovations. It is assumed that process innovations affect the efficiency of labour and capital, and product innovations affect the demand curve. A successful product innovation implies that the quality of the product increases, and demand increases. In addition, process innovations are distinguished from capital investment. It is assumed that capital investment stands for the quantity effects of (homogeneous) capital, while process innovations capture the quality effects. Complementarities between product and process innovations, and between innovations and investment are taken into account in the analysis.

First, a basic model of a delayed adjustment of the capital stock and capital-labour substitution is developed. Output, prices, and employment are determined in the short run with predetermined capacities, factor productivities, and innovations. Capital investment and the capital-labour ratio are determined in the long run under uncertainty about demand, output, and prices. The modifications implied by endogenous innovations are discussed afterwards. Innovations are treated as investments in "knowledge capital", analogously to capital investment, but most of the analysis is confined to discrete innovation projects.

2.1 The basic model of the firm

2.1.1 Assumptions

In the theoretical model, a strong separability of the short-run and the long-run decisions of the firm is assumed. In the short run, output, prices, and employment are endogenous. Wages are treated as exogenous for the firm. In the long run, the firm decides on investment and capital-labour substitution under uncertainty about demand, employment and prices.⁸

In most models, a dynamic adjustment is analysed under the assumption of adjustment costs which depend on the size of the adjustment. However, it is difficult to find examples for adjustment costs which can account for the observed slow adjustment of many economic variables. On the other hand, changing decision variables necessarily takes time, and even a short time delay between a decision and the realization of an exogenous variable can introduce considerable uncertainty.⁹

⁸There is an extensive literature about the slow adjustment of the capital stock and the capital-labour ratio. Mayer, Sonenblum (1955) and Mayer (1958,1960) found planning, decision, and delivery lags for capital of about 2 years; Jorgenson (1963) and Jorgenson, Stephenson (1967) made dynamic adjustment models for investment common. Johansen (1959) introduced a slow adjustment of the capital-labour ratio with vintage models and a putty-clay assumption, and Nadiri, Rosen (1969) analysed interrelated factor demand decisions. The putty-clay assumption became common with the work of Bishoff (1971a,b).

⁹See Kydland, Prescott (1982) and Peeters (1994) for a discussion of the implicate "time-to-build" assumption.

The analysis of the dynamic adjustment in terms of adjustment delays and uncertainty has the further advantage to reduce the dynamic decision problem of the firm to a sequence of static problems which can be solved stepwise:

- the short-run determination of output, employment, and prices can be analysed with predetermined capital stock, capital-labour ratio, and knowledge capital;
- the long-run decision on the capital stock, capital-labour substitution, and innovations can be analysed under uncertainty of demand, taking into account the short-run decision on output, prices, and employment.

The analysis is carried out within a framework of monopolistic competition. In order to distinguish between demand shifts, the price elasticity of demand, and demand uncertainty, a log-linear demand curve is assumed.¹⁰

$$\ln YD = \eta \cdot \ln p + \ln Z + \varepsilon \quad (1)$$

with: $\eta < -1$, $E(\varepsilon) = 0$, $\text{Var}(\varepsilon) = \sigma^2$

Demand YD depends negatively on the price p with a constant elasticity η , exogenous and predetermined factors incorporated in Z , and an error term ε which is not known at the time of the investment decision:¹¹ Z , η , and σ are treated as predetermined in the short run; they depend on product innovations and on competitors' behaviour in the long run. Supply YS is determined by a short-run limitational production function with capital K and labour L as inputs:

$$YS = \min(YC, YL) = \min(\pi_k \cdot K, \pi_l \cdot L) \quad (2)$$

YC are capacities, YL is the employment constraint of the short-run production function, and π_l , π_k are the productivities of labour and capital. The factor productivities depend on the capital-labour ratio k and production efficiency θ :

$$\pi_l = \pi_l(k, \theta), \quad \pi_k = \pi_k(k, \theta)$$

Production efficiency depends on predetermined process innovations and productivity spillovers; capacities and the capital-labour ratio are also treated as predetermined in the short run. They are determined by the long-run investment and innovation decision. In the basic model, K and k are determined without recurrence to innovations, the modifications implied by explicitly modelling endogenous innovation behaviour are discussed afterwards.

¹⁰See Barro (1972) and Blanchard, Kiyotaki (1987). Deaton, Muellbauer (1980) derive logarithmic demand curves from CES-utility functions.

¹¹The time index is omitted for convenience.

2.1.2 Optimal output, employment, and prices

The theoretical framework of the short-run decision is a model of monopolistic competition with predetermined capacity constraints. In the short run, the firm decides on output, prices, and employment. The optimization problem can be written as:

$$\max_{\rightarrow L} p \cdot Y - w \cdot L - c \cdot K \quad \text{s.t.} \quad Y \leq \{YC, YL, YD\} \quad (3)$$

Wages w and capital costs c are treated as exogenous. The first order condition is given by:

$$\begin{aligned} p \cdot \frac{\partial Y}{\partial YL} \cdot \frac{\partial YL}{\partial L} + \frac{\partial p}{\partial Y} \cdot \frac{\partial Y}{\partial YL} \cdot \frac{\partial YL}{\partial L} \cdot Y - w &= \\ p \cdot (1 + 1/\eta) \cdot (1 - \lambda_{YC}) \cdot \pi_l - w &= 0 \end{aligned} \quad (4)$$

λ_{YC} is the shadow price of the capacity constraint; it is zero in case of sufficient capacities and one in case of capacity shortages:

$$\lambda_{YC} = \begin{cases} 0 & \text{for } \varepsilon < \bar{\varepsilon} \\ 1 & \text{for } \varepsilon > \bar{\varepsilon} \end{cases}$$

$\bar{\varepsilon}$ is defined by: $\bar{\varepsilon} := \ln YC - \eta \cdot \ln p(w) - \ln Z$

For the optimal solution, two cases can be distinguished: in case of sufficient capacities, i.e. $\lambda_{YC} = 0$, the optimal price, output, and employment result from:

$$p(w) = \frac{w}{\pi_l \cdot (1 + 1/\eta)} \quad (5)$$

$$\ln Y(w) = \eta \cdot \ln p(w) + \ln Z + \varepsilon \quad (6)$$

$$\ln L(w) = \ln Y(w) - \ln \pi_l \quad (7)$$

The price is determined by unit labour costs and the price elasticity of demand, output results from introducing this price into the demand function, and employment is the labour input required to produce this output. In case of capacity shortages, i.e. $\lambda_{YC} \neq 0$, output, employment, and prices are determined as:

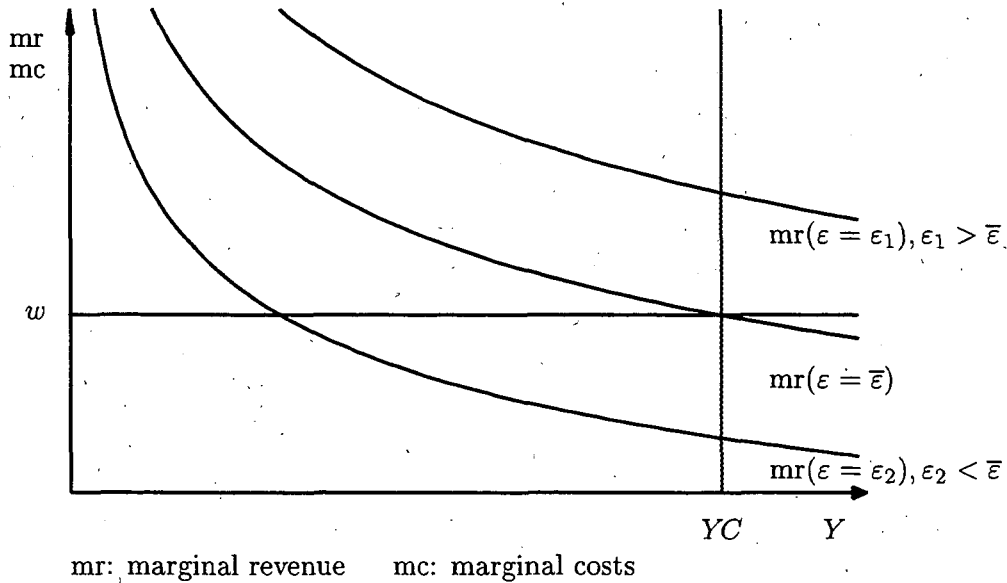
$$Y = YC \quad (8)$$

$$\ln L_{YC} = \ln YC - \ln \pi_l \quad (9)$$

$$\ln p(YC) = (\ln YC - \ln Z - \varepsilon)/\eta \quad (10)$$

Output is equal to the capacity constraint, employment is again given as the corresponding labour requirement, and the price follows from solving the demand function for p at $YD = YC$. There is exactly one value of the demand shock $\varepsilon = \bar{\varepsilon}$

Figure 1: Optimal output



which distinguishes these cases. Figure 1 gives a visual impression of the model. In case of a negative demand shock ($\varepsilon_2 < \bar{\varepsilon}$), the price is determined by unit labour costs and the mark-up is determined by the price elasticity of demand. The firm suffers from underutilization of capacities. In case of a positive demand shock ($\varepsilon_1 > \bar{\varepsilon}$), insufficient capacities restrain output and the firm increases the price. $\varepsilon = \bar{\varepsilon}$ is the borderline which distinguishes these cases. That means, in the short run firms adjust with respect to demand

- either by changing the price (in the capacity constrained regime),
- or by changing output and employment (in the unconstrained regime).

Note that a large variance of demand shocks requires a high variance of price and output adjustments. Finally, optimal output can be written as:

$$Y = \min(Y(w), YC) \quad (11)$$

The model can be extended to allow for a slow adjustment of prices and employment. Again, the assumption of a delayed adjustment provides a useful analysing tool.¹² Delays imply that the adjustment of prices and employment

¹²Adjustment delays for employment can be justified with legal/contractual periods of notice and searching time. The assumption that the firm sets price tags also appears reasonable, and even a short delay between the price decision and the realization of demand can introduce considerable uncertainty. See Smolny (1996) and Andersen (1996).

becomes smoother. In case of an expected decrease in demand, the firm reduces the price and/or employment; in case of an expected increase in demand, the firm increases the price and/or employment; the medium-run fixed capacities again imply an upper bound on the employment adjustment. In case of autocorrelated demand shocks, the model can be interpreted as an error correction model: prices and employment adjust to achieve an optimal utilization of employment.¹³ Alternatively, adjustment costs for prices and employment can be assumed.¹⁴ Then the (medium-run) adjustment of prices and employment with respect to demand shocks depends on the price elasticity of demand: a low absolute value of the price elasticity of demand $|\eta|$ favours quantity adjustments against price adjustments.

2.1.3 Optimal capacities and capital-labour substitution

In the long run, the firm decides on capacities and the capital-labour ratio (and innovations). Since there is uncertainty about the demand shock ε , the realized future values of output, prices, and employment are not known at the time of the investment decision. However, the decision rule for those variables is known: it is given by the solution of the short-run optimization problem above. First, expected (real) output can be written as:¹⁵

$$E(Y) = \int_{-\infty}^{YC} Y(w) \cdot f_{YD} dYD + \int_{YC}^{\infty} YC \cdot f_{YD} dYD \quad (12)$$

f_{YD} is the probability distribution function (p.d.f.) of demand YD . The first integral sums up output in the demand constrained regime, the second integral is output in the capacity constrained regime. Changing integration variables yields:

$$E(Y) = \int_{-\infty}^{\bar{\varepsilon}} Y(w) \cdot f_{\varepsilon} d\varepsilon + \int_{\bar{\varepsilon}}^{\infty} YC \cdot f_{\varepsilon} d\varepsilon \quad (13)$$

f_{ε} is the p.d.f. of the demand shock ε , and $\bar{\varepsilon} = \ln YC - \eta \cdot \ln p(w) - \ln Z$ (see above). Output is determined

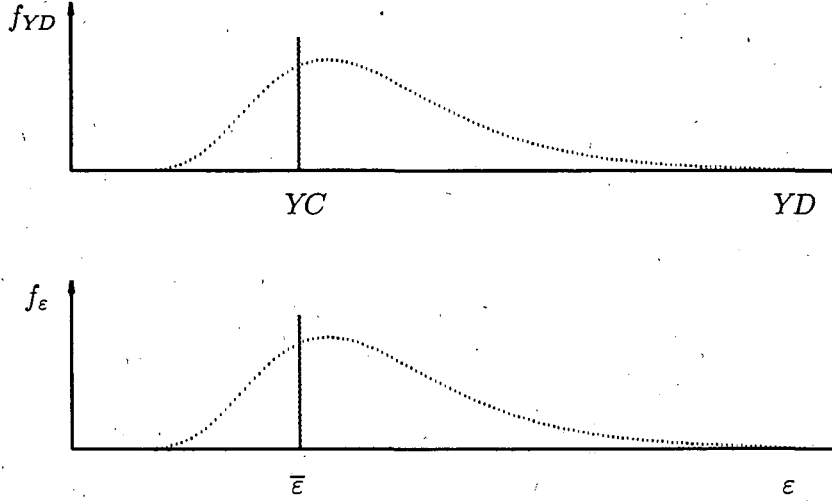
- either by demand at the minimum price $p(w)$, i.e. the first integral in eq. (13) or the horizontal line in figure 1 (demand constrained regime);
- or by capacities YC , i.e. the second integral in eq. (13) or the vertical line in figure 1 (capacity constrained regime);
- there is one value of the demand shock $\varepsilon = \bar{\varepsilon}$ which distinguishes these cases. The choice of capacities can be understood as the optimal choice of the regime probabilities which are determined by $\bar{\varepsilon}$ (see figure 2).

¹³See Nickell (1985) for a discussion of the error correction model.

¹⁴See Barro (1972) and Blanchard, Kiyotaki (1987) for menu costs of price adjustment and e.g. Hamermesh, Pfann (1996) for dynamic models of employment adjustment. Hansen (1996) develops a model with adjustment costs for prices and quantities.

¹⁵Expected output refers to $E_{t-\tau}(Y_t)$, i.e. expected output in t with expectations formed at $t - \tau$, the time of the investment decision.

Figure 2: Optimal capacities



The firm maximizes expected profits which depend on expected nominal output (sales), expected employment, wages, and capital costs. The decision variables are the capital stock K and the capital-labour ratio k . Expected sales result from introducing the corresponding prices from eqs. (5) and (10) into eq. (13); expected employment is given by the corresponding labour requirement; the wage rate is w . The optimization problem can be written as:

$$\max_{K,k} \int_{-\infty}^{\bar{\epsilon}} \left(p(w) - \frac{w}{\pi_l} \right) \cdot Y(w) \cdot f_{\epsilon} d\epsilon + \int_{\bar{\epsilon}}^{\infty} \left(p(YC) - \frac{w}{\pi_l} \right) \cdot YC \cdot f_{\epsilon} d\epsilon - c \cdot K \quad (14)$$

The first order condition with respect to the capital stock K is given by:¹⁶

$$\int_{\bar{\epsilon}}^{\infty} \left(\frac{\partial p(YC)}{\partial YC} \cdot YC + p(YC) - \frac{w}{\pi_l} \right) \cdot \frac{\partial YC}{\partial K} \cdot f_{\epsilon} d\epsilon - c =$$

$$\int_{\bar{\epsilon}}^{\infty} \left(p(YC) \cdot (1 + 1/\eta) - w/\pi_l \right) \cdot \pi_k \cdot f_{\epsilon} d\epsilon - c = 0 \quad (15)$$

Marginal costs are given by the user costs of capital c . Marginal returns to capital are achieved only, if capacities become the binding constraint for output, i.e. if $\epsilon > \bar{\epsilon}$. They are given by the price, minus the price reduction of a marginal increase in output, minus wage costs in the capacity constrained regime. A unique optimum exists, $p(YC)$ is decreasing in YC and K .¹⁷ Since prices are determined

¹⁶The value of both integrands at $\bar{\epsilon}$ is equal.

¹⁷The integrand is equal to 0 at the lower border of the integral.

as¹⁸

$$\ln p(YC) = \ln p(w) + (\bar{\varepsilon} - \varepsilon)/\eta \quad \text{and} \quad p(w) = \frac{w}{\pi_l \cdot (1 + 1/\eta)}$$

the first order condition can be rewritten as:

$$\int_{\bar{\varepsilon}}^{\infty} (\exp[(\bar{\varepsilon} - \varepsilon)/\eta] - 1) \cdot f_{\varepsilon} d\varepsilon - \frac{c}{\pi_k} \frac{\pi_l}{w} = 0 \quad (16)$$

This implies that the optimal value of $\bar{\varepsilon}$ depends only on the price elasticity of demand η , relative capital costs $(c/\pi_k)/(w/\pi_l)$, and the parameters of the p.d.f. of the demand shock ε . Assuming a p.d.f. of ε which is completely characterized by its expected value and its variance σ^2 , it can be written as:

$$\bar{\varepsilon} = h \left(\eta, \sigma, \frac{c}{\pi_k} \frac{\pi_l}{w} \right) \quad (17)$$

It can be shown that a higher share of capital costs relative to wage costs reduces the optimal value of $\bar{\varepsilon}$. In case of high fixed costs, the firm chooses a higher probability of the capacity constrained regime. A higher absolute value of the price elasticity of demand $|\eta|$ also reduces $\bar{\varepsilon}$; both, higher relative capital costs and more competition increase the ratio between the marginal costs and the marginal returns of capital. The effect of uncertainty is analysed for a normal distribution of ε .¹⁹ For this case, the first order condition becomes

$$\int_{\bar{\varepsilon}/\sigma}^{\infty} \{ \exp[(\bar{\varepsilon} - z \cdot \sigma)/\eta] - 1 \} \cdot f_z dz = \frac{c}{\pi_k} \frac{\pi_l}{w} \quad (18)$$

with $z = \varepsilon/\sigma$ standard (normal) distributed. Even for the normal distribution, an analytical solution is not possible, but all characteristics can be analysed by numerical methods.²⁰ It can be shown that an increase in uncertainty σ increases the optimal value of $\bar{\varepsilon}$ for plausible parameter values of the price elasticity of demand, uncertainty about demand shocks, and relative capital costs. The optimal value of $\bar{\varepsilon}$, in turn, determines the optimal expected utilization of capacities U

$$U := \frac{E(Y)}{YC} = \int_{-\infty}^{\bar{\varepsilon}} \exp(\varepsilon - \bar{\varepsilon}) \cdot f_{\varepsilon} d\varepsilon + \int_{\bar{\varepsilon}}^{\infty} f_{\varepsilon} d\varepsilon \quad (19)$$

and the optimal regime probabilities:

$$\text{prob}(YD < YC) = \int_{-\infty}^{\bar{\varepsilon}} f_{\varepsilon} d\varepsilon \quad (20)$$

¹⁸See eqs. (5), (10) and the definition of $\bar{\varepsilon}$.

¹⁹An advantage of the assumption of a normal distribution is that it allows an easy aggregation.

See Lambert (1988), Lewbel (1992), and Smolny (1993).

²⁰Eq. (18) can be reformulated as

$$\exp(\bar{\varepsilon}/\eta + 0.5 \cdot (\sigma/\eta)^2) \cdot \int_{\bar{\varepsilon}/\sigma + \sigma/\eta}^{\infty} f_z dz - \int_{\bar{\varepsilon}/\sigma}^{\infty} f_z dz = \frac{c}{\pi_k} \frac{\pi_l}{w}$$

which can be solved by standard numerical algorithms.

Note that equal regime probabilities, or equality of supply and demand in expected values has no specific meaning in the model, and does not define an equilibrium. The equilibrium regime probability is defined by the optimal solution of the model, i.e. the optimal $\bar{\varepsilon}$ which, in turn, is completely determined by the price elasticity of demand, uncertainty, and relative capital costs. Higher relative capital costs increase the optimal utilization of capacities and reduce the probability of the demand constrained regime; more competition also increases optimal utilization and reduces the probability of the demand constrained regime, since it reduces the returns to capital; more uncertainty reduces optimal utilization, since it becomes more difficult to achieve a higher utilization, and the probability of the demand constrained regime increases.²¹ Both, the expected utilization of capacities and the regime probabilities are independent from expected demand shifts Z ! For the optimal solution, the following properties can be derived. First, expected prices are determined as:²²

$$E(p) = p(w) \cdot \left(1 + \frac{c \pi_l}{w \pi_k}\right) = \left(\frac{w}{\pi_l} + \frac{c}{\pi_k}\right) / (1 + 1/\eta) \quad (21)$$

Expected prices are determined as a constant mark-up over labour and capital costs, i.e. expected prices do not depend on uncertainty σ or on expected demand shocks Z . Therefore, the solution is equal to the solution of the model without uncertainty about demand. Second, expected nominal sales are determined by expected costs and the mark-up:

$$E(p \cdot Y) = \left(E(Y) \cdot \frac{w}{\pi_l} + \frac{c}{\pi_k} \cdot YC\right) / (1 + 1/\eta) \quad (22)$$

The term in paranthesis is the sum of capital costs and expected labour costs. From eq. (22), the average price can be determined as:²³

$$E(p \cdot Y)/E(Y) = \left(\frac{w}{\pi_l} + \frac{c}{U \cdot \pi_k}\right) / (1 + 1/\eta) \quad (23)$$

The average price depends on costs and the expected utilization of capacities: an increase in uncertainty reduces the expected utilization of capacities; a lower utilization of capacities, in turn, exhibits the same effect on average prices as higher capital costs c . Finally, optimal capacities are determined as:

$$\ln YC = \eta \cdot \ln p(w) + \ln Z + h \left(\eta, \sigma, \frac{c \pi_l}{\pi_k w} \right) \quad \text{with} \quad \bar{\varepsilon} = h \left(\eta, \sigma, \frac{c \pi_l}{\pi_k w} \right) \quad (24)$$

²¹ σ affects the relation between average $p(YC)$ and $p(w)$.

²² Expected prices are defined by:

$$E(p) = \int_{-\infty}^{\bar{\varepsilon}} p(w) \cdot f_{\varepsilon} d\varepsilon + \int_{\bar{\varepsilon}}^{\infty} p(YC) \cdot f_{\varepsilon} d\varepsilon$$

Inserting the first order condition for the second integral yields eq. (21).

²³ Eq. (23) is a structural relation between endogenous variables. U is endogenous.

Optimal capacities depend loglinear on the demand shift Z , i.e. expected demand shifts increase all quantities proportionally and do not affect prices or relative quantities. A higher share of capital costs relative to wage costs reduces capacities through the optimal value of \bar{e} . A proportional increase in c and w leaves \bar{e} , the regime probabilities, and capacity utilization unchanged, but increases all prices proportionally. Capacities decrease with elasticity $|\eta|$. That means, the model exhibits linear homogeneity both in prices and quantities.

Less competition reduces capacities through a lower optimal utilization and through higher prices;²⁴ more uncertainty reduces optimal capacities through the lower optimal utilization which exhibits the same effect as higher capital costs.²⁵ The model without uncertainty is included as a special case for $\sigma \rightarrow 0$. In that case, the price is set as a mark-up over total costs and the mark-up is determined by the price elasticity of demand. Optimal capacities and employment are given by the equality of demand YD , capacities YC , and the corresponding employment constraint YL .

The second component of the capacity decision concerns the choice of the optimal capital-labour ratio k . The capital-labour ratio, in turn, determines the productivities of labour and capital. It is assumed that the production function is characterized by constant returns to labour and physical capital. The optimal capital-labour ratio can be derived from differentiating eq. (14) with respect to k . The calculations are tedious but not difficult, and the result is intuitive:

$$-\frac{\frac{\partial \pi_k}{\partial k} \cdot \frac{k}{\pi_k}}{\frac{\partial \pi_l}{\partial k} \cdot \frac{k}{\pi_l}} = \frac{w \cdot U}{c} \cdot \frac{\pi_k}{\pi_l} \quad (25)$$

It can be shown that the optimal relation between the elasticities of the factor productivities of labour and capital with respect to the capital-labour ratio is chosen equal to the ratio of the corrected factor shares. In case of a Cobb-Douglas production function, i.e.

$$Y = \theta \cdot L^\alpha \cdot K^{1-\alpha} \quad (26)$$

this relation is equal to the relative output elasticities of the factors, and the optimal capital-labour ratio is determined as:

$$k = \frac{\pi_l}{\pi_k} = \frac{1-\alpha}{\alpha} \cdot \frac{w \cdot U}{c} \quad (27)$$

i.e. k depends on the relative output elasticities of the factors and relative factor costs. α is the constant elasticity of output with respect to employment. In case of a CES production function, i.e.

$$Y^{-\rho} = \delta \cdot (\theta_l \cdot L)^{-\rho} + (1-\delta) \cdot (\theta_k \cdot K)^{-\rho} \quad (28)$$

²⁴For this evaluation, the model is normalized at $p(=\bar{p}) = 1$ to avoid demand level effects from a change in η .

²⁵There is an extensive literature on the effect of uncertainty on investment. Lucas, Prescott (1971) analysed investment under stochastic demand. A recent overview is Pindyck (1991).

the elasticities of the factor productivities with respect to the capital-labour ratio are given by:

$$\frac{\partial \pi_l}{\partial k} \cdot \frac{k}{\pi_l} = (1 - \delta) \cdot \theta_k^{-\rho} \cdot \pi_k^\rho, \quad \frac{\partial \pi_k}{\partial k} \cdot \frac{k}{\pi_k} = -\delta \cdot \theta_l^{-\rho} \cdot \pi_l^\rho \quad (29)$$

ρ is the substitution parameter, δ is the distribution parameter, and θ_l, θ_k are the efficiencies of labour and capital. For the CES, the first order condition can be rewritten as

$$\frac{w \cdot U}{c} \cdot \frac{\pi_k}{\pi_l} = \frac{\delta \cdot \theta_l^{-\rho} \cdot \pi_l^\rho}{(1 - \delta) \cdot \theta_k^{-\rho} \cdot \pi_k^\rho} \quad (30)$$

and the optimal capital-labour ratio is determined as:

$$k = \frac{\pi_l}{\pi_k} = \left(\frac{w \cdot U}{c} \right)^{1/(1+\rho)} \cdot \left(\frac{\delta}{1 - \delta} \right)^{1/(1+\rho)} \cdot \left(\frac{\theta_l}{\theta_k} \right)^{-\rho/(1+\rho)} \quad (31)$$

with $\rho = 1/\sigma - 1$. σ is the elasticity of substitution. Again, the inefficiency due to uncertainty exhibits the same effects as higher capital costs and favours substitution of labour against capital; the model without uncertainty is contained as a special case for $\sigma \rightarrow 0$ and $U \rightarrow 1$.²⁶

The assumption of a delayed adjustment of capacities and capital-labour substitution extends the standard deterministic model by introducing uncertainty and allows to analyse the resulting inefficiencies.

- Ex ante, the firm must choose capacities and the factor productivities before knowing the location of the demand curve, i.e. there is uncertainty about the demand shock ε . The immediate adjustment is contained as a special case for $\sigma \rightarrow 0$. As compared to this model, optimal capacities and expected output are lower due to the additional costs of underutilization of capacities. Average prices are higher, and uncertainty reduces the optimal capital-labour ratio through the effect on capacity utilization. Optimal capacities are linear in expected demand shifts Z and depend with elasticity η on proportional cost increases.

The optimal regime probabilities, the optimal utilization of capacities, and the optimal capital-labour ratio are independent from the level of costs and from the level of demand. They are determined by relative capital costs, uncertainty, and the price elasticity of demand.²⁷

That means, the model exhibits linear homogeneity both in prices and in quantities.

²⁶In case of a delayed employment (and price) adjustment, the effect on substitution is smaller: a slow adjustment of employment reduces the average utilization of employment. See Smolny (1993,1996).

²⁷In the model, underutilization of capacities and different regimes on the goods market occur without recurrence to constraints on the price adjustment.

- Ex post, different regimes on the goods market and underutilization of capacities are possible. In case of a positive demand shock $\varepsilon > \bar{\varepsilon}$, the firm increases the price; in case of a negative demand shock $\varepsilon < \bar{\varepsilon}$, underutilization of capacities occurs, since variable costs and the finite price elasticity of demand imply a lower bound on optimal prices. Cost shocks increase prices in the short-run only in the demand constrained regime, i.e. for $\varepsilon < \bar{\varepsilon}$.

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

The model also provides a framework to analyse the price and quantity adjustment during the business cycle. Consider a positive demand shock. The short-run response of the firm depends on the availability of capacities: in case of sufficient capacities, the firm increases output and employment, i.e. capacity utilization increases; in case of full utilization of capacities, only the price increases. Now consider the case that the stochastic process generating the demand shocks ε is autocorrelated. Then, a positive demand shock increases output, capacity utilization, employment, and/or prices today. If the firm expects that the higher demand persists, it will, with a delay, increase capacities. That means, the model can be interpreted as an error correction model for investment: capacities adjust, if capacity utilization differs from the optimal value. With higher capacities, output and employment increase further, while capacity utilization and prices should be reduced to the former (optimal) level. That means, unexpected demand shocks should exhibit an effect on prices and capacity utilization only in the short run.

A similar asymmetry results in case of cost shocks. If the firm experiences capacity constraints, output, prices, and employment remain unchanged in the short run; with sufficient capacities, the firm increases the price and reduces output and employment. In the long-run, the firm will reduce capacities which in turn reduces employment and increases the price. The relevant variable for the adjustment from an aggregate view is the share of firms experiencing capacity constraints.

Finally, credit market imperfections can be introduced into the model by specifying a constraint on the borrowing. In this case, the firm chooses a lower capital stock, a higher capital productivity, and a lower labour productivity. In addition, investment depends positively on cash flow and retained profits, i.e. unexpected demand shocks in the past and the price elasticity of demand exhibit an additional effect. The same effect results if capital market imperfections drive a wedge between the market rate and the internal interest rate.²⁸ In addition, an irreversibility of investment decisions can be introduced. In this case, the adjustment of capacities becomes smoother. However, in both cases, the model becomes difficult to solve. In addition, an analytical solution would require restrictive assumptions about linearity and expectation formation.

²⁸Fazzari, Hubbard, Petersen (1988a,b) found that liquidity is important for investment.

2.2 Endogenous innovations

The model so far implies a clear testable hypothesis for the capacity adjustment during the business cycle: capacities should increase in case of an expected increase in demand; an indicator for unexpected demand shocks is the utilization of capacities; lower costs increase optimal capacities, and higher relative capital costs, less competition, and more demand uncertainty reduce optimal capacities; constraints on the borrowing can restrict the adjustment in the short run. The model also provides a framework to analyse the determinants of innovative activities. Innovations can be treated as investments in knowledge capital, analogously to physical investment. The innovation decision is analysed in a less formal framework to keep the model tractable.

Most of the analysis here is confined to the case of discrete innovations. Both, theoretical consideration and the available data-set inhibit the analysis of continuous innovations. First, the data-set contains qualitative data on innovations for a large number of firms from the business survey of the ifo institute. The data are distinguished for the planning and the implementation of product and process innovations. Quantitative data are available only for a subset of the data-set and only for innovation activities (see below).²⁹ It would be desirable to distinguish between the implementation of "small" and "large" innovations, but those information is not contained in the data-set. Second, the implementation of an innovation can be viewed as a discrete decision for the firm from theoretical arguments: indivisibilities of innovation projects make the analysis of "marginal innovations" to some extent artificial; in addition, what can be learned if the comparison of the costs and the returns of an innovation project is replaced by the comparison of the marginal costs and the marginal returns of innovations? The only exception is the analysis of the effects of firm size which is different for the probability to innovate as opposed to the extent of innovative activities. This difference is taken into account below.³⁰ According to these arguments, the probability of an innovation project can be written generally as:

$$\text{prob}(\text{inno}) = \text{prob} \left(\frac{\text{returns}(\text{inno})}{\text{cost}(\text{inno})}, \text{financing constraints} \right) \quad (32)$$

The probability of an innovation project (inno) depends on the incentives to innovate, the costs of innovations, and the possibility to finance it: an innovation is performed only, if returns exceed costs, and if a financing of the innovation project is possible.

²⁹The *implementation* of an innovation should be distinguished from R&D activities. Innovation *activities* include R&D expenditures, but include also costs of implementation.

³⁰An alternative is to develop a theoretical model of the quantitative innovation behaviour. In the empirical model, it can be assumed that firms report an innovation, if innovation activities exceed a borderline value. This borderline value should be different for different firm sizes. However, this procedure also appears artificial.

2.2.1 Innovations and investment

In the analysis, it is distinguished between the implementation of product and process innovations.³¹ In addition, process innovations are distinguished from capital investments.³² It is assumed that capital investment is related to the quantity effects of (homogeneous) capital, and process innovations capture the quality effects. It is further assumed that the costs of capital can be treated as variable costs, i.e. they depend on the level of production, while process innovations impose fixed costs. Complementarities between product and process innovations, and innovations and investment are taken into account in the discussion. Note that it must be distinguished between technological complementarities and the simultaneity of the innovation and investment decision.

It is assumed that process innovations affect the productivities of labour and capital through their efficiency parameters θ_l, θ_k . The firm can produce the same output with less labour and/or capital input and therefore with lower costs.³³ In addition, it is allowed for an induced bias of technological progress for capital-labour substitution. For instance, if a process innovation requires a specialized machine, the firm has an incentive to choose a more capital-intensive production technique.³⁴

Product innovations affect the demand curve. A successful product innovation implies that the quality of the product increases, and demand increases. In addition, new and better products are probably more specialized which protects the firm from competition. In the model, it can be distinguished between effects on the level of demand Z , effects on the price elasticity of demand η , and effects on demand uncertainty σ . In Smolny (1996); it was found, that product innovations increase the level of demand Z and reduce competition, i.e. reduce the absolute value of the price elasticity of demand $|\eta|$: 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. The estimated effect of own product innovations on demand uncertainty σ was not clear,³⁵ but a large share of product innovators in the sector reduces demand uncertainty: the empirical

³¹The distinction between product and process innovations is clear only at the disaggregate level. At the aggregate level, a product innovation of one firm can be a process innovation for another firm.

³²It is difficult to disentangle process innovations and investment in quantitative data due to double-counting. See Schankerman (1981). The problem does not occur for the specification of discrete process innovations and quantitative investment.

³³It could also be distinguished between effects on the scale and/or the distribution parameter of the production function.

³⁴In Smolny (1996), it was found that process innovations (and investment) increase employment.

³⁵Product innovations may increase or decrease uncertainty: on the one hand, the output of an innovation is uncertain, and the firm has less information about the new market; on the other hand, the firm is better protected from competitive pressure, i.e. demand reacts less with respect to changes in competitors' behaviour.

results revealed that both price and output adjustment are much less frequent in those sectors. A large share of process innovators in the sector, on the other hand, increases the frequency of output and price adjustments which indicates a higher price elasticity of demand $|\eta|$ and more demand uncertainty σ .³⁶

Therefore, if innovations would be treated as a predetermined variable for the investment decision, an increase in investment for innovating firms is expected.³⁷ demand shifts due to product innovations increase optimal capacities proportionally; the positive effect on the level of demand was found to outweigh the negative effect from the lower price elasticity; a lower uncertainty of demand shocks makes it easier to achieve a higher utilization which implies a further positive effect on capacities; since process innovations reduce production costs, prices should decrease and optimal output and capacities should also increase.

However, the possible simultaneousness of the investment and innovation decision, and complementarities between product and process innovations, and between innovations and investment should be taken into account. First, new products often require new production processes, and new production processes allow to produce better products. For instance, a higher quality of the product can be achieved only with a new, computer-controlled machine, or, taken the other way round, a computer-controlled machine permits to produce a higher quality of the product. Second, both product and process innovations may be complementary with capital investment. For instance, if the firm plans to expand capacities, it has more incentives (i.e. less costs) to implement a process innovation. In addition, if the production technique is specialized, capital investment opens the opportunity to introduce a new product.³⁸

The complementarity of innovations and investment implies that the probability to implement an innovation depends positively on the amount of investment, and the amount of investment depends positively on the implementation of innovations. Taken differently, the same incentives and constraints, that drive capital investment also affect innovation behaviour, and the determinants of innovations also affect investment. Since the complementarity between capital investment and process innovations is probably stronger, the determinants of those variables are expected to be more similar. Taken together, it can be concluded that endogenous innovations increase investment, and growing markets favour innovations!³⁹

³⁶ Effects of innovations on the market structure are discussed in Phillips (1971), Vickers (1986), Levin, Reiss (1988), Geroski, Pomroy (1990), Pohlmeier (1992), and Geroski (1995).

³⁷ Lach, Schankerman (1989), Lach, Rob (1992), and Nickell, Nicolitsas (1996) develop models where current R&D causes future investments.

³⁸ It should be distinguished between "technological complementarities" and the simultaneity of the innovation and investment decision: it is one argument, if positive gross investment lowers the costs of process innovations, or process innovations increases the returns to capital investments; it is another argument that process innovations increase optimal output and optimal capacities which requires more capital investment.

³⁹ These arguments could be introduced into the formal model of the investment decision by allowing for an effect of (gross) investment on the costs of innovation projects. However, in this case, the model becomes dynamic; the derivation of a formal model of innovation

An additional argument for an effect from an expected increase in demand on innovations can be derived from the long-run nature of innovation projects. The costs of innovations can be viewed as sunk costs. On the other hand, they increase knowledge permanently. This implies that on growing markets firms can expect to earn returns from the innovation for a longer time period. This argument implies also that firms that must fear to be driven out of the market have less incentives to innovate.⁴⁰

A related area of research on the determinants of innovations are the effects of the business cycle. This connects the microeconomic analysis of the determinants of innovations to the macroeconomic discussion of the relation between growth and the business cycle. If the business cycle affects innovations, changes in aggregate demand affect productivity and output permanently.⁴¹ The assumption of a delayed adjustment of capacities and innovations applied in the model here provides a consistent framework to discuss demand-induced effects. Four different arguments can be distinguished: first, the complementarity between capital investment and innovations implies a positive effect from capacity utilization on innovations. Therefore, demand shocks which increase capacity utilization and increase the optimal capital stock also favour innovations. Second, increasing demand in the past indicates growing markets also in the future which favours innovations. Third, extraordinary cash flows and profits in case of a high capacity utilization and higher prices permit to finance a larger share of innovation expenditures from retained profits in period of excess demand. In addition, banks are less hesitant to finance risky innovation projects in case of high profits and a larger share of internal finance.

On the other hand, it can be argued with opportunity costs and intertemporal substitution to derive a positive effect from periods of slack demand on innovations. Non-production activities such as reorganizations of production processes, R&D, and training exhibit less opportunity costs in case of excess capacities; in addition, the incentives to increase demand by better products are higher in case of underutilization of capacities.⁴² Therefore, the effect from the business cycle on innovations cannot be derived without ambiguity from theoretical arguments; it must be left to the empirical analysis.

2.2.2 Firm size and market structure

A main difference between capital investments and innovations, i.e. investments in knowledge, is that the costs of the former are variable costs, while the latter impose at least partially a fixed cost. The costs of an improvement of a production process or a product do not increase proportionally with the level of production.

behaviour is beyond the scope of the work here.

⁴⁰ A similar argument can be derived from an irreversibility of investment decisions.

⁴¹ For a discussion, see Cambell, Mankiw (1987,1989), Stadler (1990), Stiglitz (1993), Beaudry, Koop (1993), Caballero, Hammour (1994), Geroski, Walters (1995), and Evans, Honkapohja, Romer (1996).

⁴² For a detailed discussion, see Bean (1990) and Aghion, Saint Paul (1993).

This implies that large firms exhibit a relative advantage as compared with small firms, since they can spread the costs on a larger quantity of output.⁴³ A related argument in favour of large firms are internal spillovers and complementarities of R&D activities, or economies of scope. Similarly, it can be argued with minimum sizes or scale economies of R&D departments. A counter-argument is that in large firms the incentives for individual scientists and entrepreneurs are lower. The benefits of individual effort and the efficiency of control diminishes, and bureaucratic inertia increases with firm size.⁴⁴

A third argument which favours large firms is based on the risk associated with innovations, and credit market imperfections. Due to asymmetric information and adverse incentives, commercial banks hesitate to finance risky innovation projects of small firms.⁴⁵ Large firms have easier access to internal finance; in addition, they perform many innovation projects which spreads the risk and reduces the risk for the bank. In addition, it can be argued that large firms can achieve lower interest rates. Note that credit market imperfections and internal spillovers imply that the relevant firm size for innovations is those of the whole firm, while in case of fixed costs, the output of the respective product or product group is important. Note also that it should be distinguished between the effects of firm size on the *amount* of R&D or innovation expenditures, and on the *probability* of innovations. It is evident that the probability of at least one innovation is higher for large firms; it is less clear, whether innovation activities increase more or less than proportionally with firm size.

In addition, firm size can affect the composition of innovation activities, i.e. the relative extent of product and process innovations. Cohen, Klepper (1996) argue that it is more difficult to licence or sell process innovations than product innovations. According to this argument, large firms should exhibit a comparative advantage for process innovations. On the other hand, it can be argued that product innovations are to a larger extent fixed costs than process innovations which are at least partially related to investment expenditures. This would give large firms a comparative advantage for product innovations.

Another area of research on innovations is the analysis of the effects of market power.⁴⁶ According to Schumpeter (1934,1942), the ability to earn large profits and expectations of a temporary monopoly cause firms to introduce innovations. However, innovations of other firms destroy the monopolistic situation on the product market, and the process of "creative destruction" is the driving force of technological change.⁴⁷ One argument in favour of innovations on monopolistic

⁴³This argument implies an imperfect licence market for innovations.

⁴⁴See Cohen, Levin (1989). Acs, Audretsch (1987) found that small firms have an advantage in sectors with a high proportion of skilled labour. In addition, Acs, Audretsch, Feldman (1994) found that small firms are the recipients of spillovers from larger firms and universities. For a detailed discussion of firm-size effects on innovation, see Rottmann (1995,1996).

⁴⁵See Stiglitz (1993) and King, Levine (1993). Himmelberg, Petersen (1994), Winker (1996), and Harhoff (1996a) found financing constraints for innovations of small firms.

⁴⁶For an overview, see Kamien, Schwarz (1975) and Cohen, Levin (1989).

⁴⁷See Ramser (1986), Grossman, Helpman (1991b), Aghion, Howitt (1992), Caballero, Jaffe

markets are monopoly profits that permit an easier finance of risky innovation projects. In addition, an oligopolistic market structure could make rival behaviour more stable and predictable. These arguments should be distinguished from the expectation of temporary market power as an incentive for innovations, i.e. it must be distinguished between the effects of ex ante market power on innovations, and ex post market power through innovations. In the model here, the effects of market power depend on the effects of innovations.

- If a product innovation implies a simple shift of demand Z , less competition, i.e. a smaller value of the price elasticity of demand $|\eta|$, implies a larger increase in profits than in the competitive case. In this case market power favours innovations.
- However, if a better quality of the product means that the firm can sell the same quantity at a higher price, the effect of an innovation on demand depends on the price elasticity η :⁴⁸ on competitive markets, a larger increase in demand in case on an innovation can be expected. In this case, the incentive to innovate is larger on competitive markets.
- The same holds for process innovations which reduce production costs: more competition implies that a firm can achieve a larger increase in the market share and of profits with a reduction of costs and the price.⁴⁹

In addition, product innovations change the market structure. The intended reduction of the price elasticity of demand is an important incentive to introduce innovations. However, it is not clear how existing market power changes the incentives of innovative activities in this case. On the one hand, it can be argued that on highly competitive markets, temporary market power vanishes quickly. Therefore, the incentive to innovate is low. On the other hand, on markets with a small number of (large) firms, each firm watches each others innovations activities more closely, and reacts on innovative activities. Then, the incentive to innovate is smaller on oligopolistic markets. In addition, a monopolist has less incentives to introduce a new product, if he already has a successful product on the market. New products destroy the monopolistic profits of existing products. Finally, it was argued that "... insulation from competitive pressure breeds bureaucratic inertia and discourages innovation."⁵⁰ Taken together, existing market power tends to lower the incentives to innovate, but increases the ability to innovate.⁵¹

(1993), and Barro, Sala-i-Martin (1994).

⁴⁸That means, the demand function can be written as:

$$\ln YD = \eta \cdot \ln(p/q) + \ln Z + \varepsilon$$

q is the quality of the product which increases with product innovations.

⁴⁹In the model here, process innovations that affect costs proportionally and product innovations that affect only the level of demand are basically equivalent.

⁵⁰Cohen, Levin, (1989), p. 1075 and Scherer, Ross (1990).

⁵¹It should be distinguished between effects of firm size and effects of market power measured by

2.2.3 Spillovers and technological opportunity

A final area of research on the relation between market structure and innovations is the question of the appropriability of the returns from innovations and knowledge spillovers from other firms.⁵² On the one hand, spillovers from other firms reduce the costs of own innovations. For instance, spillovers from other firms (and hints from customers) are among the mostly cited sources of informations for innovations in the ifo firm panel.⁵³ In this sense, own and others innovations can be viewed as complements.⁵⁴ On the other hand, spillovers reduce the returns of own innovations: if other firms can imitate quickly, demand increases and monopolistic situations on the goods market are short-lived. These arguments imply that the probability of innovations also depends on innovations of other firms.⁵⁵

A different argument in favour of an effect from others innovations on the costs and returns of own innovation projects stems from technological opportunity. First, innovations shift the technological frontier for the whole industry outwards, and make it easier for other firms to follow, i.e. innovations *affect* technological opportunity. Second, a large share of innovators in a sector is an *indicator* for technological opportunity.⁵⁶ These arguments are related to the technology of innovation, i.e. the "knowledge production function", as opposed to the market structure arguments above.

Another variable which is related to technological opportunity is the own innovation behaviour in the past. First, innovative activities in the past increase the stock of knowledge which is thought to exhibit a positive impact on the productivity of innovative activities in the present.⁵⁷ Firms can build on historically accumulated knowledge and exhibit advantages on the learning curve. In addition, innovative success in the past indicates the specific inventive capability of firms. For both variables, i.e. others innovations and own innovations in the past, it is difficult to distinguish whether they exhibit an *effect* on innovations, or whether they are only *indicators* of opportunities for innovations.

The innovative success in the past may also exhibit a negative effect on today's innovations: a firm has less incentive to introduce a new product, if it has already

the price elasticity of demand. Both capture to some extent market power, but the arguments are different. The (common) analysis in terms of market shares does not allow to identify the different effects of firm size, on the one hand, and market power, on the other hand, on innovations.

⁵²Technology spillovers are central for many models of endogenous growth and received a lot of attention in the recent literature. See Bernstein, Nadiri (1986), Jaffe (1986,1988), Levin, Klevorick, Nelson, Winter (1987), Cohen, Levinthal (1989), Segerstrom (1991), Nadiri (1993), and Young (1993).

⁵³See also Harhoff (1996b), who reports the same result from the innovation panel of the ZEW.

⁵⁴For a discussion, see Cohen, Levinthal (1989).

⁵⁵It implies also that others innovations are endogenous: other firms' innovation decisions depend on own innovations. The theoretical and empirical evidence whether spillovers increase or decrease *equilibrium* innovations is ambiguous.

⁵⁶Empirically, it is difficult to distinguish between easiness of imitation and technological opportunity.

⁵⁷See Flaig, Stadler (1994,1996) and Hall, Mairesse (1995).

a successful product in the market. Similarly, others innovations may also exploit the technological opportunities, and better products and lower prices of competitors tend to decrease demand.⁵⁸ Therefore, the effects of others innovations and own innovations in the past on current innovations cannot be determined unambiguously from theoretical arguments; they are determined within the empirical model.

2.3 Estimation strategy

In the empirical model, it is tested to what extent these arguments of the theoretical model can be related to the observed innovation and investment behaviour of West-German manufacturing firms. The empirical specification is build on the assumption that firm-specific demand shocks are autocorrelated. The firms exploit this autocorrelation when forming their expectation about future demand.⁵⁹ This assumption allows to use the degree of utilization today as an indicator for expected demand tomorrow: there is some value of expected demand, where firms would leave capacities unchanged. This value corresponds to a certain (average) degree of utilization. If the actual utilization is higher, the firms should increase capacities, and vice versa. That means, the basic specification for investment can be interpreted as an error correction model, and the test of the impact of the capacity utilization rate on investment provides a test for the appropriateness of these assumptions.

The endogenous variables in the empirical model are the implementation of product (prod) and process innovations (proc), the amount of innovation expenditures relative to sales ie/s , and the share of investment in sales i/s . In addition, it is tested for an effect of the explanatory variables on innovation plans and innovation impediments. According to the simultaneousness of the investment and innovation decision, and the complementarity of investment and innovation, the explanatory variables in the empirical model are the same for investment and innovation. That means, a reduced form of the long-run model is estimated. In addition, some direct evidence on the complementarity of innovations and investment and on the dynamics of innovation behaviour is drawn from cross-tabulations.⁶⁰

In the empirical analysis, the identification of the model is sought through lagged values of the explanatory variables, i.e. the restrictions from the theoretical model are exploited for the estimation. The decision on output, prices, and employment takes place after the decision on investment and innovation; therefore, the lagged values of output, prices, and capacity utilization can be treated as predetermined for the innovation and investment behaviour. The identification

⁵⁸In addition, others innovations change the market structure.

⁵⁹That means $E_{t-\tau}(\varepsilon_t) = \rho \cdot \varepsilon_{t-\tau}$.

⁶⁰The estimation of a dynamic simultaneous model of innovation and investment is beyond the scope of the work here and is left for future work. See e.g. Pohlmeier (1989) and Flaig, Stadler (1996).

of the model through lags of the explanatory variables in panel data is disputable in case of autocorrelation, but the model implies a clear recursive structure which should be exploited for the estimates. In addition, most variables are implicitly specified as changes.

The explanatory variables can be grouped together as those related to the demand conditions at the firm level, those related to firm size and the market structure, and those related to knowledge spillovers and appropriability:

The first explanatory variable is the lagged value of the degree of utilization of capacities DUC . For investment, this describes the basic adjustment model for capacities. Innovations should depend on capacity utilization through the complementarity with capital investment, through the effect of capacity utilization on cash flows and profits, and through the expected increase in product demand. A countereffect on innovations could stem from lower opportunity costs during recessions and intertemporal substitution. Additional variables which capture the demand conditions, cash flow, and profits in the past are price increases Δp and output increases Δy . However, price increases in the past may also indicate market power. A further direct indicator of growing markets are the medium-run (about 5 years) demand expectations of the firm which are also contained in the data-set. As a final business cycle indicator, the average capacity utilization of the other firms in the sector DUC^s is used as an explanatory variable. This should reflect an increased competition from other firms on the market which may reduce demand. In addition, it is a determinant of others future investment and innovation behaviour.

Second, it is tested for an effect of firm size. Firm size should increase innovations through fixed cost arguments and through the financing conditions. A countereffect could stem from bureaucratic inertia in large firms. In addition, there is a simple scale argument for an effect on the probability of at least one innovation project. Therefore, here the quantitative information about innovation expenditures is important to determine, whether innovation activities increase more or less than proportionally with firm size. A firm-size effect on investment could stem from credit market imperfections and the complementarity with innovations. As an empirical measure of firm size, dummy variables according to the number of employees for a specific product or a product group are constructed. In addition, a dummy variable is created for diversified firms, i.e. if the number of employees for the product is less than half of the number of employees in the whole firm, on average. A positive effect from diversification would indicate the importance of credit market imperfections and/or internal spillovers of R&D activities. Again, the average size of the other firms in the sector is included as an additional explanatory variable. The firm size in relation to the size of other firms is an indicator for the market power of the firm, i.e. the price elasticity of demand, and may also approximate the appropriability conditions. The relative impact of the firm size of competitors should give some hints on the total firm-size effect on innovations.

Third, an indicator of market power is constructed from the price-setting behaviour of the firm. In the theoretical model, a straightforward measure of the price elasticity of demand is given by the price/cost relation. In the model, prices are determined as mark-up over costs, and the mark-up is determined by the price elasticity of demand. That means, market power can be measured by market behaviour.⁶¹ However, the data-set does not contain informations on firm-specific cost conditions. In addition, past periods' profits can also result from unexpected demand shocks. Therefore, an indicator for the price elasticity of demand is constructed from the frequency of price and output adjustments: less competition favours output adjustments against price adjustments; therefore, a low frequency of price adjustments and a high frequency of output adjustments indicates a low absolute value of the price elasticity of demand.⁶²

Fourth, it is tested for an effect of innovations of other firms in the sector. The impact of this variable is related firstly to technology spillovers and the appropriability of the returns of innovations; second, others innovations both indicate and affect the technological opportunities for innovations; third, it is an indicator of the prices and the qualities of competitors' products. The test on the impact of this variable should reveal whether positive spillover effects outweigh negative displacement effects from competition. In the empirical model, others innovations as well as market power are treated as predetermined variables.

A final indicator of market structure, market size, and technological opportunity is given by the information, whether the product is also exported. This captures, on the one hand, the competitiveness and therefore the quality of the product, i.e. it indicates the inventive capability of the firm. In addition, the world market is another source of spillovers. On the other hand, if the product is sold on the world market, competition is probably stronger and the market power of the firm is lower, *ceteris paribus*.⁶³

In most cases, the theoretical arguments do not allow to derive unambiguous effects from these variables on the innovation and investment behaviour of the firm. The relative importance of these arguments is estimated within the empirical model.

⁶¹For a discussion, see Hall (1988). Harhoff (1996a) derives a similar result for oligopolistic markets.

⁶²For a more detailed discussion, see Smolny (1996).

⁶³See Entorf, Krader, Pohlmeier (1990), Entorf, Pohlmeier (1990), Aitken, Hanson, Harrison (1994), Barro, Sala-i-Martin (1995), and Nadiri, Kim (1996). The export activity in the past is also treated as a predetermined variable in the empirical model.

3 Data and empirical specification

3.1 Data

The data base for the empirical application consists of a panel of West-German manufacturing firms over 13 years (1980–92), the ifo firm panel.⁶⁴ The data stem from three sources:

- The business survey (Konjunkturtest) of the ifo institute which contains detailed monthly and quarterly informations on the short-run demand and supply conditions. Once a year, the questionnaire includes a question on innovations. 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 (product groups) in the panel; the panel consists of 2405 observation units from 1982 firms. Most of the data from the business survey are qualitative.
- The innovation survey (Innovationstest) of the ifo institute which contains detailed data on innovation activities, innovation targets, innovation impediments, sources of information, and the technology area. The innovation survey is annually and related to the product level. The survey also contains quantitative data on innovation activities.
- The investment survey (Investitionstest) of the ifo institute which contains detailed data on investment activities. The investment survey is annually and related to the company level. From this survey, the quantitative data on investment, employment, and sales were used.⁶⁵

Note that the composition of firms in the ifo firm panel is not representative as compared with total manufacturing. The sectoral distribution of the firms is captured rather accurately (see table 11 in the appendix), but small firms are underrepresented and large firms are strongly oversampled.⁶⁶ This need not be a problem, but it should be hold in mind when interpreting the results. The size class distribution of the firms in the panel is reported in figure 3. In the upper plot, the size class distribution of the firms according to the number of employees

⁶⁴For a detailed description of the data, see Schneeweis, Smolny (1996) and Smolny (1996). The surveys are described in Oppenländer, Poser (1989). I like to thank the ifo institute, München, for providing the data.

⁶⁵The matching of the data was part of the research project “Growth and Innovation”. Until recently, most empirical work on innovations with the ifo data was constrained to the business survey data. See König (1987), Entorf, Pohlmeier (1990), Zimmermann (1991), Laisney, Lechner, Pohlmeier (1992), Pohlmeier (1992), König, Laisney, Lechner, Pohlmeier (1993), Flaig, Stadler (1994), and Rottmann (1995,1996). Winker (1996), Rottmann, Ruschinski (1996), and Smolny, Schneeweis (1996) are based on the matched data from the ifo firm panel. A similar data-set for Germany is constructed at the ZEW (Zentrum für Europäische Wirtschaftsforschung) in Mannheim. However, the time span is still short, the starting year of the survey is 1993. See Felder, Licht, Nerlinger, Smid (1993).

⁶⁶See Schneeweis, Smolny (1996).

at the firm level is shown. Average employment per firm \bar{l} during the sample period for all firms is about 1400, and about 80 percent of the firms are within the range $20 \leq \bar{l} < 2000$. Therefore, it can be concluded that most observations stem from medium-size firms, despite the oversampling of large firms. The largest firms are within the sectors car manufacturing (33) and chemicals (25) (see table 20 on page 83 in the appendix). A sector list is contained in table 11 in the appendix.

The plot below depicts the distribution of the firms according to the number of employees for the specific product or product group in the survey. Average product employment is slightly below 500, and only one percent of the observations stem from products with more than 5000 employees. The minimum average product employment for the sectors is about 100 in the wood industry (26) and the plastics industry (45), the maximum is about 2700 in car manufacturing and chemicals.⁶⁷

In the bottom plot, a measure of diversification is reported, i.e. the distribution of the relation between the number of employees at the product level and at the firm level is depicted.⁶⁸ In some cases, the product in the survey is only a small part of the firm, but in most cases, it is the most important product of the firm: in 25 percent of cases, product level employment is more than 90 percent of firm-level employment; in 67 percent of the cases, the product is more than half of the firm. The largest share of diversified firms is in the sector electrical products (34).

In the empirical model for innovations, firm size is specified by dummies according to the average number of employees \bar{l} at the product level. In addition, a diversification dummy is included for those firms, where product level employment is below half of firm-level employment. Note that the data on investment are available only at the firm level, while data for the explanatory variables of the model are available only at the product level. Therefore, for the investment equation, a constrained sample of those firms is constructed, where product level employment is at least half of firm-level employment. For the investment equations, firm size is measured by dummies according to the average number of employees at the firm level. Finally, competitors' firm size is specified as the average number of employees of the other firms in the sector.

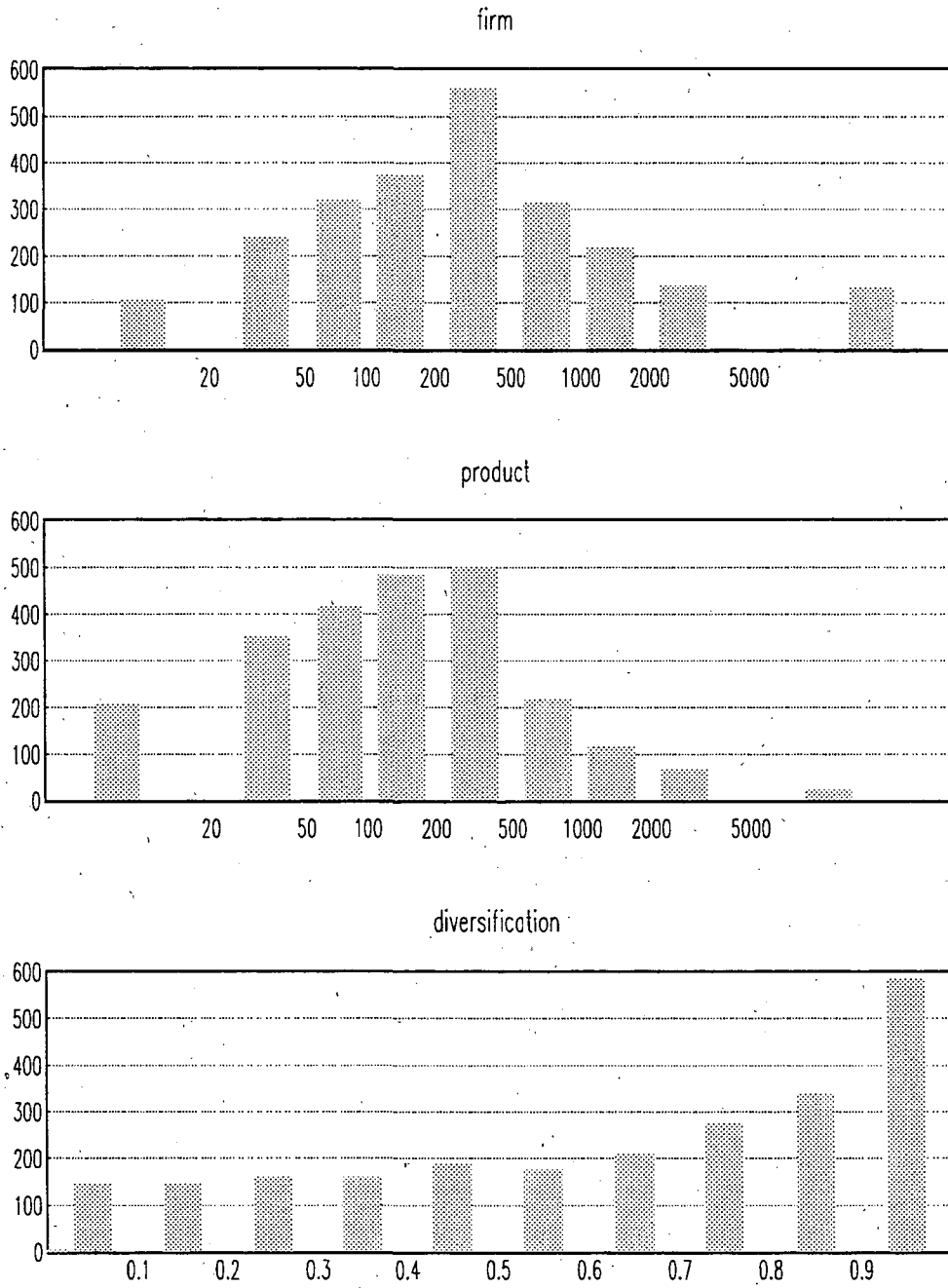
Once a year, in december, the business survey contains a question about innovations. In the survey, innovations are defined as novelties or essential improvements of the product or the production technique. The firms are asked, whether innovations within the year for the respective product were

- implemented (prod, proc)
- stopped (stop)
- planning stage completed (planc)

⁶⁷See again table 20 in the appendix.

⁶⁸Some firms have more than one product in the survey. The number of employees at the firm level always exceeds the number of employees at the product level, i.e. the data are consistent.

Figure 3: Firm size and diversification



Source: ifo firm panel, 1982 firms, 2405 products, average for 1980-92

- still in planning stage (plan)
- not intended (notint)

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. While multiple answers for this question are possible (i.e. for different innovation projects), most firms made only one choice for product innovations and one choice for process innovations.⁶⁹ multiple answers were given in only about 15 percent of the observations, the most common combination was innovations implemented and innovations still in planning stage.

In figure 4 and figure 5, the relative frequency of product and process innovations is reported. It can be seen that most firms in the panel innovate, at least in some years. Only about 400 (from 2405) firms never implemented a product innovation, only about 300 firms never implemented a process innovation, and only about 200 firms never implemented an innovation.⁷⁰ Correspondingly, about 250 (140) firms implemented a product (process) innovation in each year. The relative frequency of both product and process innovations is distributed quite evenly within the range $\{0, 1\}$, the average is about 0.5, i.e. on average, firms implement a product and a process innovation every second year (see also table 1). Therefore, it can be concluded that the specification of innovations as a discrete decision appears to be consistent with the data.

The data also reveal that more than 80 percent of the firms never stopped a product or a process innovation. About one half of the firms never reported completed innovation plans, and more than 700 firms never reported innovations in planning stage. This accentuates that most firms gave only a single answer for each, product and process innovations in the survey. In addition, only about 100 firms always reported that they did not intend a product (process) innovation.

In the empirical model, it is tried to explain the implementation of innovations. In addition, the difference between the determinants of innovation implementations and innovation plans, and the determinants of a cancelling of an innovation project can give important hints on the sources of innovation impediments. Therefore, all variables from this question are used as endogenous variables in the empirical model.

In table 1, annual averages and averages according to the firm-size classes for innovations are reported.⁷¹ It can be seen that apart from the first year, this is the starting year of the question,⁷² the share of innovators slightly increased

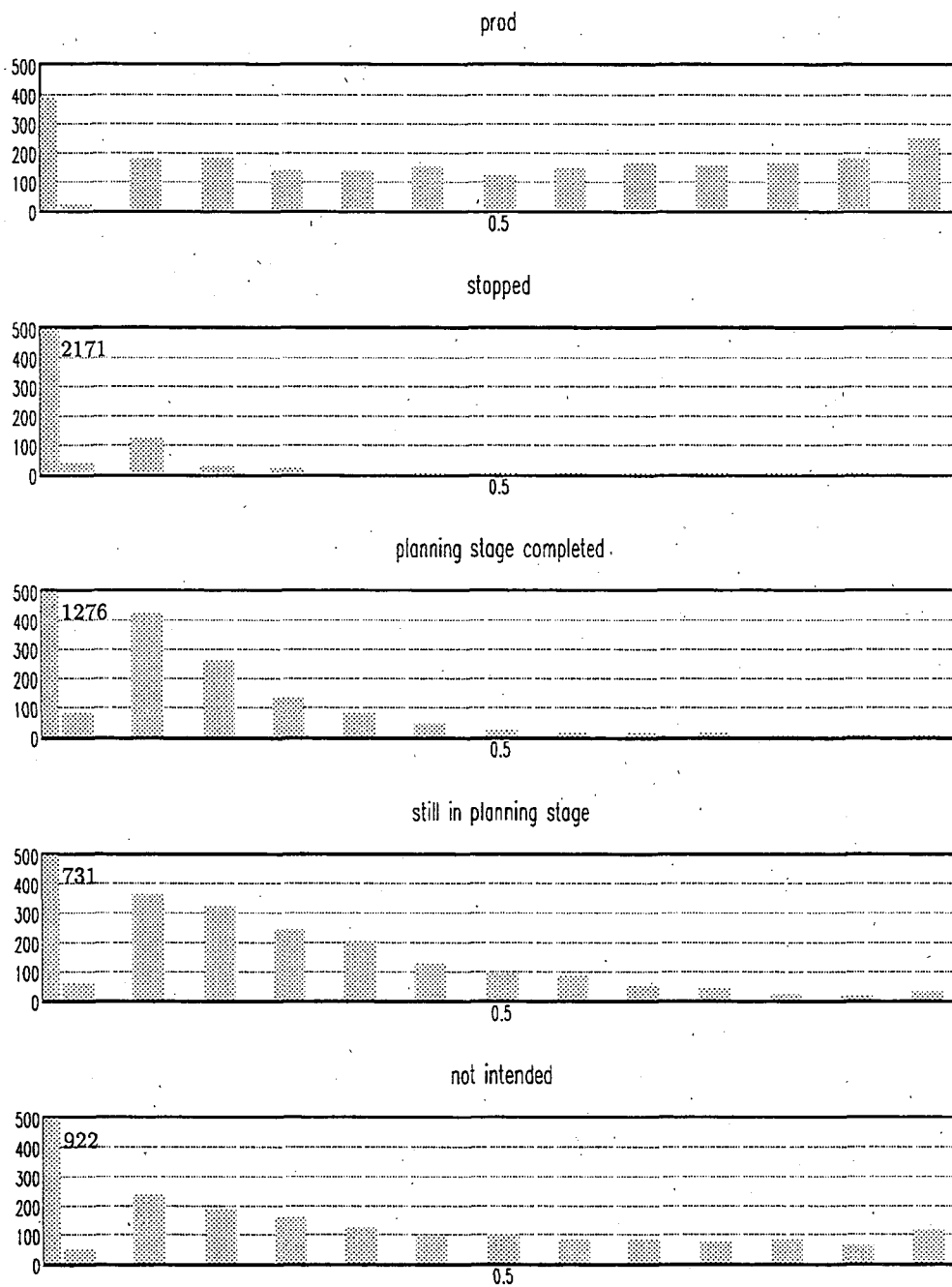
⁶⁹The estimation sample includes all firms that have at least one answer in those ten possible answers, therefore, some firms in the sample do give no information on either product or process innovation.

⁷⁰See also figure 7 and tables 13 and 14 in the appendix. *both* denotes firms that implemented a product and a process innovation, and *inno* denotes that the firm introduced either a product or a process innovation.

⁷¹The corresponding sectoral data are reported in table 12 on page 74 in the appendix.

⁷²Note the lower number of observations for 1980.

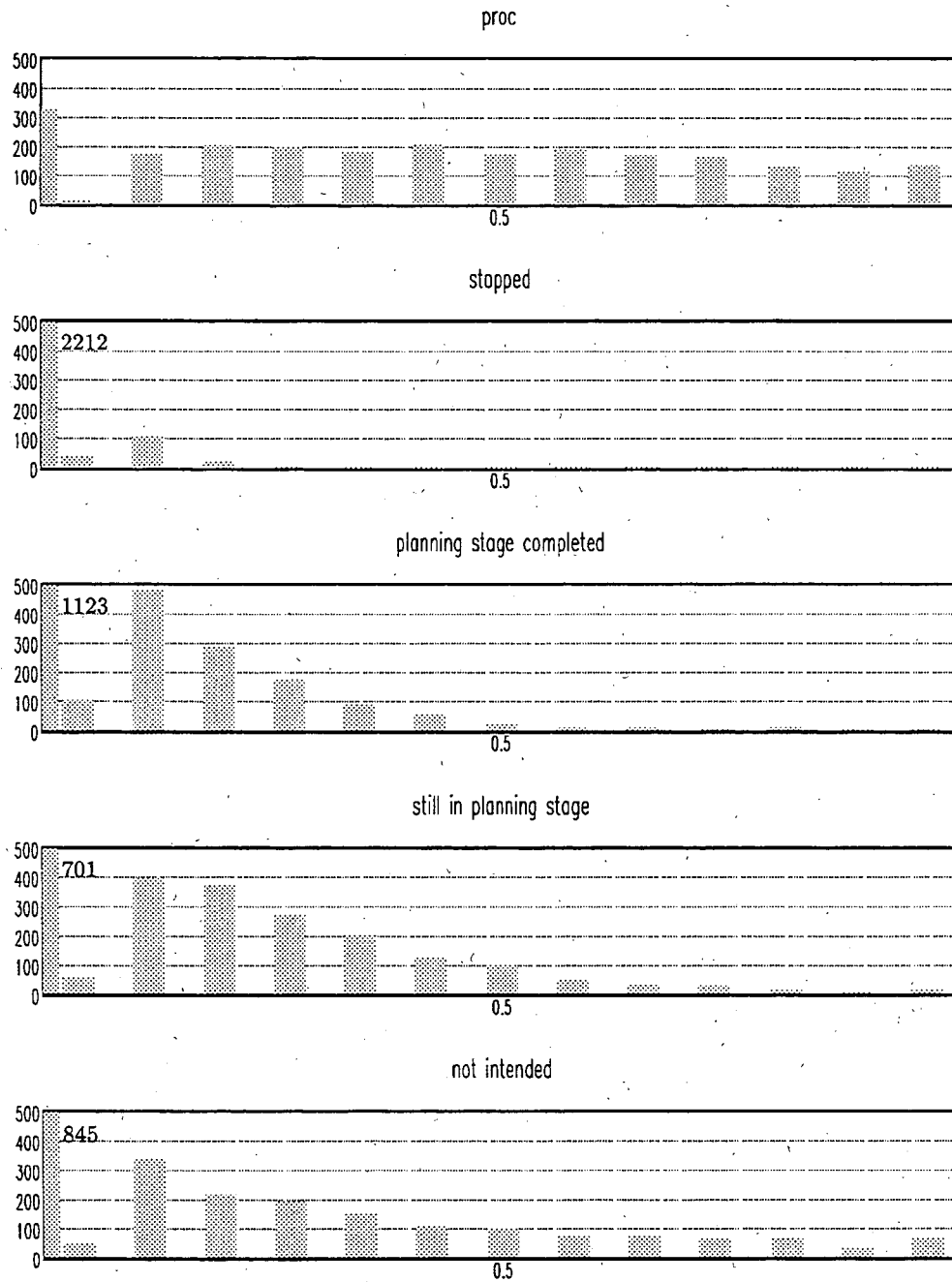
Figure 4: Product innovations



Source: ifo firm panel, 2405 firms, 13 years (1980-92)

The first bar denotes 0, the class width is 1/13.

Figure 5: Process innovations



Source: ifo firm panel, 2405 firms, 13 years (1980–92)

The first bar denotes 0, the class width is 1/13.

Table 1: Product and process innovations

	product innovations					process innovations					
year	prod	stop	planc	plan	notint	proc	stop	planc	plan	notint	obs
1980	0.506	0.027	0.164	0.261	0.234	0.496	0.022	0.123	0.261	0.193	1007
1981	0.427	0.020	0.092	0.253	0.317	0.396	0.013	0.106	0.230	0.295	1860
1982	0.471	0.020	0.104	0.237	0.283	0.411	0.017	0.108	0.207	0.272	1866
1983	0.464	0.014	0.093	0.228	0.269	0.415	0.012	0.114	0.203	0.248	1924
1984	0.494	0.008	0.108	0.226	0.263	0.442	0.005	0.129	0.193	0.232	1912
1985	0.498	0.011	0.104	0.214	0.253	0.449	0.006	0.120	0.215	0.222	1897
1986	0.493	0.011	0.115	0.221	0.250	0.469	0.008	0.118	0.196	0.245	1858
1987	0.506	0.010	0.105	0.221	0.245	0.463	0.004	0.113	0.223	0.221	1766
1988	0.521	0.009	0.105	0.224	0.236	0.494	0.009	0.119	0.219	0.199	1736
1989	0.542	0.014	0.110	0.212	0.219	0.519	0.008	0.128	0.204	0.181	1710
1990	0.512	0.017	0.109	0.209	0.240	0.492	0.008	0.120	0.211	0.196	1647
1991	0.533	0.012	0.107	0.210	0.235	0.482	0.008	0.119	0.201	0.210	1573
1992	0.518	0.016	0.111	0.205	0.248	0.479	0.014	0.116	0.215	0.236	1481
size											
$\bar{l} < 20$	0.189	0.016	0.028	0.140	0.561	0.198	0.015	0.049	0.133	0.485	1559
$20 \leq \bar{l} < 50$	0.284	0.011	0.072	0.171	0.415	0.304	0.010	0.079	0.170	0.340	3072
$50 \leq \bar{l} < 100$	0.410	0.012	0.078	0.212	0.301	0.384	0.012	0.098	0.201	0.261	3839
$100 \leq \bar{l} < 200$	0.522	0.011	0.102	0.224	0.213	0.486	0.007	0.115	0.216	0.199	4537
$200 \leq \bar{l} < 500$	0.593	0.014	0.121	0.231	0.179	0.517	0.009	0.130	0.220	0.176	5026
$500 \leq \bar{l} < 1000$	0.677	0.018	0.169	0.281	0.123	0.596	0.011	0.153	0.263	0.137	2089
$1000 \leq \bar{l} < 2000$	0.668	0.018	0.142	0.259	0.144	0.643	0.004	0.160	0.226	0.133	1195
$2000 \leq \bar{l} < 5000$	0.810	0.028	0.255	0.368	0.084	0.888	0.017	0.259	0.319	0.070	642
$5000 \leq \bar{l}$	0.948	0.026	0.319	0.453	0.009	0.706	0.013	0.310	0.418	0.022	232
total	0.497	0.014	0.108	0.224	0.255	0.459	0.010	0.118	0.212	0.229	22237

Source: ifo firm panel.

over time until the beginning of the nineties. On average, each year less than 2 percent of the firms report that they had an innovation project stopped. This number is larger in the first years and in the last year which were recession years, i.e. years with a decreasing utilization of capacities and lower output growth.

The classification according to firm size shows a strong positive relation between the proportion of innovators and firm size. The share of innovators is below 30 percent for firms with less than 50 employees, and exceeds 80 percent for the large firms with more than 2000 employees. Correspondingly, large firms much less often report that they do not intend innovations, and more often report (completed) innovation plans.⁷³ On average, in only about 25 percent of the observations, the firms report that they do not intend an innovation. This accentuates that the additional information on innovation plans is important and can reveal additional insights about innovation incentives and impediments.⁷⁴

Finally, the sectoral innovation behaviour reveals remarkable differences (see table 12 in the appendix). The highest shares of innovators with above 60 percent are observed in sector 32 (machinery), sector 34 (electrical products), and sector 411 (fine ceramics), the lowest share with 20 (30) percent is observed for product (process) innovations in the wood industry (26). The sectoral correlation of product and process innovations is large.

The ifo firm panel contains, in addition, detailed information on innovation activities from the innovation survey of the ifo institute.⁷⁵ These data are available only for a sub-sample of the data-set, which is caused mainly by the low response rate of this survey: the response rate for the question on innovation in the business survey is about 90 percent (and higher for the other questions), and it is below 50 percent in the innovation survey. The total number of observations from the business survey is above 22000, as compared with about 10000 for the innovation survey.⁷⁶ However, the innovation survey contains an additional information on innovations. First, in the innovation survey, the firms are asked about innovation activities (ia), as opposed to the implementation of innovations in the business survey. The firms can also give the response of no innovation activities because

- they were not required (notreq)
- there were impediments (imped)

In 64 percent of the observations, the firms report innovation activities, 28 percent report that innovations were not required, and 8 percent report innovation

⁷³It can be seen that the large firms more often gave multiple answers: the row sum of the averages for the answers is about 1 for the small firms, and far above 1 for the large firms.

⁷⁴Large firms more often report that they had stopped an innovation project, but they also more often report innovations.

⁷⁵See Penzkofer, Schmalholz, Scholz (1989).

⁷⁶See figures 7 and 8 in the appendix and Schneeweis, Smolny (1996).

impediments. Note the large share of small firms which report innovation impediments. The responses are generally consistent with those from the business survey.⁷⁷

Second, the firms are asked about the extent of their innovation activities, i.e. the innovation survey contains quantitative data on innovation expenditures.⁷⁸ In figure 6, a histogram with the share of innovation expenditures in sales ie/s is depicted.⁷⁹ For about 3500 (out of about 10000) observations, the firms report no innovation activities (due to impediments or because they were not required). For about 1200 cases, the innovation rate is non-zero but below 1 percent, and slightly above 1 percent of the firms report innovation rates above 20 percent.

In table 2, annual averages and the averages according to firm size are reported. The average share of innovation activities in sales is slightly below 3 percent. Note that in the first two years, the survey includes only innovators. More informative is the distribution according to firm size: for small firms with less than 100 employees, the innovation rate is about 2 percent, for large firms with more than 2000 (5000) employees, it exceeds 5 (8) percent. Remarkable is also the large variance of innovation expenditures within the size classes. Across the sectors, the largest innovation rates are in machinery (32), car manufacturing (33), electrical products (34), and precision and optical goods (35).⁸⁰

Figure 6 and table 2 also contain the corresponding data on the share of investment expenditures in sales.⁸¹ i/s is the total investment rate, below the corresponding figures for equipment investment i^e/s and investment in structures i^s/s are depicted. Investment and sales are based on firm-level data, as opposed to innovations which are related to a specific product or product group. The data are depicted for those firms only, where the share of product-level employment to firm-level employment is above 0.5. On average, the share of investment in sales is about 5 percent which corresponds to the respective figure for total manufacturing.⁸² The largest share is equipment investment, investments in structures account for about 20 percent of total investment. The averages do not reveal important differences according to firm size. However, the variance of investment rates is lower for large firms.⁸³

⁷⁷Some measures of the data are reported in tables 13, 14, and figure 8 in the appendix. In the first two years, the survey contains only innovators. The innovation survey contains also an question about the number of innovation projects, distinguished for product and process innovations. However, the response rate for this question is very low.

⁷⁸Innovation expenditures include R&D, but contain also costs of implementation.

⁷⁹Sales correspond to the respective product or product group. The stock of innovation capital or the stock of physical capital are not available in the data-set.

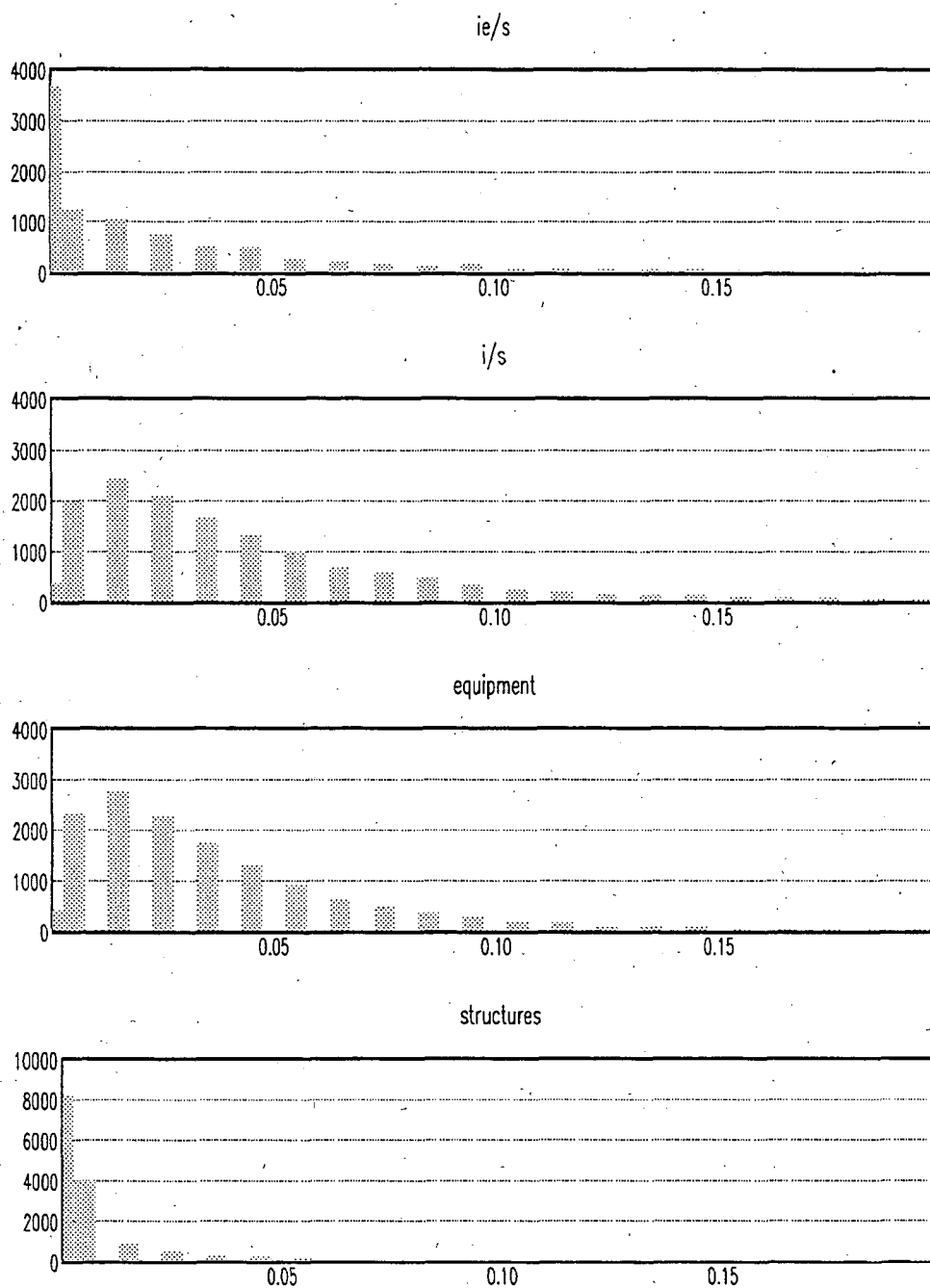
⁸⁰See table 15 in the appendix.

⁸¹Sectoral data are contained in table 15 in the appendix.

⁸²387 firms report a share of investment expenditures in sales above 20 percent. The corresponding figures for equipment (structures) are 228 (74).

⁸³The size classes correspond to firm-level employment.

Figure 6: Innovation expenditures and investment



Source: ifo firm panel, 13 years (1980-92)
The first bar denotes 0. The class width is 0.01.

Table 2: Innovation expenditures and investment

year	ie/s	σ	obs	i/s	σ	obs	i^e/s	σ	i^s/s	σ	obs
1980	0.045	0.052	219	0.055	0.074	1192	0.041	0.053	0.013	0.040	1188
1981	0.049	0.061	321	0.046	0.058	1215	0.036	0.041	0.010	0.031	1215
1982	0.025	0.042	738	0.043	0.075	1203	0.034	0.043	0.008	0.042	1199
1983	0.026	0.049	779	0.043	0.060	1230	0.036	0.048	0.007	0.025	1224
1984	0.029	0.056	845	0.043	0.061	1219	0.036	0.043	0.007	0.034	1216
1985	0.027	0.047	789	0.046	0.067	1242	0.039	0.050	0.007	0.030	1239
1986	0.028	0.056	886	0.050	0.061	1244	0.042	0.049	0.008	0.028	1242
1987	0.028	0.050	858	0.053	0.068	1173	0.043	0.050	0.010	0.033	1171
1988	0.029	0.053	820	0.054	0.062	1100	0.045	0.050	0.009	0.028	1099
1989	0.027	0.045	773	0.060	0.088	1021	0.048	0.055	0.012	0.053	1019
1990	0.027	0.053	806	0.063	0.087	1009	0.052	0.073	0.011	0.033	1007
1991	0.028	0.059	693	0.063	0.086	941	0.052	0.070	0.011	0.031	940
1992	0.020	0.041	791	0.057	0.070	873	0.046	0.055	0.011	0.033	872
size											
$\bar{l} < 20$	0.019	0.058	813	0.045	0.081	691	0.037	0.061	0.006	0.033	688
$20 \leq \bar{l} < 50$	0.022	0.051	1470	0.054	0.103	1724	0.045	0.078	0.010	0.048	1712
$50 \leq \bar{l} < 100$	0.022	0.046	1750	0.053	0.079	2192	0.043	0.057	0.011	0.043	2184
$100 \leq \bar{l} < 200$	0.027	0.047	1779	0.052	0.070	2449	0.042	0.052	0.010	0.036	2445
$200 \leq \bar{l} < 500$	0.032	0.048	1955	0.052	0.073	3416	0.042	0.053	0.010	0.035	3415
$500 \leq \bar{l} < 1000$	0.032	0.051	808	0.050	0.041	1894	0.042	0.034	0.008	0.018	1892
$1000 \leq \bar{l} < 2000$	0.044	0.062	364	0.052	0.043	1113	0.042	0.032	0.010	0.019	1113
$2000 \leq \bar{l} < 5000$	0.054	0.060	232	0.046	0.035	615	0.039	0.029	0.007	0.012	615
$5000 \leq \bar{l}$	0.087	0.065	100	0.047	0.029	568	0.039	0.025	0.007	0.009	567
total	0.028	0.051	9318	0.051	0.071	14662	0.042	0.053	0.009	0.034	14631

Source: ifo firm panel.

The business survey also contains quarterly information on the degree of capacity utilization *DUC*.⁸⁴ The average utilization is 83 percent, the standard deviation is about 13 percent. This low average utilization and the large variance across the firms is consistent with the assumption of a slow adjustment of capacities applied in the model, and underlines the importance to control for short-run demand induced effects.

The impact of the utilization of capacities on investment stems from the adjustment model. In addition, in case of autocorrelated demand shocks, a high capacity utilization is an indicator for expected demand. The data-set also contains a direct measure of expected demand. Once a year, the firms are asked about their estimate of the development of the product market in the medium run.⁸⁵ The medium-run is defined as 5 years. The answers are qualitative, i.e. the firms can report a growing market, a stagnating market, or a shrinking market.⁸⁶ For the estimates, dummy variables were created for firms which expect a growing (demand⁺) and a shrinking market (demand⁻), respectively; a stagnating market is the reference case. Some measures of the data are reported in table 19 and 20 in the appendix. On average, in 43 percent of the observations an expected increase was reported, and 13 percent reported an expected shrinking. The time series development of the data depicts mainly the business cycle (the maximum of demand⁺ is in 1989/1990), large firms more often reported an expected increase, the variance across the sectors is enormous.

Third, expected demand and the development of cash flows and profits in the past is approximated by the development of output and prices. Every month, the firms were asked about realized price and output changes, as compared with the preceding month. Again, the information is qualitative, i.e. it is distinguished between increase, no change, and decrease. On average, each month 11 percent of the firms reported that they had increased their prices, and 5 percent reported that they had decreased their prices. That means, there is about one price increase every year, and one price decrease every second year for each firm. The corresponding figures for output are 14 percent for increases and 18 percent for decreases, i.e. price changes were less frequent than output changes. This indicates a slow adjustment of prices with respect to demand.

Since the data on output and prices are qualitative, one may question their reliability. For each, prices and output, no quantitative information is available at either the firm or the product level. However, the investment survey contains an annual information about sales. Therefore, it is possible to test to what extent

⁸⁴The averages and the cross-sectional standard deviations are reported in table 19 and 20 in the appendix. The data 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 and averaged over the year.

⁸⁵The question is in december, together with the question on innovations.

⁸⁶Since 1982, the firms can also differentiate between a slight and a strong growth (shrinkage). For the estimates, the answers were grouped together.

Table 3: Correlation between qualitative and quantitative data

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

const.	y^+	y^-	$y1^+$	$y1^-$	p^+	p^-	$p1^+$	$p1^-$	SEE	\bar{R}^2	obs
0.044 (26.0)	0.097 (17.0)	-0.150 (29.5)			0.059 (8.8)	-0.067 (-9.0)			0.132	0.082	18247
0.044 (19.6)			0.034 (16.9)	-0.052 (-24.9)			0.016 (7.8)	-0.027 (-10.5)	0.133	0.060	18247
0.046 (20.7)	0.082 (10.2)	-0.121 (-17.9)	0.010 (3.5)	-0.018 (-6.4)	0.048 (5.8)	-0.037 (-3.4)	0.005 (2.0)	-0.012 (-3.3)	0.131	0.085	18247

Note: OLS-estimates, sample 1981-1992

the qualitative monthly price and output informations together correspond to the annual information on sales. In table 3, some results of least squares regressions of quantitative sales changes on qualitative price and output changes are reported. In the first row, the logarithmic change in sales $\Delta \ln s$ is regressed on the relative number of price and output increases p^+, y^+ and decreases p^-, y^- within the corresponding year. All variables are highly significant with the expected sign. In addition, the absolute value of the coefficients on increases and decreases is very similar. The coefficients imply that

- the growth rate of sales for a firm that reported an output increase (decrease) in each month is 10 percentage points higher (15 percentage points lower) than those of a firm that reported no output changes,
- the growth rate of sales for a firm that reported a price increase (decrease) in each month is 6 percentage points higher (7 percentage points lower) than those of a firm that never reported price changes,
- i.e. each monthly reported output change implies an about one percent change in sales, each monthly reported price change implies an about 0.5 percent change in sales.

In the next rows, it is tested for a non-linearity of the relation between qualitative and quantitative changes. $p1^+, (p1^-)$ is a dummy variable that takes the value 1, if the firm reported an price increase (decrease) at least once a year, the output variables are defined correspondingly. It can be seen that this specification of the qualitative answers contains less information about the quantitative changes. However, it contains an additional information. For instance, increasing output in each month implies less than 12 times the effect of increasing output once a year. However, all reported qualitative price and output changes are still significant and meaningfully related to the quantitative data. Therefore, it can be concluded that the qualitative information on prices and output appears to be reliable. For

the empirical estimation, annual net price and output increases are calculated as $\Delta p = p^+ - p^-$ and $\Delta y = y^+ - y^-$.⁸⁷

That means, the business survey supplies three different informations about the demand conditions at the firm level. The first is capacity utilization which captures the adjustment model for investment. An impact on innovations would indicate a complementarity of innovations and investment; second, a direct measure of the medium-run demand expectations is available; third, price and output increases in the past give an information about past periods' cash flows and profits which affect the financing conditions of the firm.

The price and output data were also used to deduce some information about the market structure. It was noted above, that in case of adjustment costs for prices, the frequency of price and output changes can serve as an indicator of the price elasticity of demand: low competition, i.e. a low absolute value of the price elasticity of demand favours output adjustments against price adjustments. Since the observed low frequency of the adjustment of prices in the data indicates price adjustment costs, the frequency of price and output adjustments at the firm level can be used as an indicator of market power. That means, the high frequency of the price and output data permits the analysis of market structure by market behaviour, i.e. price and output changes. For the estimates, the frequency of price and output changes is calculated as the relative sum of increases and decreases during each year, i.e. $pc = p^+ + p^-$ and $yc = y^+ + y^-$. In addition, the frequency of price and output adjustment at the sectoral level can supply an additional information about the market structure; sectoral means are calculated, excluding the respective firm (pc^s, yc^s).⁸⁸

A final indicator of the market structure is given by the information, whether the respective product is also exported. Again, a qualitative information is available from the business survey. The data reveal that about 80 percent of the firms also export their product (see table 19 and 20 in the appendix). The share is increasing over time; in addition, nearly all large firms export their product.

3.2 Attrition

An important topic when dealing with panel-data is attrition.⁸⁹ Since the panel covers a rather long period, a large number of firms left the panel during the

⁸⁷Some measures of the data are reported in tables 16 and 17 in the appendix. This kind of balancing is not without problems; relevant information may be lost. However, the results of the estimates above give some confidence into this proceeding.

⁸⁸The frequency of price and output changes is lower for large firms. For more than 8000 observations, the firms did report price changes during the year, and another 9000 firms reported one price change. For the observed frequency of price and output changes, see tables 16 and 17 in the appendix.

⁸⁹See Heckman (1979). An overview is given by Verbeek, Nijman (1995). 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.

observation period: in 1980, 2156 firms (products) participated in the panel. Since then, 243 firms entered the panel, while 548 firms left it. Therefore, in 1992, 1851 firms remained. The annual attrition rate since 1985 is about 3.5 percent.⁹⁰

Attrition is not random. For instance, every year about 2 percent of all firms in manufacturing were closed due to insolvency.⁹¹ Other firms are liquidated or 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 table 21 at the end of the paper, some results for a selection equation are reported. The endogenous variable is a dummy which is one, if the firm leaves the business survey in the current year (*exit*). Explanatory variables are the same as those for the economic model, i.e. it is tested to what extent selection (attrition) is correlated with the explanatory variables of the model. The explanatory variables refer to the preceding year. Whether a firm leaves the panel in the last year is unknown, therefore the endogenous variable is not defined for this year. The equation is estimated as a pooled probit model.⁹²

The results show clearly the endogeneity of attrition. First, a high degree of capacity utilization significantly reduces the probability of leaving the panel. Second, output increases in the past and an expected increase in demand also reduce the probability of exit. This confirms the hypothesis that at least some firms leave the panel due to exit out of the market. Third, large firms leave the panel less often. This is again consistent with the view that leaving the panel is correlated with leaving the market. Finally, if the other firms in the sector are large, the probability of exit is higher.⁹³

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 some of the endogenous variables, e.g. exit as a kind of dis-investment: 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

⁹⁰See table 19 and 20 in the appendix. 6 firms which participated for less than 7 months were excluded. Before 1984, attrition is very low. The reason is that for firms which left the business survey before 1985 the business survey could not be matched with the investment survey. Therefore, those data were excluded for the analysis here. However, business survey information is available also for those firms.

⁹¹See Harhoff, Stahl, Woywode (1995) and Winker (1996).

⁹²Similar results were achieved with a fixed-effects linear-probability model (not reported).

⁹³In Smolny (1996), it was shown that introducing an innovation reduces the probability of leaving the panel. That means, if leaving the panel can be seen as an indicator for leaving the market, the results did not confirm the view that innovation increases uncertainty and thereby exit from the market.

to include a dummy variable for leavers of the panel.⁹⁴ 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.⁹⁵ 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 leavers and exits are included in all model equations. The results are discussed below. This procedure does not “solve” the selection problem entirely. It does not yield unbiased parameters for the model, since attrition is an endogenous variable.⁹⁶ Nevertheless, it gives an impression about the importance of the sample selection problem for the model parameters.

3.3 Empirical specification

In the empirical model, the innovation behaviour of the firm is explained with firm size, demand factors, indicators of the market structure, and competitors' behaviour. First, the results of binary probit models for the innovation variables from the business survey are reported. It is distinguished between product and process innovations, and between innovation plans, stoppages, and implementations. Second, the complementarity between product and process innovations, and between innovations and investment is analysed by cross-tabulations. Third, the results achieved with the innovation activity variables from the innovation survey are discussed. Finally, tobit models for innovation expenditures and investment (structures and equipment) are estimated.

A reduced form is estimated, and due to the simultaneousness of the innovation and investment decision, and the complementarity between innovations and investment, the same set of explanatory variables is employed in all equations. The investment equations are estimated for a reduced sample of firms. Explanatory variables related to the demand conditions are the degree of utilization of capacities DUC , price and output increases $\Delta p, \Delta y$, and the medium-run demand expectations (demand⁺, demand⁻). Firm size is measured by dummies according to the average number of employees \bar{l} and a diversification dummy (divers). Indicators of the market structure are own and others price and output changes (pc, yc, pc^s, yc^s). Additional explanatory variables are the average innovation behaviour of the other firms in the sectors which should approximate technological opportunity and the appropriability conditions. Others firm size \bar{l}^s and others capacity utilization DUC^s should capture demand pressure. Finally, an export dummy is included.

⁹⁴The difference between both model refers to the distinction between selection by observables versus selection by unobservables.

⁹⁵In Smolny (1996), it was found that leavers exhibit about one percentage point less output and sales growth. In the equation, it was controlled for capacity utilization and innovation behaviour.

⁹⁶See Heckman, Hotz (1989). Since nearly all variables from the data base are more or less related to the business conditions of the firm, an instrumental-variable technique also does not appear feasible.

All explanatory variables with the exception of competitors' innovation behaviour are taken from the preceding year. That means, the identification of the model is sought through lagged values of the explanatory variables. This is in accordance to the assumed sequential decision structure of the theoretical model and the autocorrelation of demand shocks. In addition, a complete set of 11 time dummies is always included (not reported in the tables). These dummies shall capture effects from aggregate interest rates, wages, and prices of raw materials and intermediates; the data-set does not include information about those variables at the firm level.⁹⁷ All equations are tested for a sample selection bias due to endogenous attrition by including dummies for leavers or exits in the next periods.

The robustness of the results was also tested with 27 sector dummies and with a fixed effects (linear probability) model. The general conclusion from these estimates was that the qualitative results for the firm-specific variables do not differ, but the sectoral variables became less significant (not reported). This was expected, since these variables should approximate the market structure which changes only slowly over time. Note that with fixed effects, those firms that always innovate are treated equal to those firms that never innovate, i.e. a main source of variation is lost.⁹⁸ In addition, most variables of the model are already specified as changes. 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 from theoretical arguments.

4 Estimation results

4.1 Innovation plans and implementations

In [table 4](#) and [table 5](#), the estimation results of binary probit models for product and process innovations are reported. Depicted are the coefficients and the respective t-values (in parantheses).⁹⁹ The first line contains the endogenous variables, in the last lines, the share of observations for category 1 (cat_1) and the number of observations are reported. It can be seen that the shares of the categories do not sum up to one due to multiple answers of some firms; therefore, the equations were estimated separately.

The estimation results reveal firstly that a high capacity utilization in the

⁹⁷Using the available sectoral data on average wages is also questionable. Inter-industry wage differentials approximate to a large extent inter-industry differences in labour qualification and therefore do not measure labour costs correctly. See Krueger, Summers (1988) and Mulligan, Sala-i-Martin (1995). The estimated model corresponds to the assumption that wages and other input costs are the same for all firms, apart from those differences captured by the dummies (time, size).

⁹⁸That means, the fixed effects estimator uses only the time-series variation of the data (within variance), as opposed to the cross-sectional variation (between variance) of the pooled estimation.

⁹⁹A complete list of variables is contained in table 10 in the appendix.

preceding year (*DUC*) increases both the probability of a product innovation (*prod*) and the probability of a process innovation (*proc*). This is a first hint for a complementarity of innovations and investment. Capacity utilization (and demand expectations) should be the most important determinants of investment, and a strong effect on innovations indicates that the firms implement innovations when they invest. This argumentation is confirmed by the larger effect of capacity utilization on process innovations. The coefficient exhibits about twice the value as those of product innovations; here a stronger complementarity was expected. A high capacity utilization also reduces the probability to stop (*stop*) an innovation project, the firms less often report innovation plans (*plan, planc*), and less often report that they do not intend an innovation project (*notint*).¹⁰⁰

Second, price and output increases $\Delta p, \Delta y$ in the past increase the probability of implementing an innovation. This indicates an effect of cash flow and the financing conditions on innovations. Output increases exhibit a stronger effect on process innovations, while price increases exhibit a stronger effect on product innovations. This confirms that process innovations are related more to the development of quantities through the complementarity with capital investment. The strong effect of prices on product innovations can also be interpreted as a positive effect of market power on innovations. A significant effect on innovation plans is not revealed, but output increases reduce the probability that the firms do not intend innovations, and reduce the probability that firms stop process innovations.

Third, the medium-run demand expectations (*demand⁺*, *demand⁻*) exhibit a very strong effect on both product and process innovations, in addition to a high capacity utilization and past periods' price and output increases. A strong effect is revealed mainly for those firms that expect a growing market; the firms that expect a shrinking market do not differ very much from those firms that report a stagnating market, the reference case. The quantitative effect is quite large: those firms that expect a growing market exhibit an about 10 percentage point higher probability to innovate. That means, growing markets strongly favour innovations which is consistent with a long-run nature of innovation decisions. Positive demand expectations also strongly increase the probability of (completed) innovation plans, and reduce the probability that firms report that an innovation is not intended; the expectation of a shrinking market increases the probability that firms do not intend innovations. This confirms that capacity utilization and price and output increases capture mainly the short-run demand situation of the firm; those variables increase mainly the probability of the implementation of an innovation. The demand expectations capture the longer-run development of demand; this variable also increases the probability of innovation plans.

A high capacity utilization of competitors (*DUC^s*), on the other hand, sig-

¹⁰⁰The only exception is the weakly significant positive effect on completed plans (*planc*) for process innovations.

Table 4: Product innovations

	prod	stop	planc	plan	notint	prod
<i>DUC</i>	0.312 (3.4)	-0.978 (-4.2)	-0.208 (-1.7)	-0.363 (-3.7)	-0.217 (-2.2)	0.267 (2.9)
Δp	0.198 (3.8)	0.040 (0.3)	0.070 (1.0)	0.010 (0.2)	-0.079 (-1.5)	0.249 (4.8)
Δy	0.221 (5.0)	0.041 (0.4)	0.086 (1.5)	-0.016 (-0.3)	-0.250 (-5.1)	0.206 (4.7)
demand ⁺	0.272 (12.2)	0.104 (1.7)	0.159 (5.5)	0.119 (5.0)	-0.358 (-14.2)	0.274 (12.3)
demand ⁻	-0.065 (-2.0)	0.050 (0.6)	-0.050 (-1.1)	-0.005 (-0.2)	0.119 (3.6)	-0.064 (-2.0)
<i>DUC</i> ^s	-1.690 (-4.5)	-3.241 (-3.1)	-1.961 (-3.8)	-1.477 (-3.6)	2.800 (7.1)	-1.362 (-3.6)
pc	-0.204 (-3.5)	0.389 (2.7)	-0.015 (-0.2)	0.149 (2.4)	-0.161 (-2.6)	-0.216 (-3.7)
pc ^s	-0.739 (-4.2)	-1.282 (-2.4)	-0.371 (-1.5)	-0.663 (-3.4)	1.237 (6.9)	-2.037 (-13.1)
yc	0.206 (5.0)	0.284 (2.8)	0.019 (0.4)	0.003 (0.1)	-0.294 (-6.4)	0.189 (4.6)
yc ^s	-0.179 (-0.8)	0.876 (1.5)	-0.775 (-2.5)	-0.110 (-0.4)	0.616 (2.6)	-0.738 (-3.3)
prod ^s	1.371 (15.6)	0.171 (0.7)	0.574 (4.9)	0.623 (6.5)	-1.288 (-13.8)	
export	0.436 (13.6)	0.311 (3.2)	0.217 (4.5)	0.231 (6.4)	-0.383 (-12.5)	0.533 (17.0)
$\bar{l} < 20$	-2.034 (-12.3)	-0.147 (-0.6)	-1.179 (-9.5)	-0.741 (-7.0)	1.856 (7.0)	-2.046 (-12.4)
$20 \leq \bar{l} < 50$	-1.847 (-11.4)	-0.192 (-0.8)	-0.814 (-7.6)	-0.615 (-6.2)	1.596 (6.0)	-1.853 (-11.5)
$50 \leq \bar{l} < 100$	-1.593 (-9.9)	-0.140 (-0.6)	-0.791 (-7.6)	-0.507 (-5.2)	1.358 (5.1)	-1.600 (-10.0)
$100 \leq \bar{l} < 200$	-1.367 (-8.5)	-0.225 (-1.0)	-0.693 (-6.8)	-0.502 (-5.2)	1.147 (4.3)	-1.370 (-8.6)
$200 \leq \bar{l} < 500$	-1.244 (-7.8)	-0.076 (-0.3)	-0.613 (-6.1)	-0.515 (-5.4)	1.078 (4.1)	-1.235 (-7.8)
$500 \leq \bar{l} < 1000$	-1.081 (-6.7)	0.049 (0.2)	-0.427 (-4.1)	-0.370 (-3.8)	0.899 (3.4)	-1.057 (-6.6)
$1000 \leq \bar{l} < 2000$	-1.108 (-6.8)	0.038 (0.2)	-0.551 (-5.1)	-0.446 (-4.4)	0.994 (3.7)	-1.086 (-6.7)
$2000 \leq \bar{l} < 5000$	-0.700 (-4.1)	0.211 (0.9)	-0.154 (-1.4)	-0.182 (-1.7)	0.759 (2.8)	-0.652 (-3.8)
divers	0.019 (0.9)	-0.170 (-2.8)	0.063 (2.3)	0.028 (1.2)	0.043 (1.8)	0.045 (2.1)
\bar{l}_p^s	-0.095 (-4.4)	0.021 (0.4)	-0.033 (-1.3)	0.008 (0.3)	0.051 (2.0)	0.009 (0.4)
cat ₁	0.512	-0.013	0.108	0.222	0.247	0.512
obs	18232	18232	18232	18232	18232	18232

Table 5: Process innovations

	proc	stop	planc	plan	notint	proc
<i>DUC</i>	0.684 (7.5)	-0.434 (-1.6)	0.214 (1.8)	-0.343 (-3.4)	-0.404 (-4.1)	0.655 (7.2)
Δp	0.077 (1.5)	0.111 (0.9)	-0.032 (-0.5)	0.044 (0.8)	-0.076 (-1.4)	0.103 (2.0)
Δy	0.253 (5.9)	-0.341 (-2.7)	0.044 (0.8)	0.038 (0.8)	-0.280 (-5.7)	0.244 (5.7)
demand ⁺	0.236 (10.8)	-0.072 (-1.0)	0.156 (5.6)	0.087 (3.6)	-0.381 (-15.2)	0.243 (11.1)
demand ⁻	-0.031 (-1.0)	0.024 (0.3)	-0.071 (-1.6)	-0.032 (-0.9)	0.088 (2.7)	-0.034 (-1.1)
<i>DUC</i> ^s	-1.239 (-3.3)	-0.440 (-0.4)	-1.172 (-2.4)	-0.350 (-0.8)	2.230 (5.5)	-0.778 (-2.1)
pc	-0.012 (-0.2)	0.541 (3.6)	0.171 (2.4)	0.242 (3.9)	-0.350 (-5.6)	-0.015 (-0.3)
pc ^s	-0.456 (-2.9)	-0.404 (-0.8)	-0.342 (-1.7)	-0.586 (-3.3)	1.418 (8.5)	-0.773 (-5.1)
yc	0.141 (3.5)	0.247 (2.0)	0.081 (1.6)	0.051 (1.2)	-0.264 (-5.8)	0.137 (3.4)
yc ^s	0.201 (0.9)	0.591 (0.9)	-0.351 (-1.2)	0.045 (0.2)	0.219 (0.9)	0.254 (1.1)
proc ^s	0.881 (8.0)	0.290 (0.8)	0.328 (2.3)	0.429 (3.5)	-0.816 (-6.6)	
export	0.180 (5.9)	0.291 (2.8)	0.047 (1.1)	0.082 (2.4)	-0.126 (-4.0)	0.206 (6.8)
$l < 20$	-1.989 (-13.6)	-0.049 (-0.2)	-1.135 (-9.6)	-0.824 (-7.7)	1.811 (7.4)	-2.003 (-13.7)
$20 \leq \bar{l} < 50$	-1.805 (-12.7)	-0.188 (-0.7)	-0.907 (-8.6)	-0.650 (-6.5)	1.546 (6.4)	-1.813 (-12.8)
$50 \leq \bar{l} < 100$	-1.641 (-11.6)	-0.067 (-0.3)	-0.799 (-7.8)	-0.554 (-5.7)	1.366 (5.6)	-1.643 (-11.7)
$100 \leq \bar{l} < 200$	-1.410 (-10.0)	-0.280 (-1.1)	-0.719 (-7.1)	-0.484 (-5.0)	1.173 (4.8)	-1.414 (-10.1)
$200 \leq \bar{l} < 500$	-1.352 (-9.6)	-0.285 (-1.1)	-0.653 (-6.6)	-0.511 (-5.3)	1.120 (4.6)	-1.345 (-9.6)
$500 \leq \bar{l} < 1000$	-1.176 (-8.3)	-0.102 (-0.4)	-0.539 (-5.3)	-0.377 (-3.8)	0.976 (4.0)	-1.159 (-8.2)
$1000 \leq \bar{l} < 2000$	-1.062 (-7.4)	-0.469 (-1.6)	-0.533 (-5.0)	-0.529 (-5.2)	0.965 (3.9)	-1.052 (-7.3)
$2000 \leq \bar{l} < 5000$	-0.885 (-5.9)	0.060 (0.2)	-0.205 (-1.9)	-0.271 (-2.5)	0.636 (2.5)	-0.863 (-5.8)
divers	0.029 (1.4)	-0.239 (-3.3)	0.030 (1.1)	-0.014 (-0.6)	0.053 (2.3)	0.043 (2.1)
\bar{l}_p^s	-0.080 (-3.8)	0.065 (1.1)	-0.019 (-0.7)	0.016 (0.7)	0.060 (2.5)	-0.026 (-1.3)
cat ₁	0.469	0.009	0.119	0.211	0.226	0.469
obs	18232	18232	18232	18232	18232	18232

nificantly reduces the probability of an implementation of innovations, and of innovation plans. This variable stands for the competitive pressure from the other firms in the sector, i.e. the results indicate that strong competition tends to reduce innovations. However, the total effect of the business cycle indicators on innovations is positive. The positive effects of own capacity utilization, price and output increases, and demand expectations clearly outweigh the negative effect from others capacity utilization.

Below, the results for the other market structure indicators, i.e. the variability of prices and output, are reported. The results reveal that a high frequency of price changes of the firm (pc) or in the sector (pc^s) reduces the probability of innovations, and a high frequency of own output changes (yc) promotes innovations. This is consistent with the interpretation that market power promotes innovations: in case of low competition, the (relative) frequency of price changes should be low; low competition favours quantity adjustment against price adjustments (see Smolny (1996)). Therefore, a high frequency of price adjustments indicates the absence of market power. Market power, in turn, permits an easier finance of risky innovation projects out of retained profits. It can be seen that the effect of price and output changes is stronger for product innovations, i.e. market power favours product innovations more than process innovations. This is consistent with the argument that price reductions in case of lower costs due to process innovations imply a stronger effect on the market share on competitive markets.

A large frequency of own price and output changes also increases the probability to stop an innovation project. In the model, a large frequency of both price and output changes can be interpreted as an indicator of demand uncertainty which increases the probability to cancel innovation projects. A large frequency of own price changes also increases the probability of innovation plans, while a large frequency of price changes in the sector reduces the probability of innovation plans. Correspondingly, own price (and output) changes reduce the probability that innovations are not intended, while a large frequency of price and output changes in the sector increases the probability that innovations are not intended. This can be seen as evidence that firm-specific uncertainty is an incentive for innovations, while sector-specific uncertainty is an impediment for innovations.

Others innovations strongly promote own innovations: the share of innovators in the sector (calculated excluding the respective firm) exhibits a significant positive effect on the implementation of innovations and on innovation plans. For product innovations, only the share of product innovators exhibits a significant effect, and for process innovations only the share of process innovators exhibits a significant effect. Therefore, for the reported results, the other sectoral innovation variable was skipped.¹⁰¹ The results indicate that the positive spillover effect from others innovations outweighs the negative displacement effect through less

¹⁰¹In addition, if the own innovation behaviour is correlated with the sectoral innovation behaviour, including the other innovation variable could introduce a simultaneous equation bias. Product and process innovations are determined simultaneously.

appropriability of the returns from innovations. It can be seen that the effect is stronger for product innovations than for process innovations. This indicates that it is easier to imitate others new products than others production technique. The positive effect of others innovations may also stand for more technological opportunity in those sectors which increases the innovation incentives for all firms. However, the effect was also significant in a fixed effects linear probability model (not reported).¹⁰²

In the last columns in the tables, the average sectoral innovation behaviour is skipped from the list of explanatory variables. In this case, the market structure variables become more significant. See especially the strong negative effect of the frequency of sectoral price changes on product innovations. This result indicates that a large share of product innovators in the sector reduces competition and the frequency of price changes. The same result was revealed by a direct test for an effect of innovation behaviour on the price setting (see Smolny (1996)).

Exporters exhibit a significantly higher probability to innovate. It can be seen that this effect is quantitatively very important: the probability to implement an innovation is about 10 percent higher for firms which export their product. Exporters also more often report innovation plans, and very seldomly report that innovations are not intended. These effects are again especially important for product innovations. This result is firstly consistent with the argument that exporters exhibit a higher capability to innovate, i.e. the effect may be based on exports as an *indicator* of technological capability. Second, the result also indicates spillovers from foreign markets which *affect* the technological capability. This second interpretation is enhanced by the stronger increase in the probability of implementing product innovations: firms that act on the international market can imitate from a larger pool of competitors' products. These result again indicates that the positive spillover effect outweighs the negative effect from less appropriability of the returns and more competition.

Firm size also exhibits a strongly positive effect on innovations. The effect is equally strong for the probability of process innovations and the probability of product innovations, i.e. firm size does not affect the composition of innovations. However, the positive effect of firm size on the probability to innovate does not imply that large firms innovate more per employee. The positive effect also depicts the simple scale argument that in large firms the probability of at least one innovation is higher. More conclusive results can be achieved only from the estimation of the effect of firm size on the share of innovation expenditures in sales (see below).

The estimates also reveal that the probability to implement an innovation is not significantly different in diversified firms. Note that the coefficient of the diversification dummy becomes significantly negative, if firm size is specified as the number of employees of the whole firm. This indicates that spillovers between

¹⁰²In the fixed effects model, the coefficients of the indicators of the market structure are less significant which is consistent with the interpretation that the market structure changes only slowly.

innovation activities within the firm between different products and the effect of the reduction of the risk of innovations on the financing conditions in diversified firms are not very important. However, diversified firm less often stop innovation projects and more often do not intend innovation projects. This can indicate a stronger screening of innovation projects in diversified firms.

A large size of the other firms in the sector, on the other hand, significantly reduces the probability to innovate. This variable is another measure of the degree of competitive pressure from other firms which can reduce the incentive to innovate. Note that the variable \bar{l}_p^s is specified in 1000's of employees, i.e. the effect is significant but not very strong.¹⁰³

Finally, all equations were tested for a bias due to endogenous attrition. For this purpose, all versions are estimated either

- with a dummy which is equal to one for those firms that leave the business survey during the observation period (leaver), or
- with two dummies, which are equal to one in one of the two periods before the firm leaves the business survey ($exit_t$, $exit_{t+1}$)

The results for selected equations are reported in table 21 in the appendix.¹⁰⁴ The equations reveal that firms which leave the panel innovate less often. The respective coefficients are significant both for product and for process innovations. This confirms the importance of the long-run nature of innovation projects: firms that expect to leave the market innovate less often. Most important, all coefficients and t -values of the model variables remain nearly unchanged. These results for attrition are comfortable, i.e. they do not destroy the confidence into the estimates of the economic model.

Summarizing the results, the estimates reveal a positive effect from the business cycle on innovations: the effect from capacity utilization especially on process innovations indicates the complementarity with capital investment; the positive effect from price and output increases indicates the importance of cash flow and retained profits on the financing of innovations; the importance of longer-run demand expectations underlines the long-run nature of innovation projects; these effects outweigh the negative effect from lower opportunity costs of innovations in recessions, and also outweigh the negative effect from capacity utilization of other firms in the sector. Second, market power enhances innovations, i.e. the positive effect of monopolistic profits on the ability to finance innovation project outweighs the negative effect on the incentives to innovate. Third, the probability of innovation projects increases with firm size but decreases with others

¹⁰³ Average sectoral employment per firm ranges from about 100 to about 2700 (see above). It was also tested for a non-linearity of the effect of others firm size on the probability to innovate by introducing, in addition, squared average sector employment. This variable did not prove significant.

¹⁰⁴ For many firms that left the panel in period t , missing values for some of the variables were encountered, and $exit_t$ is not defined for the year 1992. Therefore, the sample is smaller.

firm size. Finally, the probability of innovations is higher, if other firms in the sector innovate also, and if the product is exported. That means, the positive spillover effects and technological opportunity outweigh the negative effects from less appropriability of the returns and more competition.

4.2 Innovations and investment

The estimated strong impact of capacity utilization on product and process innovations already indicates the complementarity of innovations and investment. In this section, some direct evidence on the complementarities and the dynamics of innovation behaviour and investment is reported. The topic of [table 6](#) is the correlation between innovation behaviour and investment. In the first columns, the (relative) numbers of product and process innovators is depicted. The total sample consists of 22237 observations from 2399 firms. In about one half of the observations, the firms reported a product or a process innovation, respectively. In 1/3 of the observations, the firms reported a product *and* a process innovation (both); in nearly 2/3 of the observations, the firms reported a product *or* a process innovation (inno). Only about 15 percent reported a product or a process innovation only. This indicates already a correlation between product and process innovations.

In the next three columns, the average values for some of the quantitative variables from the investment survey for the different groups are depicted. The first is the average rate of change of employment $\Delta \ln l$. Average employment change per year is about -1 percent for all firms during the observation period, i.e. employment is decreasing. The shrinking of employment is nearly 2 percent per year for firms that did not innovate; innovating firms exhibited a shrinkage of employment of only 0.3 percent, and firms that implemented a process innovation exhibited a stable employment path. The figures for sales growth $\Delta \ln s$ and capacity utilization DUC are similar: average sales growth (capacity utilization) for all firms was 3.5 percent (83 percent), innovators exhibited about 1 percentage point more sales growth and a 2 percentage points higher capacity utilization rate. The table does not allow to draw a conclusion on causes and effects: the demand conditions affect innovations, and innovations affect the demand conditions. However, the estimation results in Smolny (1996) and Smolny, Schneeweis (1996) revealed that the quantitative impact of innovations on growth and capacity utilization was about in this dimension.

In the last columns, the average shares of investment in sales $(i/s)_t$ are depicted for the different groups. In addition, the investment rates in the preceding $(i/s)_{t-1}$ and in the subsequent $(i/s)_{t+1}$ year are depicted. The average share of investment in sales for all firms is about 5 percent. As expected, the data reveal that investment is nearly 1 percentage point higher for firms that implemented a process innovation. However, the data do not reveal that firms invest more, if they implement a product innovation: firms that implemented a product innovation only invested even less than firms that did not innovate. The largest invest-

Table 6: Innovations and investment

	obs	obs%	$\Delta \ln l_t$	$\Delta \ln s_t$	DUC_t	$(i/s)_{t-1}$	$(i/s)_t$	$(i/s)_{t+1}$
prod	11053	0.497	-0.004	0.043	0.847	0.051	0.051	0.050
proc	10212	0.459	0.001	0.045	0.851	0.057	0.059	0.053
inno	13929	0.626	-0.003	0.043	0.845	0.054	0.055	0.051
both	7336	0.330	0.001	0.047	0.856	0.054	0.055	0.051
prod only	3717	0.167	-0.014	0.035	0.830	0.044	0.043	0.048
proc only	2876	0.129	-0.001	0.041	0.839	0.064	0.070	0.057
no inno	8308	0.374	-0.019	0.022	0.803	0.047	0.044	0.049
all	22237	1.000	-0.009	0.035	0.829	0.051	0.051	0.051

Table 7: Innovation dynamics

	prod _{t-1}	prod _t	prod _{t+1}	proc _{t-1}	proc _t	proc _{t+1}	$(ie/s)_{t-1}$	$(ie/s)_t$	$(ie/s)_{t+1}$
prod	0.739	1	0.742	0.606	0.664	0.605	0.040	0.039	0.037
proc	0.657	0.718	0.660	0.674	1	0.674	0.041	0.040	0.035
inno	0.662	0.794	0.665	0.596	0.733	0.598	0.039	0.038	0.035
both	0.771	1	0.772	0.718	1	0.713	0.044	0.042	0.038
prod only	0.674	1	0.680	0.380	0	0.389	0.033	0.033	0.033
proc only	0.352	0	0.365	0.555	1	0.571	0.032	0.034	0.028
no inno	0.241	0	0.240	0.247	0	0.242	0.015	0.013	0.017
all	0.510	0.497	0.512	0.470	0.459	0.470	0.030	0.029	0.028

prod: product innovation implemented
 proc: process innovation implemented
 inno: product or process innovation implemented
 both: product and process innovation implemented
 prod only: product innovation, but not process innovation implemented
 proc only: process innovation, but not product innovation implemented
 no inno: neither product nor process innovation implemented

$\Delta \ln l$: growth rate of employment
 $\Delta \ln s$: growth rate of nominal sales
 DUC : capacity utilization rate
 i/s : share of investment expenditures in sales
 ie/s : share of innovation expenditures in sales

Source: ifo firm panel

ment rates are observed for those firms that implemented a process innovation only (7 percent). Therefore, the data indicate a complementarity between process innovations and investment, but no direct complementarity between product innovations and investment.¹⁰⁵

The investment rates of the current, the preceding, and the subsequent years show first that the largest correlation between process innovations and investment is contemporary. Somewhat surprisingly, the correlation between current process innovations and past investment is higher than the correlation between current process innovations and future investment. That means, the data do not indicate that process innovations follow investment. This finding may be caused by the different formulation of the questions on innovations and investment in the survey: investment refers to *expenditures* in the current period, while innovations refer to the *implementation*, i.e. the completion of an innovation project.

This interpretation is confirmed by the data on *innovation expenditures* in table 7. In the last columns of this table, the shares of innovation expenditures in sales *ie/s* are depicted for the different groups. It can be seen that firms that implement innovations exhibit more innovation expenditures in the preceding period than in the current period, i.e. the implementation of innovations follows innovation expenditures. The data also reveal that innovation expenditures are higher both for product and for process innovators. The average share of innovation expenditures in sales is about 3 percent for all firms, about 4 percent for firms that implemented an innovation, and only 1.3 percent for firms that did not implement an innovation.

The first columns in table 7 contain more detailed informations about the correlation between product and process innovations:

- first, about 72 percent of those firms that implemented a process innovation also implemented a product innovation in the same year, as compared with only 50 percent for all firms;
- second, about 66 percent of those firms that implemented a product innovation also implemented a process innovation in the same year, as compared with only 46 percent of all firms.

That means, product and process innovations are correlated. In addition, the data reveal that innovation behaviour is autocorrelated:

- 74 percent of those firms that implemented a product innovation in the current year implemented a product innovation also in the preceding and the subsequent year, as compared with 50 percent for all firms;
- 67 percent of those firms that implemented a process innovation in the current year implemented a process innovation also in the preceding and the subsequent year, as compared with 46 percent for all firms;

¹⁰⁵ Again, the correlations should not be interpreted in a causal sense. They also reflect a similar development of the determinants of innovation behaviour and investment.

Taken together, innovative firms are more successful; they exhibit a higher capacity utilization and more output and employment growth. Second, firms that implement process innovations invest more which indicates a complementarity of process innovations and investment. A corresponding direct correlation between product innovations and investment is not found. However, product innovations are correlated with process innovations. Finally, the innovation behaviour is auto-correlated which is consistent with the argument that past innovation behaviour indicates or enhances the innovative capability of the firm. However, the correlation should not be interpreted in a causal sense; they might also result from (auto-)correlation of the determinants of innovation behaviour and investment. More conclusive results can be achieved only with the estimation of a dynamic simultaneous model of innovation and investment behaviour. This is on the agenda for future research.

4.3 Innovation activities

For the qualitative innovation variables from the innovation survey, i.e. innovation activities (*ia*), no innovation activities, because they were not required (*notreq*), or due to impediments (*imped*), different specifications may be appropriate:

- One proceeding is to specify a two-step model: in the first step, the firm decides whether an innovation is required; in the second step, it is determined whether the firm can innovate or whether there are impediments. This model requires the estimation of a binary probit model for the variable *notreq*; the second step must be estimated as a conditional probit model.
- For an economic decision model of innovations, a different specification is appropriate: the firm decides whether it innovates or not. The differentiation whether no innovation activities were performed, because they were not required or because there were impediments is not important and cannot be interpreted meaningfully in a profit maximizing framework. This model requires the estimation of a binary probit model for innovation activities *ia*.
- A third kind of modelling is that the firm at first has to overcome impediments, for instance, to guaranty the financing, or to convince the employees or the works council,¹⁰⁶ the second stage is the decision whether innovation activities are required or not. This model would require a binary probit model for the variable *imped*, the second step must again be estimated as a conditional probit model.
- There is even a fourth interpretation: if a firm reports that innovation activities were not required, it must not fill out the rest of the questionnaire.

¹⁰⁶Schnabel, Wagner (1994) found positive effect from work councils on innovation behaviour. This indicates cooperative behaviour.

Experiences with survey data show that those shortcuts are often used by survey participants. In this case, the information that innovations were not required should be treated as a missing value, and the binary probit model for *notreq* should be interpreted as a selection model.

Since theoretical arguments do not yield a clear preference for one of these models, here the results of binary models for each of these variables are reported. The model for innovation activities (*ia*) can be interpreted as the specification of the economic decision model, the specification for the other variables (*notreq*, *imped*) can be interpreted as the first step of the corresponding two-step model. In table 8, the estimation results are depicted. For comparison, in the first two columns, the results for the combined innovation implementation variables (both, *inno*) from the business survey are reported.¹⁰⁷ See the much smaller number of observations from the innovation survey which is caused by missing values due to non-response of the firms. In addition, the sample is restricted to 1982-92, since in the first two years, only innovators participated in the innovation survey. However, the share of innovators is strikingly similar in the business survey and in the innovation survey (see the bottom lines in table 8).

The results firstly reveal that the effect from capacity utilization on innovation activities (*ia*) is smaller and less significant than the effect on the implementation of innovations (*inno*). This indicates that the complementarity with capital investment is important mainly for the implementation of innovations, and less for innovation activities. Second, price increases in the past affect only the implementation of an innovation significantly, but not innovation activities. Both results together indicate that the financing of innovation activities does not depend that much on retained profits (cash flow) from a short-run excess demand situation on the goods market. On the other hand, output increases in the past period increase the probability of innovation activities, i.e. innovation activities increase with the level of production activities. The most important business cycle indicator for innovation activities are the medium-run demand expectations which strongly increase the probability of innovation activities. A high capacity utilization of competitors, on the other hand, strongly reduces the probability of innovation activities.

These results together confirm that the probability of innovation activities is mainly determined by the longer-run demand situation of the firm; the short-run demand situation determines mostly the probability of implementation, i.e. the timing of the introduction of a new product or a new production technique. These results also correspond to the positive effect of the short-run demand situation on the implementation only, and the positive effect of demand expectations on innovation plans also which was revealed from the business survey data in the preceding section.

¹⁰⁷ A multinomial model (the three variables *ia*, *notreq*, and *imped* sum up to one) is not estimated, because it is difficult to interpret the variables from the innovation survey meaningfully in terms of a multiple choice model for the firm.

Table 8: Innovation activities

	both	inno	ia	notreq	imped	ia
<i>DUC</i>	0.483 (4.9)	0.583 (6.3)	0.254 (1.8)	0.137 (1.0)	-0.739 (-4.1)	0.174 (1.3)
Δp	0.102 (1.8)	0.192 (3.7)	0.023 (0.3)	-0.005 (-0.1)	-0.007 (-0.1)	0.029 (0.4)
Δy	0.242 (5.4)	0.280 (6.2)	0.335 (4.9)	-0.242 (-3.5)	-0.253 (-2.7)	0.320 (4.7)
demand ⁺	0.267 (11.7)	0.287 (12.5)	0.239 (6.8)	-0.187 (-5.2)	-0.179 (-3.5)	0.251 (7.2)
demand ⁻	-0.004 (-0.1)	-0.092 (-2.9)	-0.069 (-1.4)	0.038 (0.8)	0.057 (0.9)	-0.074 (-1.6)
<i>DUC</i> ^s	-1.236 (-3.1)	-1.712 (-4.5)	-3.186 (-5.8)	3.043 (5.5)	0.614 (0.8)	-3.316 (-6.1)
pc	-0.167 (-2.7)	-0.065 (-1.1)	-0.019 (-0.2)	0.056 (0.7)	-0.077 (-0.7)	-0.035 (-0.4)
pc ^s	-0.349 (-1.9)	-0.864 (-5.0)	-1.033 (-4.2)	0.698 (2.8)	0.719 (2.1)	-1.741 (-7.6)
yc	0.113 (2.7)	0.269 (6.4)	0.391 (6.2)	-0.420 (-6.5)	-0.024 (-0.3)	0.392 (6.2)
yc ^s	0.301 (1.2)	-0.152 (-0.7)	-0.739 (-2.2)	1.349 (4.1)	-0.822 (-1.8)	-0.996 (-3.0)
proc ^s	0.434 (3.1)	0.122 (0.9)				
prod ^s	0.797 (7.3)	0.877 (8.3)				
ia ^s			0.959 (8.8)	-0.775 (-7.0)	-0.514 (-3.4)	
export	0.388 (10.7)	0.300 (9.9)	0.361 (8.6)	-0.374 (-9.0)	0.043 (0.8)	0.418 (10.0)
$\bar{l} < 20$	-2.155 (-15.7)	-2.214 (-9.6)	-2.313 (-6.0)	1.717 (4.3)	1.650 (4.5)	-2.409 (-6.1)
$20 \leq \bar{l} < 50$	-2.039 (-15.6)	-1.964 (-8.6)	-1.974 (-5.1)	1.681 (4.3)	1.305 (3.6)	-2.051 (-5.3)
$50 \leq \bar{l} < 100$	-1.740 (-13.5)	-1.779 (-7.8)	-1.716 (-4.5)	1.445 (3.7)	1.260 (3.5)	-1.776 (-4.6)
$100 \leq \bar{l} < 200$	-1.500 (-11.7)	-1.526 (-6.7)	-1.419 (-3.7)	1.256 (3.2)	0.941 (2.6)	-1.475 (-3.8)
$200 \leq \bar{l} < 500$	-1.400 (-11.0)	-1.427 (-6.3)	-1.226 (-3.2)	1.069 (2.7)	0.851 (2.3)	-1.252 (-3.2)
$500 \leq \bar{l} < 1000$	-1.217 (-9.4)	-1.239 (-5.4)	-0.926 (-2.4)	-0.794 (2.0)	0.652 (1.8)	-0.928 (-2.4)
$1000 \leq \bar{l} < 2000$	-1.115 (-8.5)	-1.267 (-5.5)	-0.658 (-1.7)	0.567 (1.4)	0.370 (0.9)	-0.652 (-1.6)
$2000 \leq \bar{l} < 5000$	-0.848 (-6.2)	-0.910 (-3.8)	-0.580 (-1.4)	0.530 (1.3)		-0.556 (-1.3)
divers	0.092 (4.2)	-0.035 (-1.6)	0.172 (4.8)	-0.118 (-3.3)	-0.142 (-2.8)	0.198 (5.6)
\bar{l}_p^s	-0.077 (-3.4)	-0.102 (-4.5)	0.037 (1.0)	-0.099 (-2.5)	0.109 (2.4)	0.147 (4.2)
cat ₁	0.342	0.639	0.627	0.294	0.080	0.627
obs	18232	18232	8341	8341	8258	8341

The estimation results for the survey response "innovation activity not required" are somewhat strange: firms less often report that innovations are not required, if output was increasing and a growing demand is expected. From the discussion of the two-step model above, it was expected that firm would report that innovation activities are not required if they are successful, i.e. exhibit more output growth and expect a growing market. Therefore, these results are not consistent with this model. That means, this response of the firms should be interpreted carefully, if at all: the results are consistent with the interpretation that those firms did not innovate, but it does not yield a clear indication for the reasons.

The results achieved for innovation impediments (imped) are more consistent: firms that exhibit a high capacity utilization, experience output increases, and expect a growing market less often report innovation impediments. This is consistent with, for instance, impediments due to the financing of innovation activities. Note that the most frequent reported innovation impediment in the ifo firm panel are financing constraints and too low returns.¹⁰⁸

The results for the measures of the market structure reveal that a high frequency of price changes in the sector tends to reduce the probability of innovation activities, and a high frequency of output changes promotes innovation activities. These results differ hardly from those for the implementation of innovations, that means, market power promotes both innovation activities and the implementation of innovations.

Innovation activities of other firms also increase the probability of own innovation activities which confirms the results which were achieved for the implementation of innovations. Again, the effect of the frequency of sectoral price changes becomes stronger and more significant, if the average sectoral innovation behaviour is skipped from the list of explanatory variables (see the last column of table 8). The results show also that innovations of other firms reduce both the probability to report innovation impediments and the response that innovations are not required. The results for the combined variables from the business survey (both, inno) reveal that product innovations of other firms exhibit a stronger effect on the implementation of innovations than process innovations of other firms. This confirms that for product innovations the positive spillover effects seem to be stronger; it is easier to imitate others products than others production technique.

Exporters exhibit a higher probability of innovation activities and less often report that innovations are not required. This corresponds to the positive effect of this variable on innovation implementations and innovation plans. Whether a firm exports the product does not exhibit an effect on reporting innovation impediments. The results for firm size also do not differ for innovation activities and the implementation of innovations. Again, this result also depicts a simple scale argument. However, innovation activities are also reported more often by diversified firms, and diversified firms less often report innovation impediments

¹⁰⁸Felder, Licht, Nerlinger, Smid (1993) report a similar result for the ZEW innovation panel.

or that innovations are not required. In addition, diversified firms more often report the implementation of both, product and process innovations. This indicates positive spillovers between innovation activities, and spillovers between the implementations of product and process innovations in diversified firms with many products.

Finally, the size of the other firms in the sector does not exhibit a significant effect on innovations activities. It increases the probability of innovation impediments, and reduces the probability of reporting that innovations are not required. This result is consistent with the interpretation that the positive effect from more competitive pressure of other (large) firms in the sector on the necessity of own innovations just outweighs the negative effect on the possibility to perform innovation activities. See also the negative effect from others capacity utilization on innovation activities.

Taken together, the empirical results reveal that innovation activities depend more on the long-run demand expectations and less on the short-run demand situation as compared with the implementation of innovations. This indicates less complementarity of innovation activities with capital investment, and less importance of the short-run financing conditions. The results for the determinants of innovation activities are consistent with an economic decision model: a high capacity utilization, output increases, positive demand expectations, and spillovers promote innovation activities. The results are also consistent with a two-step model, where in the first step innovation impediment must be overcome: impediments are more often reported in periods of slack demand (expectations), and more firms report impediments if prices are changed often and other firms are large in the sector. The results for the variable *notreq* are difficult to interpret: they are consistent with the interpretation that those firms do not innovate; they do not allow to draw conclusions for the reasons.¹⁰⁹

4.4 Innovation expenditures and investment

In table 9, the estimates for the quantitative innovation expenditures ie/s from the innovation survey are reported. In addition, the results for the total investment rate i/s , equipment investment i^e/s , and investment in structures i^s/s are depicted. For these variables, tobit models were estimated, because those variables cannot become negative.¹¹⁰ In the last rows, the sample means of the variables and the number of observations for the equations are reported. For innovation expenditures, slightly less than 8000 observations, and for investment, slightly less than 11000 observations are available. For the investment equation, the diversified firms are excluded from the sample. Since the model is estimated

¹⁰⁹The tests for a bias due to endogenous attrition are again depicted in table 21 in the appendix. The estimates reveals that leavers less often report innovation activities. Again, the coefficients of the other explanatory variables remain nearly unchanged.

¹¹⁰Note the large share of zeros especially for investments in structures and innovation expenditures (see figure 6 above).

by tobit, the coefficients reflect the effects on the latent variables, not on the means of the variables.

First, the results for the effects of the business cycle indicators on innovation rates do not reveal remarkable differences, as compared with the effects on the probability of innovation activities: the capacity utilization rate and price increases in the past do not exhibit a significant effect on innovation rates, but output increases and the expectation of a growing market increase innovations; a high capacity utilization of competitors reduces innovation expenditures.

However, the estimates allow to quantify the effects. For instance, a firm that had always reported output increases (decreases) in the preceding year, exhibits on average a more than 1 percentage point higher (lower) innovation rate, as compared with a firm that reported the same number of output increases and decreases ($-1 \leq \Delta y \leq 1$). In addition, firms that expect a growing market also exhibit a more than 1 percentage point higher (latent) innovation rate, as compared with firms that expect a stagnating or shrinking market. A 10 percentage points higher average capacity utilization rate of competitors leads to an about 1.6 percentage points lower innovation rate. Since the average innovation rate in the sample is about 2.8 percent (the standard deviation is about 5 percent), the relative demand situation exhibits a very strong effect on innovation behaviour.

Second, a large frequency of price changes in the sector reduces innovation rates which is again consistent with the interpretation that market power, i.e. a low absolute value of the price elasticity of demand, increases innovations. A large frequency of own output changes increases innovations, while a large frequency of output changes by other firms reduces innovation rates. This is consistent with the interpretation that firm-specific uncertainty is an incentive to perform innovation activities, while sectoral uncertainty affects innovation rates negatively.

Third, the estimates reveal again that the sectoral innovation behaviour is highly correlated. This result indicates positive spillovers between firms in the sector.¹¹¹ In addition, the higher innovation rates for exporters indicate spillovers from the foreign markets. The effect is quite large; exporters exhibit about 1.6 percentage points higher latent innovation rates, *ceteris paribus*. Note however that this variable is also an indicator of technological opportunity.

Fourth, firm size exhibits a very significant and quantitatively strong effect on innovations rates. The empirical results reveal that small firm with less than 50 employees spend more than 7 percentage points less for innovations than large firms with more than 5000 employees, the reference case.¹¹² The coefficients indicate a clear positive relation between firm size and innovation rates. That means, the fixed cost argument is very important for innovation behaviour. In addition, the about 1 percentage point higher innovation rates of diversified firms

¹¹¹ Again, the effect from price changes is larger if the sectoral innovation behaviour is skipped from the list of explanatory variables.

¹¹² The estimated coefficients reflect the effect on the latent variable. The effect on the means is slightly lower. See also table 2.

Table 9: Innovation expenditures and investment

	ie/s	i/s	i^e/s	i^s/s	ie/s	i/s
<i>DUC</i>	0.006 (0.8)	0.037 (5.9)	0.027 (5.8)	0.029 (5.2)	0.005 (0.6)	0.037 (5.8)
Δp	-0.003 (-0.7)	-0.000 (-0.1)	-0.000 (-0.0)	-0.003 (-1.1)	-0.002 (-0.5)	0.001 (0.4)
Δy	0.013 (3.5)	0.008 (2.8)	0.008 (3.6)	0.005 (1.9)	0.012 (3.2)	0.008 (2.7)
demand ⁺	0.014 (7.1)	0.009 (5.8)	0.006 (5.5)	0.005 (4.1)	0.015 (7.7)	0.011 (7.0)
demand ⁻	-0.004 (-1.5)	-0.001 (-0.5)	0.001 (0.9)	-0.006 (-3.2)	-0.005 (-1.8)	-0.002 (-1.1)
<i>DUC</i> ^s	-0.159 (-5.0)	-0.135 (-5.5)	-0.102 (-5.5)	-0.101 (-4.8)	-0.188 (-5.9)	-0.166 (-6.6)
pc	-0.002 (-0.3)	-0.003 (-0.8)	-0.001 (-0.3)	-0.000 (-0.1)	-0.002 (-0.4)	-0.006 (-1.6)
pc ^s	-0.058 (-4.2)	0.021 (2.1)	0.016 (2.1)	0.034 (4.0)	-0.084 (-6.2)	0.040 (3.9)
yc	0.016 (4.6)	0.001 (0.4)	0.001 (0.3)	-0.001 (-0.3)	0.016 (4.6)	0.001 (0.5)
yc ^s	-0.060 (-3.1)	0.025 (1.7)	0.025 (2.3)	0.011 (0.9)	-0.087 (-4.5)	0.033 (2.3)
ie/s^s	0.550 (8.2)					
i/s^s		0.673 (19.3)	0.600 (22.9)	0.226 (7.6)		
export	0.016 (6.1)	-0.006 (-3.3)	-0.006 (-4.2)	0.003 (1.9)	0.017 (6.5)	-0.010 (-5.4)
$\bar{l} < 20$	-0.090 (-10.4)	-0.013 (-2.7)	-0.014 (-3.8)	-0.047 (-10.7)	-0.093 (-10.7)	-0.011 (-2.2)
$20 \leq \bar{l} < 50$	-0.074 (-9.0)	-0.006 (-1.4)	-0.007 (-2.3)	-0.037 (-10.7)	-0.078 (-9.4)	-0.002 (-0.5)
$50 \leq \bar{l} < 100$	-0.067 (-8.3)	-0.004 (-1.0)	-0.006 (-2.0)	-0.031 (-9.5)	-0.070 (-8.6)	-0.003 (-0.6)
$100 \leq \bar{l} < 200$	-0.055 (-6.8)	0.000 (0.1)	-0.003 (-0.9)	-0.022 (-7.2)	-0.058 (-7.2)	0.001 (0.2)
$200 \leq \bar{l} < 500$	-0.047 (-6.0)	0.001 (0.2)	-0.002 (-0.6)	-0.016 (-5.6)	-0.049 (-6.2)	0.003 (0.8)
$500 \leq \bar{l} < 1000$	-0.044 (-5.5)	-0.001 (-0.2)	-0.002 (-0.6)	-0.008 (-2.8)	-0.045 (-5.5)	0.000 (0.1)
$1000 \leq \bar{l} < 2000$	-0.031 (-3.6)	0.004 (1.0)	0.001 (0.4)	-0.001 (-0.2)	-0.033 (-3.8)	0.005 (1.2)
$2000 \leq \bar{l} < 5000$	-0.023 (-2.6)	-0.001 (-0.3)	-0.002 (-0.5)	-0.001 (-0.3)	-0.024 (-2.6)	-0.001 (-0.3)
divers	0.010 (5.3)				0.012 (5.9)	
\bar{l}^s	0.001 (0.8)	-0.001 (-2.4)	-0.001 (-3.4)	0.000 (0.7)	0.007 (3.8)	-0.000 (-1.1)
mean	0.028	0.051	0.042	0.009	0.028	0.051
obs	7872	10819	10796	10796	7872	10819

indicate positive spillovers between innovation expenditures for different products and/or an easier financing of innovations in large firms. These effects outweigh the negative effects of firm size on individual efforts and more bureaucratic inertia in large firms. The size of other firms in the sector does not exhibit a significant effect on innovation expenditures; the same result was revealed for the probability of innovation activities above.

The results for investment are contained in the next columns. The model is estimated for the total investment rates, and distinguished for structures and equipment. First, the capacity utilization rate exhibits the expected positive and significant effect on investment. This confirms both the assumptions of a slow adjustment of capacities and the autocorrelation of demand shocks. The effect is of about equal importance for total investment i/s , equipment investment i^e/s , and investment in structures i^s/s . A high capacity utilization of competing firms, on the other hand, strongly reduces investment. This confirms that competitive pressure from other firms affects the long-run decision on investment (and innovation activities) negatively.

Price increases in the past do not exhibit a significant effect on investment, but output increases in the past. This confirms that investment is related more to the development of quantities, and less to the development of prices, as expected. The basic model of capacity adjustment implies a linear homogeneity of capacities and output. Firms that expect a growing market exhibit an about 1 percentage point higher latent investment rate than firms that expect a stagnating market. The expectation of a demand increase affects to an about equal extent equipment investment and investment in structures. Notable is also the negative effect of an expected shrinking of demand on investment in structures. These results show that innovations and investment depend on the same set of variables, albeit with a different weighting for each: price increases affect only the implementation of innovations, capacity utilization affects mainly investment and the implementation of innovations, output increases and expected demand affect the implementation of innovations, innovation activities, and investment.

The effects of the market structure variables are different for investment and innovations. The effect of a high frequency of price changes in the sector on investment is positive which indicates a negative effect of market power on investment. Albeit the coefficient is only weakly significant, it is consistent with the theoretical model: a lower absolute value of the price elasticity of demand should lead to price increases and output (capacity) decreases. A high frequency of output changes in the sector also exhibits a positive effect on investment. The effect is again only weakly significant; it would imply that sectoral uncertainty exhibits a positive effect on investment. The investment shares of the other firms in the sector also exhibit a positive effect. This variable captures, to a large extent, the different capital intensities of the sectors. The innovation behaviour of the other firms is not introduced as an explanatory variable for investment: sectoral innovations are highly correlated with own innovations which are endogenous.

Therefore, sectoral innovations cannot be treated as exogenous in the investment equations.

Remarkable are the lower equipment (and total) investment rates of exporters. This can reflect the stronger competition on the world market which forces firms to a careful investment policy. For this variable, the results for innovations and investment differs sharply. While for innovations, the positive spillover effect outweighs the negative effects from more competitive pressure, for investment the second effect dominates. Remarkable is also that firm size exhibits only a small effect on equipment (and total) investment. The results reveal that small firms with less than 100 employees exhibit lower equipment investment rates, but the investment rates of medium-size and large firms do not differ significantly. The size of other firms, on the other hand, exhibits a negative effect on equipment investment. This result corresponds to the negative effect of this variable on the probability to implement innovations.¹¹³

Finally, the equations were again tested for a sample selection bias due to endogenous attrition. The results in table 21 reveal that prospective leavers of the panel exhibit about 1 percentage point lower innovation and investment rates. This result indicates again the long-run nature of innovation and investment projects: firms that exhibit a higher probability to leave the market invest and innovate less. Again, the coefficients of the variables of the economic model remain nearly unchanged.

4.5 Summary of estimation results

In the previous sections, the estimation results for innovations and investment were discussed in detail. The following conclusions can be drawn:

- First, the rate of capacity utilization strongly affects investment. This confirms the basic model of capacity adjustment. The positive effect on the implementation of innovations indicates complementarities especially between process innovations and investment. New production processes are implemented with capital investment. The cross-tabulations revealed that the direct complementarity between product innovations and investment seems to be low. However, the implementation of product innovations seems to be complementary with the implementation of process innovations. New products require new production processes and/or new production processes allow to produce better products.
- Output increases in the past and the medium-run demand expectations affect all kinds of innovation activities, innovation plans, and investment. This confirms that growing markets favour innovations and investment. The capacity utilization of other firms in the sector, on the other hand, reduces own innovations and investment. However, the total effect of the

¹¹³Since the sample excludes the diversified firms, this variable is left out.

business cycle on innovations and investment is positive. The effects of the firm-specific business cycle indicators outweigh the effect of others capacity utilization. That means, short-run demand disturbances affect long-run growth. The complementarity of innovations and investment, the effect of cash flows on the financing conditions, and the expectation of a growing markets outweigh the effect of lower opportunity costs in recessions and intertemporal substitution. The short-run business situation affects mainly the implementation of innovations, innovation *activities*, in contrast, depend more on output increases and longer-run demand expectations.

- Price increases in the past affect especially the implementation of product innovations, a significant effect on the implementation of process innovations, innovation activities, and investment is not revealed. This indicates that past periods' profits and cash flows affect the financing conditions. It indicates also a positive effect of market power on product innovations. The positive effect of market power is confirmed by the strongly negative effect of the frequency of own and sectoral price changes. A negative effect of the frequency of price changes is also revealed for the implementation of process innovations and innovation activities, the effect on investment is positive. Market power promotes innovations, but not investment.
- Innovations depend positively on other firms' innovations. This indicates that the positive spillover effect outweighs the negative effect from less appropriability of the returns from innovations. The effect is stronger for product innovations than for process innovations: it is easier to imitate others new products than others production processes. The positive effect of others innovations may also stem from (exogenous) technological opportunities conditions for innovations. However, it is also revealed for a fixed effects model.

Positive spillover effects are also indicated by the higher probability of innovations and the higher innovation rates of exporters. The investment rates of exporters, on the other hand, are lower. For innovations, the positive spillover effect outweighs the negative effects from more competitive pressure, for investment the second effect dominates.

The data also reveal a high autocorrelation of innovation behaviour. It is not clear yet, to what extent this effect is caused by an autocorrelation of the determinants of innovations, past innovations as an indicator of technological opportunities, or whether past innovations affect the returns of current innovations. A more detailed investigation of this issue is on the agenda for future research.

- Firm size increases both the probability of innovations and the amount of innovation expenditures relative to sales. An impact on the composition of innovation activities is not revealed, the effect on investment is small.

Diversified firms also spend more for innovations, and more often implement both, product and process innovations. This indicates that the positive effect of scale economies associated with innovations, and the effects on the financing conditions outweigh the negative effect of less incentives and more bureaucratic inertia in large firms. The size of other firms, on the other hand, exhibits a negative effect on innovations (and investment), but the total effect of firm size on innovations is positive. The positive effect of own firm size clearly outweighs the negative effect of others firm size.

- Finally, the model equations were tested for a sample selection bias due to endogenous attrition. The estimation results revealed that attrition is endogenous. Firms which exhibit a higher capacity utilization, more output growth, and expect a growing market leave the panel less often. This indicates that leaving the panel can be seen as an indicator of leaving the market. In addition, the estimation results revealed that prospective leavers of the panel exhibit a significantly lower innovation probability, lower innovation rates, and lower investment rates. The coefficients of the economic model did not change much with the introduction of dummies for exits or leavers. This result is comfortable, it does not destroy the confidence into the coefficients of the economic model.

5 Conclusions

Innovations increase the quality of goods and reduce the input requirement. In Smolny (1996), the effects of innovations on output, employment, and prices were analysed. It was found that innovative firms are more successful; they exhibit a higher capacity utilization and more output and employment growth. In addition, innovations change the market structure; the results are consistent with a temporary monopolistic situation of product innovators.

On the other hand, innovations depend on the market structure and on the business cycle situation of the firm. In this paper, a theoretical model of the determinants of innovative behaviour and investment is developed. It is assumed that the price, output, and employment adjustment of the firms takes place in the short run, while innovations and investment are determined in the long run. Innovations are treated as investments in knowledge capital, analogously to investments in physical capital. The assumption of a delayed adjustment of innovations and investment under uncertainty of demand allows to discuss business cycle induced effects consistently within the framework of the theoretical model. Demand shocks affect prices and output in the short run, and affect the financing conditions for innovations and investment. The complementarity of innovations and investment emphasizes the similarity of the investment and innovation decision. Market power affects innovation through effects on the financing conditions, and firm size is important in case of scale economies associated with innovations. A measure of the market structure is derived from the price-setting behaviour

of the firms.

The model is estimated with micro data for West-German manufacturing firms from the ifo firm panel. The empirical results revealed that the different business cycle indicators exhibit a strong positive effect on innovation behaviour and investment. That means, short-run demand disturbances and the business cycle affect long-run growth. This confirms the results which were achieved with sectoral data in Smolny (1995a). Therefore, a successful stabilization policy can promote long-run growth. Firm size and market power also promote innovations, a significant effect on investment was not found. This indicates scale economies associated with innovations, and hints towards the financing of innovation activities out of cash flow and retained profits. This provides an argument for the importance of an efficient financial system for long-run growth.

Innovations of competitors also strongly promote own innovation activities. This indicates that own innovations and others innovations are complementary. Firms imitate others new products and production processes; the positive spillover effects outweigh the negative effects from more competitive pressure and less appropriability of the returns of innovations. The finding of positive spillovers between firms within a sector complements the finding of inter-sectoral spillovers in Smolny (1995a,b). The direct estimation of the extent of productivity spillover between firms is contained in Smolny (1997). Spillover effects from international trade are indicated by the higher innovation probability and the higher innovation rates of exporters. This confirms the finding of intra-sectoral across-border spillovers and productivity convergence in Smolny (1995b).

Endogenous innovations and knowledge spillovers are important concepts in recent models of endogenous growth. From a theoretical perspective, they allow to understand technological change as endogenously determined by the profit maximizing behaviour of competing firms within the economic system. From a welfare economic perspective, knowledge spillovers deserve attention since they indicate an inefficiency of a decentralized market system. If knowledge is distributed for free, firms have too low incentive to engage in innovative activities. Knowledge spillovers supply an argument in favour of a economic policy which promotes R&D. In addition, spillovers across borders supply an argument for a policy which promotes international cooperation through trade and foreign direct investment. This enhances the interest into further empirical investigations of the determinants of innovations and the extent of spillovers.

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Appendix

Table 10: List of variables

innovations from the business survey
prod: dummy variable, 1 for product innovation
proc: dummy variable, 1 for process innovation
stop: dummy variable, innovation stopped
planc: dummy variable, planning stage of innovation completed
plan: dummy variable, innovation still in planning stage
notint: dummy variable, innovation not intended
both: dummy variable, product and process innovations implemented
inno: dummy variable, product or process innovation implemented
innovations from the innovation survey
ia: dummy variable, 1 for innovation activity
notreq: dummy variable, innovation not required
imped: dummy variable, no innovation due to impediments
ia, notreq, and imped sum up to 1
ie/s: share of innovation expenditures in sales
investment
i/s: share of investment in sales
i ^e /s: share of equipment investment in sales
i ^s /s: share of investment in structures in sales
explanatory variables
DUC: capacity utilization, $0.3 \leq DUC \leq 1.0$
pc: number of price changes relative to the number of observations
p ⁺ : difference between the number of price increases and price decreases in relation to the number of observations
yc, y ⁺ : are the corresponding variables for output, the variables are calculated for each year and each firm
demand ⁺ : dummy var., expected medium-run (5 years) increase of demand
demand ⁻ : dummy var., expected medium-run (5 years) decrease of demand
\bar{l}^p : average employment at the product level
\bar{l}^f : average employment at the firm level
divers: dummy variable for diversified firm, i.e. 1 for $\bar{l}^p \leq 0.5 \cdot \bar{l}^f$
export: dummy variable, 1 if the product is exported

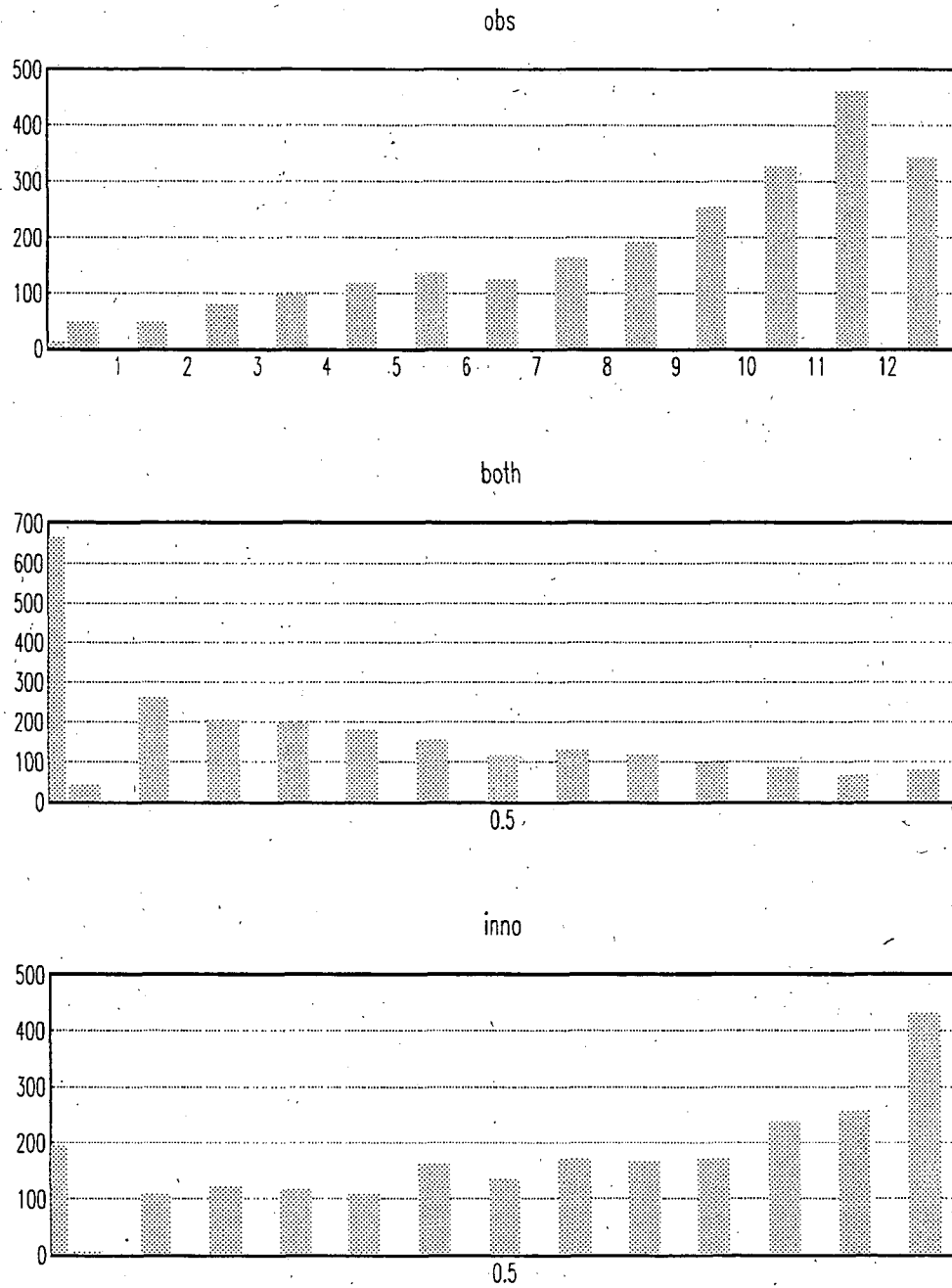
Most variables refer to the product, only investment refers to the firm level. The suffix ^s denotes the averages for each sector, calculated excluding the respective firm.

Table 11: 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.

Figure 7: Product and process innovations



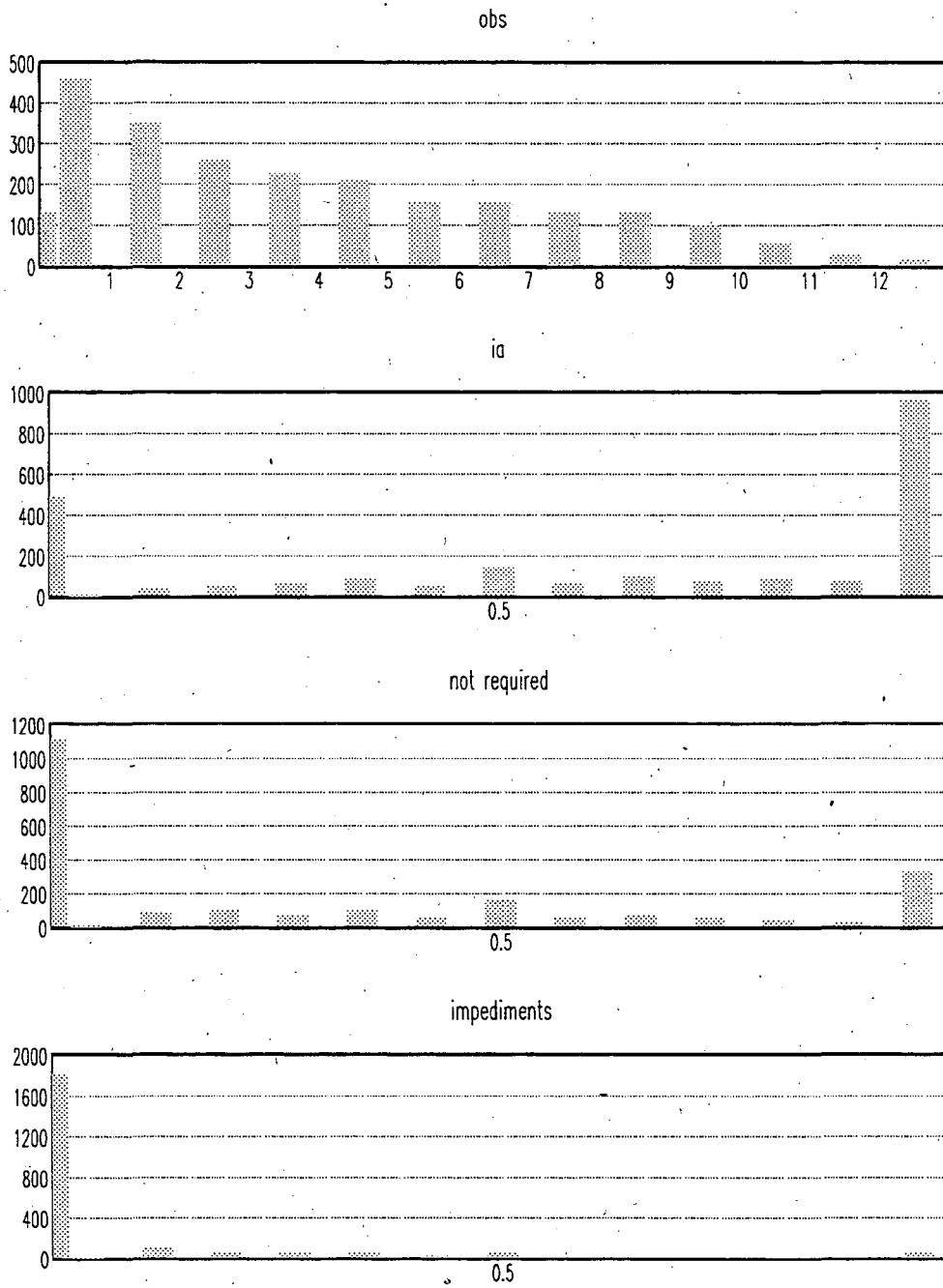
Source: ifo firm panel, 2405 firms, 13 years (1980-92)
 The first bar denotes 0, the class width is 1 (1/13).

Table 12: Sectoral product and process innovations

sector	prod	stop	planc	plan	notint	proc	stop	planc	plan	notint	obs
21	0.330	0.018	0.076	0.162	0.382	0.358	0.010	0.102	0.169	0.262	905
22	0.405	0.026	0.073	0.103	0.358	0.409	0.004	0.086	0.190	0.250	232
23	0.368	0.006	0.122	0.190	0.340	0.465	0.008	0.173	0.252	0.241	353
24	0.379	0.000	0.190	0.207	0.431	0.466	0.000	0.241	0.241	0.414	58
25	0.450	0.015	0.081	0.225	0.295	0.413	0.007	0.100	0.181	0.306	271
26	0.206	0.009	0.056	0.125	0.499	0.300	0.011	0.095	0.133	0.395	751
27	0.324	0.004	0.073	0.153	0.427	0.427	0.006	0.094	0.190	0.297	522
28	0.677	0.000	0.228	0.346	0.126	0.496	0.000	0.142	0.268	0.157	127
31	0.404	0.007	0.072	0.205	0.328	0.356	0.007	0.088	0.174	0.300	570
32	0.647	0.011	0.172	0.327	0.106	0.510	0.008	0.149	0.269	0.145	3467
33	0.670	0.032	0.161	0.292	0.142	0.572	0.018	0.168	0.275	0.164	719
34	0.684	0.021	0.192	0.323	0.094	0.625	0.009	0.160	0.282	0.105	1679
35	0.612	0.021	0.133	0.242	0.176	0.447	0.010	0.098	0.183	0.197	722
37	0.408	0.017	0.101	0.226	0.284	0.487	0.013	0.153	0.237	0.205	779
38	0.494	0.019	0.131	0.265	0.254	0.487	0.014	0.130	0.239	0.213	1156
411	0.670	0.017	0.111	0.153	0.149	0.628	0.021	0.153	0.205	0.125	288
412	0.578	0.025	0.096	0.240	0.223	0.509	0.013	0.144	0.238	0.198	529
42	0.590	0.012	0.090	0.199	0.190	0.447	0.014	0.111	0.200	0.200	1113
43	0.570	0.009	0.085	0.188	0.229	0.480	0.018	0.094	0.139	0.247	223
441	0.342	0.008	0.055	0.146	0.407	0.383	0.012	0.074	0.178	0.320	1034
442	0.238	0.007	0.047	0.140	0.423	0.409	0.007	0.097	0.176	0.271	1633
45	0.472	0.028	0.086	0.247	0.242	0.440	0.012	0.095	0.230	0.231	995
46	0.490	0.006	0.050	0.184	0.332	0.378	0.002	0.084	0.184	0.376	500
471	0.583	0.008	0.064	0.146	0.237	0.492	0.006	0.087	0.141	0.277	1491
472	0.495	0.004	0.070	0.148	0.280	0.392	0.004	0.080	0.132	0.330	515
51	0.416	0.017	0.086	0.218	0.313	0.365	0.012	0.102	0.200	0.266	1513
52	0.511	0.022	0.174	0.239	0.337	0.522	0.022	0.120	0.207	0.272	92
total	0.497	0.014	0.108	0.224	0.255	0.459	0.010	0.118	0.212	0.229	22237

Source: ifo firm panel. The sector definitions are contained in table 11.

Figure 8: Innovation activities



Source: ifo firm panel, 2405 firms, 13 years (1980-92)
 The first bar denotes 0, the class width is 1 (1/13).

Table 13: Innovation activities

year	both	inno	obs	ia	notreq	imped	obs
1980	0.349	0.653	1007	1.000	0.000	0.000	321
1981	0.260	0.563	1860	1.000	0.000	0.000	380
1982	0.288	0.593	1866	0.625	0.247	0.128	803
1983	0.298	0.581	1924	0.565	0.327	0.108	834
1984	0.324	0.612	1912	0.612	0.309	0.079	910
1985	0.319	0.628	1897	0.596	0.322	0.082	839
1986	0.340	0.622	1858	0.635	0.280	0.085	996
1987	0.339	0.630	1766	0.630	0.289	0.080	933
1988	0.362	0.653	1736	0.663	0.269	0.068	898
1989	0.382	0.679	1710	0.665	0.273	0.062	853
1990	0.346	0.658	1647	0.621	0.327	0.052	869
1991	0.358	0.657	1573	0.604	0.336	0.060	762
1992	0.351	0.646	1481	0.532	0.379	0.088	838
size							
$\bar{l} < 20$	0.092	0.294	1559	0.261	0.512	0.226	853
$20 \leq \bar{l} < 50$	0.141	0.447	3072	0.418	0.471	0.112	1578
$50 \leq \bar{l} < 100$	0.244	0.550	3839	0.562	0.341	0.098	1884
$100 \leq \bar{l} < 200$	0.345	0.663	4537	0.692	0.258	0.050	1958
$200 \leq \bar{l} < 500$	0.395	0.715	5026	0.777	0.183	0.040	2196
$500 \leq \bar{l} < 1000$	0.490	0.783	2089	0.854	0.118	0.028	925
$1000 \leq \bar{l} < 2000$	0.531	0.780	1195	0.906	0.082	0.012	427
$2000 \leq \bar{l} < 5000$	0.642	0.874	642	0.934	0.062	0.004	258
$5000 \leq \bar{l}$	0.853	0.983	232	0.991	0.009	0.000	108
total	0.330	0.626	22237	0.641	0.284	0.076	10236

Source: ifo firm panel.

Table 14: Sectoral innovation activities

sector	both	inno	obs	ia	notreq	imped	obs
21	0.182	0.506	905	0.521	0.437	0.042	522
22	0.272	0.543	232	0.592	0.320	0.088	125
23	0.272	0.561	353	0.821	0.139	0.040	173
24	0.276	0.569	58	0.742	0.226	0.032	31
25	0.325	0.539	271	0.511	0.388	0.101	139
26	0.129	0.377	751	0.332	0.429	0.239	452
27	0.245	0.506	522	0.483	0.457	0.060	234
28	0.409	0.764	127	0.772	0.140	0.088	57
31	0.218	0.542	570	0.692	0.258	0.050	240
32	0.420	0.738	3467	0.849	0.113	0.037	1475
33	0.495	0.747	719	0.874	0.048	0.078	294
34	0.523	0.787	1679	0.897	0.077	0.025	594
35	0.371	0.688	722	0.711	0.179	0.110	346
37	0.303	0.592	779	0.655	0.273	0.072	388
38	0.356	0.625	1156	0.632	0.272	0.096	573
411	0.479	0.819	288	0.842	0.120	0.038	133
412	0.405	0.682	529	0.714	0.241	0.045	199
42	0.347	0.691	1113	0.652	0.280	0.068	528
43	0.386	0.664	223	0.584	0.327	0.088	113
441	0.237	0.488	1034	0.429	0.455	0.117	462
442	0.160	0.487	1633	0.468	0.452	0.081	832
45	0.307	0.606	995	0.620	0.288	0.092	489
46	0.294	0.574	500	0.568	0.415	0.017	229
471	0.393	0.681	1491	0.654	0.280	0.066	546
472	0.274	0.614	515	0.450	0.437	0.114	229
51	0.235	0.546	1513	0.534	0.376	0.090	785
52	0.413	0.620	92	0.750	0.208	0.042	48
total	0.330	0.626	22237	0.641	0.284	0.076	10236

Source: ifo firm panel. The sector definitions are contained in table 11.

Table 15: Sectoral innovation expenditures and investment

sector	ie/s	σ	obs	i/s	σ	obs	i^e/s	σ	i^s/s	σ	obs
21	0.024	0.064	490	0.103	0.125	694	0.085	0.102	0.016	0.040	693
22	0.020	0.032	114	0.062	0.074	101	0.051	0.060	0.011	0.032	101
23	0.025	0.049	149	0.040	0.030	237	0.031	0.021	0.009	0.017	237
24	0.004	0.006	28	0.016	0.017	60	0.016	0.017	0.001	0.001	60
25	0.023	0.044	118	0.049	0.064	146	0.044	0.060	0.005	0.013	146
26	0.023	0.069	423	0.064	0.105	538	0.053	0.084	0.012	0.036	536
27	0.030	0.099	212	0.086	0.147	252	0.071	0.119	0.015	0.038	251
28	0.017	0.020	54	0.041	0.025	94	0.037	0.022	0.005	0.008	94
31	0.021	0.035	222	0.029	0.026	403	0.024	0.018	0.005	0.014	403
32	0.038	0.046	1308	0.041	0.051	2162	0.033	0.030	0.009	0.033	2158
33	0.058	0.061	271	0.049	0.044	509	0.039	0.029	0.010	0.029	509
34	0.059	0.061	517	0.054	0.042	690	0.044	0.026	0.010	0.027	689
35	0.046	0.063	315	0.037	0.035	495	0.030	0.025	0.006	0.021	494
37	0.021	0.031	350	0.052	0.044	547	0.044	0.035	0.008	0.023	547
38	0.024	0.038	520	0.040	0.042	706	0.034	0.030	0.006	0.027	703
411	0.034	0.042	120	0.046	0.041	232	0.040	0.036	0.006	0.010	232
412	0.035	0.058	178	0.061	0.049	297	0.049	0.040	0.011	0.025	297
42	0.019	0.029	474	0.039	0.055	776	0.026	0.025	0.013	0.045	771
43	0.030	0.040	107	0.049	0.054	200	0.044	0.045	0.005	0.017	200
441	0.018	0.048	436	0.058	0.083	732	0.046	0.052	0.012	0.052	729
442	0.022	0.054	779	0.074	0.098	1574	0.062	0.073	0.012	0.047	1570
45	0.027	0.043	463	0.065	0.067	528	0.051	0.041	0.014	0.049	528
46	0.012	0.024	213	0.021	0.030	335	0.016	0.022	0.005	0.019	333
471	0.025	0.046	479	0.037	0.040	807	0.032	0.032	0.005	0.020	805
472	0.010	0.025	215	0.020	0.075	367	0.015	0.029	0.005	0.048	366
51	0.016	0.038	720	0.047	0.058	1129	0.038	0.046	0.008	0.023	1128
52	0.008	0.010	43	0.031	0.070	51	0.024	0.049	0.006	0.024	51
total	0.028	0.051	9318	0.051	0.071	14662	0.042	0.053	0.009	0.034	14631

Source: ifo firm panel. The sector definitions are contained in table 11.

Table 16: Price and output changes

year	Δp	σ	pc	σ	Δy	σ	yc	σ	obs
1980	0.129	0.199	0.196	0.198	-0.060	0.256	0.302	0.258	2156
1981	0.099	0.231	0.193	0.205	-0.148	0.276	0.348	0.269	2194
1982	0.014	0.237	0.179	0.203	-0.179	0.270	0.374	0.262	2222
1983	0.033	0.191	0.140	0.180	-0.031	0.267	0.336	0.257	2272
1984	0.078	0.230	0.167	0.208	0.001	0.254	0.327	0.255	2287
1985	0.051	0.190	0.139	0.177	0.015	0.252	0.305	0.255	2319
1986	0.019	0.189	0.129	0.169	-0.003	0.245	0.297	0.256	2267
1987	0.018	0.187	0.126	0.178	-0.050	0.249	0.300	0.257	2219
1988	0.087	0.211	0.146	0.199	0.034	0.259	0.299	0.262	2177
1989	0.124	0.223	0.167	0.211	0.075	0.256	0.283	0.263	2116
1990	0.105	0.212	0.167	0.199	0.079	0.256	0.273	0.261	2037
1991	0.067	0.222	0.163	0.197	-0.043	0.283	0.301	0.263	1950
1992	-0.014	0.229	0.167	0.198	-0.176	0.286	0.358	0.273	1853
size									
$\bar{l} < 20$	0.038	0.231	0.151	0.202	-0.096	0.273	0.329	0.269	2147
$20 \leq \bar{l} < 50$	0.044	0.249	0.186	0.219	-0.067	0.284	0.326	0.264	4014
$50 \leq \bar{l} < 100$	0.075	0.228	0.169	0.199	-0.034	0.293	0.339	0.261	4860
$100 \leq \bar{l} < 200$	0.068	0.220	0.165	0.201	-0.024	0.274	0.323	0.258	5774
$200 \leq \bar{l} < 500$	0.068	0.200	0.152	0.182	-0.028	0.261	0.304	0.256	6096
$500 \leq \bar{l} < 1000$	0.064	0.180	0.135	0.167	-0.021	0.259	0.288	0.264	2541
$1000 \leq \bar{l} < 2000$	0.070	0.181	0.148	0.186	-0.002	0.255	0.282	0.263	1443
$2000 \leq \bar{l} < 5000$	0.049	0.158	0.125	0.172	-0.006	0.257	0.278	0.265	815
$5000 \leq \bar{l}$	0.079	0.148	0.121	0.124	0.020	0.191	0.237	0.256	272
total	0.062	0.216	0.160	0.195	-0.036	0.274	0.315	0.262	28069

Source: ifo firm panel.

Table 17: Sectoral price and output changes

sector	Δp	σ	pc	σ	Δy	σ	yc	σ	obs
21	0.013	0.219	0.149	0.189	-0.075	0.256	0.344	0.265	1107
22	0.112	0.224	0.182	0.193	-0.004	0.332	0.401	0.271	318
23	0.013	0.352	0.346	0.296	-0.062	0.263	0.291	0.248	457
24	0.004	0.252	0.569	0.344	-0.034	0.204	0.223	0.250	93
25	0.031	0.242	0.167	0.216	-0.049	0.244	0.305	0.271	371
26	-0.005	0.326	0.271	0.264	-0.099	0.242	0.264	0.258	1003
27	0.052	0.325	0.287	0.243	-0.036	0.248	0.248	0.218	647
28	-0.002	0.253	0.174	0.213	-0.049	0.227	0.181	0.227	202
31	0.013	0.222	0.146	0.186	-0.051	0.289	0.270	0.250	835
32	0.069	0.135	0.105	0.123	-0.040	0.270	0.273	0.254	4169
33	0.080	0.173	0.125	0.153	-0.014	0.260	0.295	0.257	882
34	0.075	0.154	0.119	0.137	-0.008	0.271	0.300	0.262	2011
35	0.088	0.138	0.112	0.131	-0.047	0.285	0.289	0.265	934
37	0.091	0.249	0.195	0.211	-0.037	0.294	0.338	0.267	1033
38	-0.077	0.130	0.112	0.119	-0.028	0.253	0.318	0.265	1384
411	0.096	0.160	0.134	0.154	-0.057	0.241	0.261	0.255	337
412	0.082	0.169	0.129	0.149	-0.060	0.281	0.318	0.262	636
42	0.076	0.161	0.127	0.140	-0.009	0.287	0.335	0.243	1377
43	0.098	0.225	0.153	0.204	-0.031	0.253	0.276	0.222	283
441	0.137	0.359	0.290	0.292	-0.005	0.320	0.357	0.259	1330
442	0.036	0.220	0.157	0.185	-0.020	0.273	0.398	0.247	2191
45	0.067	0.227	0.202	0.215	-0.058	0.291	0.362	0.252	1201
46	0.075	0.173	0.133	0.165	-0.061	0.240	0.248	0.255	654
471	0.051	0.214	0.148	0.195	-0.059	0.278	0.291	0.245	1922
472	0.066	0.150	0.108	0.133	-0.060	0.262	0.258	0.242	631
51	0.051	0.237	0.180	0.210	-0.004	0.276	0.399	0.296	1956
52	0.046	0.104	0.092	0.099	0.057	0.284	0.561	0.277	105
total	0.062	0.216	0.160	0.195	-0.036	0.274	0.315	0.262	28069

Source: ifo firm panel. The sector definitions are contained in table 11.

Table 18: Price and output changes

Price changes						net increases		
freq	obs	increase	decrease	no change	changes		Δp	Δy
0	3196	11468	22807	201	8406	-12	12	52
1	172	9017	2088	371	9087	-11	24	52
2	168	3849	1045	471	4429	-10	45	84
3	219	1535	662	566	2092	-9	78	157
4	268	831	435	707	1215	-8	97	220
5	301	458	339	925	856	-7	142	380
6	412	305	222	1144	606	-6	186	588
7	472	190	180	1492	436	-5	272	804
8	612	131	113	1993	301	-4	330	1169
9	995	105	89	3007	262	-3	517	1697
10	1796	85	52	4814	195	-2	779	2540
11	4140	48	25	7282	109	-1	1373	3723
12	18514	47	12	5096	75	0	9049	7634

Output changes								
freq	obs	increase	decrease	no change	changes			
0	3196	12369	10290	447	5400	1	8348	3358
1	172	5212	5079	744	3780	2	3523	2121
2	168	3586	3924	1053	3482	3	1373	1397
3	221	2548	2937	1496	3184	4	695	844
4	263	1771	2143	1752	2901	5	400	552
5	305	1225	1497	2198	2585	6	264	279
6	409	677	951	2397	2038	7	168	196
7	468	363	575	2760	1669	8	116	94
8	612	164	280	2891	1210	9	100	59
9	1001	79	196	2833	878	10	84	41
10	1779	44	92	2942	507	11	47	20
11	4104	23	53	2944	299	12	47	8
12	18567	8	52	3612	136			

Source: ifo firm panel.

Table 19: Other explanatory variables

year	DUC	σ	export	demand ⁺	demand ⁻	divers	\bar{l}_f	\bar{l}_p	exit	exit%
1980	0.842	0.117	0.806	0.322	0.108	0.332	1403	476	0	0.000
1981	0.804	0.130	0.809	0.226	0.129	0.332	1403	476	0	0.000
1982	0.778	0.134	0.807	0.206	0.101	0.332	1403	476	1	0.000
1983	0.792	0.133	0.805	0.412	0.138	0.332	1403	476	0	0.000
1984	0.813	0.136	0.813	0.404	0.167	0.332	1403	476	20	0.009
1985	0.830	0.135	0.813	0.431	0.134	0.332	1403	476	63	0.027
1986	0.834	0.128	0.817	0.409	0.159	0.332	1403	476	57	0.025
1987	0.824	0.133	0.829	0.392	0.188	0.332	1403	476	52	0.024
1988	0.843	0.125	0.822	0.546	0.093	0.332	1403	476	70	0.032
1989	0.866	0.117	0.847	0.656	0.064	0.332	1403	476	83	0.039
1990	0.880	0.108	0.845	0.679	0.070	0.332	1403	476	93	0.046
1991	0.861	0.110	0.855	0.541	0.124	0.332	1403	476	99	0.051
1992	0.819	0.119	0.850	0.401	0.213	0.332	1403	476		
size										
$\bar{l} < 20$	0.726	0.171	0.511	0.275	0.196	0.427	71	11	66	0.033
$20 \leq \bar{l} < 50$	0.798	0.131	0.668	0.355	0.157	0.345	129	33	112	0.030
$50 \leq \bar{l} < 100$	0.826	0.126	0.758	0.407	0.144	0.308	250	72	97	0.021
$100 \leq \bar{l} < 200$	0.838	0.120	0.868	0.460	0.119	0.370	571	142	105	0.020
$200 \leq \bar{l} < 500$	0.855	0.112	0.924	0.456	0.121	0.298	1146	317	89	0.016
$500 \leq \bar{l} < 1000$	0.859	0.108	0.979	0.510	0.094	0.304	2340	713	37	0.016
$1000 \leq \bar{l} < 2000$	0.859	0.110	0.967	0.491	0.115	0.345	5304	1350	10	0.007
$2000 \leq \bar{l} < 5000$	0.854	0.110	0.975	0.530	0.094	0.328	8717	3020	5	0.007
$5000 \leq \bar{l}$	0.858	0.118	0.974	0.658	0.054	0.227	28200	15520	0	0.000
total	0.829	0.129	0.824	0.433	0.130	0.332	1403	476	538	0.021

Source: ifo firm panel.

Table 20: Other explanatory variables

sector	DUC	σ	export	demand ⁺	demand ⁻	divers	\bar{l}_f	\bar{l}_p	exit	exit%
21	0.782	0.167	0.542	0.255	0.300	0.253	246	156	16	0.016
22	0.801	0.143	0.708	0.512	0.095	0.308	373	144	6	0.020
23	0.852	0.101	0.882	0.474	0.057	0.325	1329	578	7	0.017
24	0.807	0.124	0.495	0.179	0.478	0.250	2295	1486	2	0.023
25	0.789	0.127	0.804	0.387	0.106	0.371	6322	2789	15	0.043
26	0.818	0.145	0.765	0.317	0.128	0.360	354	92	17	0.018
27	0.919	0.087	0.939	0.592	0.052	0.545	1286	318	3	0.005
28	0.868	0.111	0.837	0.461	0.121	0.421	2716	906	8	0.042
31	0.818	0.138	0.831	0.310	0.186	0.430	1783	377	34	0.043
32	0.842	0.126	0.983	0.504	0.121	0.341	1594	745	35	0.009
33	0.801	0.137	0.955	0.520	0.079	0.370	10016	2738	29	0.035
34	0.836	0.110	0.981	0.580	0.073	0.579	4543	765	20	0.011
35	0.807	0.132	0.968	0.451	0.096	0.304	667	324	20	0.023
37	0.825	0.119	0.864	0.362	0.182	0.275	463	218	26	0.027
38	0.811	0.121	0.942	0.391	0.149	0.287	399	248	15	0.012
411	0.870	0.089	1.000	0.403	0.098	0.276	1564	694	8	0.025
412	0.846	0.124	0.904	0.400	0.126	0.438	747	343	22	0.038
42	0.837	0.127	0.815	0.487	0.120	0.170	269	201	18	0.014
43	0.817	0.115	0.813	0.410	0.109	0.148	365	178	12	0.045
441	0.833	0.125	0.618	0.453	0.147	0.276	399	150	28	0.023
442	0.821	0.115	0.364	0.502	0.082	0.130	198	160	37	0.018
45	0.776	0.131	0.893	0.537	0.068	0.429	285	120	12	0.011
46	0.882	0.128	0.983	0.249	0.222	0.364	357	219	21	0.034
471	0.853	0.136	0.963	0.290	0.191	0.432	632	283	50	0.028
472	0.874	0.116	0.805	0.323	0.223	0.189	362	214	14	0.024
51	0.807	0.117	0.638	0.343	0.104	0.276	516	214	58	0.032
52	0.779	0.166	0.867	0.366	0.280	0.300	950	556	5	0.050
total	0.829	0.129	0.824	0.433	0.130	0.332	1403	476	538	0.021

Source: ifo firm panel. The sector definitions are contained in table 11.

Table 21: Attrition

	exit	prod	prod	proc	proc	ia	ie/s	i/s
<i>DUC</i>	-1.018 (-5.3)	0.302 (3.2)	0.303 (3.2)	0.677 (7.4)	0.681 (7.2)	0.221 (1.6)	0.006 (0.7)	0.035 (5.6)
p ⁺	0.007 (0.1)	0.199 (3.8)	0.172 (3.1)	0.073 (1.4)	0.077 (1.5)	0.019 (0.2)	-0.002 (-0.6)	-0.000 (-0.1)
y ⁺	-0.285 (-2.8)	0.220 (5.0)	0.225 (4.9)	0.250 (5.8)	0.226 (5.0)	0.331 (4.8)	0.013 (3.4)	0.008 (2.8)
demand ⁺	-0.144 (-2.7)	0.272 (12.1)	0.274 (11.7)	0.233 (10.7)	0.237 (10.4)	0.231 (6.5)	0.014 (6.9)	0.008 (5.7)
demand ⁻	-0.007 (-0.1)	-0.064 (-2.0)	-0.061 (-1.8)	-0.029 (-0.9)	-0.028 (-0.8)	-0.066 (-1.4)	-0.004 (-1.4)	-0.001 (-0.3)
<i>DUC</i> ^s	0.588 (0.7)	-1.640 (-4.3)	-1.729 (-4.5)	-1.225 (-3.3)	-1.336 (-3.5)	-2.879 (-5.2)	-0.153 (-4.7)	-0.128 (-5.2)
pc	-0.186 (-1.3)	-0.205 (-3.5)	-0.210 (-3.4)	-0.013 (-0.2)	-0.010 (-0.2)	-0.014 (-0.2)	-0.002 (-0.4)	-0.003 (-0.9)
pc ^s	0.367 (1.1)	-0.739 (-4.2)	-0.736 (-4.0)	-0.461 (-2.9)	-0.484 (-3.0)	-1.087 (-4.4)	-0.060 (-4.3)	0.022 (2.2)
yc	0.102 (1.1)	0.208 (5.1)	0.201 (4.7)	0.142 (3.6)	0.137 (3.3)	0.392 (6.2)	0.016 (4.5)	0.001 (0.4)
yc ^s	0.388 (0.8)	-0.156 (-0.7)	-0.193 (-0.8)	0.210 (0.9)	0.216 (0.9)	-0.703 (-2.1)	-0.060 (-3.1)	0.025 (1.8)
sec. mean		1.366 (15.5)	1.370 (14.8)	0.868 (7.8)	0.861 (7.5)	0.935 (8.6)	0.539 (8.0)	0.657 (18.7)
export	0.087 (1.3)	0.438 (13.6)	0.444 (13.3)	0.183 (6.0)	0.176 (5.6)	0.366 (8.6)	0.016 (6.1)	-0.006 (-3.4)
$\bar{l} < 20$	0.738 (3.1)	-2.030 (-12.3)	-2.058 (-11.8)	-1.971 (-13.4)	-1.980 (-13.0)	-2.257 (-5.8)	-0.088 (-10.1)	-0.011 (-2.2)
$20 \leq \bar{l} < 50$	0.731 (3.2)	-1.837 (-11.4)	-1.859 (-10.9)	-1.785 (-12.5)	-1.800 (-12.1)	-1.929 (-5.0)	-0.073 (-8.8)	-0.004 (-0.9)
$50 \leq \bar{l} < 100$	0.655 (2.9)	-1.587 (-9.9)	-1.587 (-9.4)	-1.625 (-11.5)	-1.621 (-11.0)	-1.688 (-4.4)	-0.066 (-8.2)	-0.002 (-0.5)
$100 \leq \bar{l} < 200$	0.626 (2.8)	-1.362 (-8.5)	-1.373 (-8.1)	-1.396 (-9.9)	-1.404 (-9.6)	-1.385 (-3.6)	-0.053 (-6.7)	0.002 (0.4)
$200 \leq \bar{l} < 500$	0.510 (2.3)	-1.240 (-7.8)	-1.245 (-7.4)	-1.343 (-9.6)	-1.340 (-9.2)	-1.209 (-3.1)	-0.047 (-5.9)	0.002 (0.6)
$500 \leq \bar{l} < 1000$	0.485 (2.1)	-1.076 (-6.7)	-1.089 (-6.4)	-1.165 (-8.2)	-1.143 (-7.7)	-0.905 (-2.3)	-0.044 (-5.4)	0.000 (0.0)
$1000 \leq \bar{l} < 2000$	0.213 (0.8)	-1.106 (-6.8)	-1.109 (-6.4)	-1.056 (-7.3)	-1.041 (-6.9)	-0.647 (-1.6)	-0.030 (-3.5)	0.005 (1.2)
$2000 \leq \bar{l} < 5000$		-0.699 (-4.1)	-0.666 (-3.7)	-0.882 (-5.9)	-0.876 (-5.6)	-0.569 (-1.4)	-0.023 (-2.5)	-0.001 (-0.2)
divers	0.107 (2.2)	0.021 (1.0)	0.024 (1.1)	0.032 (1.5)	0.039 (1.8)	0.181 (5.1)	0.011 (5.4)	
\bar{l}^s	0.149 (3.6)	-0.093 (-4.3)	-0.096 (-4.3)	-0.077 (-3.6)	-0.081 (-3.7)	0.046 (1.2)	0.002 (0.9)	-0.001 (-2.1)
leaver		-0.042 (-1.4)		-0.092 (-3.1)		-0.259 (-5.6)	-0.008 (-2.8)	-0.010 (-5.2)
exit _t			-0.689 (-3.1)		-0.503 (-2.3)			
exit _{t+1}			-0.223 (-2.9)		-0.168 (-2.2)			
mean	0.026	0.511	0.510	0.469	0.467	0.627	0.028	0.051
obs	14570	18232	16849	18232	16849	8341	7872	10819