Price Adjustment at the Firm Level: A Theoretical and Empirical Analysis

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ABSTRACT. The price-setting behaviour of firms and the adjustment of prices with respect to changes in the economic environment is relevant for the short-run analysis of the business cycle as well as for the analysis of the long-run development of the market. In this paper, a theoretical model of the price adjustment of the firm is developed and estimated with a unique panel of firm-level data from West German manufacturing. The empirical results reveal that capacity constraints significantly affect the price setting. The price and quantity adjustment also depends significantly on variables that are related to competition.

1. Introduction

The price-setting behaviour of firms and the short-run adjustment of prices with respect to changes in the economic environment is relevant for the short-run analysis of the business cycle. In neoclassical models, an immediate or very fast adjustment of prices and permanent market clearing is assumed. Keynesian models, in contrast, emphasize the relevance of price rigidities, market disequilibria and quantity reactions. Both models yield opposite policy implications; therefore, the analysis of the relevance of price rigidities is important for economic policy. In this paper, a theoretical model of the microeconomic adjustment of prices under uncertainty about demand is developed. A special emphasis is placed on medium-run capacity constraints. In the model, a delayed adjustment of prices and employment is assumed. The analysis of a dynamic adjustment permits the consistent introduction of capacity constraints and uncertainty into the model. The analysis of the dynamics in terms of adjustment delays simplifies the theoretical analysis of the model; it reduces the dynamic decision problem of the firm into a sequence of static decision models which can be solved stepwise.

The price-setting behaviour of firms is also relevant for the analysis of the long-run development of market structure. In industrial economics, the interdependence of the price setting and the nature of competition is emphasized. This implies that the analysis of the price-setting behaviour can reveal important insights into the competitive situation on the markets. This is important for industrial policy and antitrust legislation. In this paper, the relation of the price-setting behaviour of the firms and indicators of competition such as firm size and innovation activities is analysed. The price adjustment is analysed within a framework of monopolistic competition on the product market. The theoretical model yields testable hypotheses for the direction and the frequency of price and quantity adjustments depending on capacity constraints, the autocorrelation and the volatility of demand shocks, and the degree of competition on the market.

The main contribution of this paper is the empirical estimation of the model with a unique panel of micro data from West German manufacturing firms. The data set contains qualitative monthly information on the price adjustment and demand changes and quarterly information on the employment adjustment and capacity utilization for 2253 firms during the period 1980–1992. In addition, it contains annual data on firm size and the innovation behaviour of the firms. The firm-level data provide a valuable source for the analysis of price rigidities and the microeconomic adjustment of prices and quantities with respect to changes in demand and competition. The time-

Final version accepted on February 12, 2001

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Small Business Economics **17**: 167–184, 2001.

series dimension of the data permits the detailed analysis of the adjustment process, and the high frequency of the data permits the analysis of the volatility of price and quantity adjustments.

2. Theoretical model

2.1. *Assumptions*

In the theoretical model, a strong separability of the dynamic structure of the firms' decisions is assumed. It is assumed that prices and employment adjust only with a delay with respect to demand changes.[1] The advantage of this assumption, as compared with the assumption of an immediate adjustment and permanent market clearing, is that disequilibria and the adjustment dynamics of prices and quantities can be explicitely taken into account.

In most adjustment models, the dynamic adjustment is analysed under the assumption of non-linear adjustment costs. However, it is difficult to find examples for adjustment costs which can account for the observed slow adjustment of many economic variables, especially for prices. On the other hand, changing decision variables necessarily takes time, and even a short delay between the decision to change the price and the realization of a demand shock can introduce considerable uncertainty.[2] In addition, the analysis of the dynamic adjustment in terms of adjustment delays and uncertainty reduces the dynamic decision problem of the firm to a sequence of static decision models which can be solved stepwise: The determination of output takes place in the short run with predetermined prices, employment and capacities; the medium-run adjustment of prices and employment can be analysed under uncertainty about demand; investment, innovation behaviour and the production technology are determined in the long run; therefore capacities and the factor productivities can be treated as predetermined for the price and employment adjustment.

The theoretical analysis is carried out within a framework of monopolistic competition on the product market.[3] In order to distinguish demand shifts, the price elasticity of demand, and demand uncertainty, a log-linear demand curve for the firm's product is assumed,

$$\ln YD = \eta \cdot \ln p + \ln Z + \varepsilon, \quad E(\varepsilon) = 0, \quad \mathrm{Var}(\varepsilon) = \sigma^2. \tag{1}$$

The time and firm indices are omitted to simplify the notation. Each firm faces a firm-specific demand function depending on its price p, exogenous and predetermined demand shifts Z and an error term ε. Demand YD depends negatively on the price with constant elasticity $\eta < -1$; the realized value of the demand shock ε is not known at the time of the price and employment decision. It is assumed that product innovations of the firm and competitors' behaviour affect the price and employment adjustment via the parameters of the demand curve, i.e. the level of demand Z, the price elasticity of demand η, and demand uncertainty σ.

Supply YS is determined by a short-run limitational production function with capital K and labour L as inputs,[4]

$$YS = \min(YC, YL) = \min(\pi_k \cdot K, \pi_l \cdot L). \tag{2}$$

YC are capacities, YL is the employment constraint, and π_l, π_k are the productivities of labour and capital. It is assumed that process innovations affect production costs via the factor productivities π_l, π_k. Firm size affects both the demand curve and marginal costs.

2.2. *Price setting, demand uncertainty and capacity constraints*

According to the sequential structure of the firm's decisions, output Y is determined in the short run as the minimum of demand and supply, i.e. $Y = \min(YD, YS)$. The medium-run optimization problem is[5]

$$\max_{\to L,\, p} p \cdot E(Y) - w \cdot L - c \cdot K \tag{3}$$

s.t. Equations (1) and (2). E is the expectation operator, w are wage costs, and c are the user costs of capital. For the optimal solution, two cases can be distinguished:

1. In case of capacity constraints, supply and employment are determined from capacities and labour productivity, i.e. $YS = YL = YC$ and $L(YC) = YC/\pi_l$. The optimal price is determined as[6]

$$\ln p(YC) = \frac{\ln YC - \ln Z - \bar{\varepsilon}(\eta, \sigma)}{\eta}. \tag{4}$$

The price depends on capacities YC, expected demand shifts Z, and the optimal value of $\bar{\varepsilon}$, the borderline case which distinguishes the demand constrained regime from the supply constrained regime, $\bar{\varepsilon} := \ln YS - \eta \cdot \ln p - \ln Z$. The elasticity of the price with respect to supply and the demand shift is $1/\eta$; it can be shown that the optimal $\bar{\varepsilon}$ depends only on the price elasticity of demand η and demand uncertainty σ.

2. In case of sufficient capacities, the optimal price follows from the first order condition of Equation (3) with respect to employment,

$$\ln p(w) = \ln w - \ln \pi_l - \ln [1 - F_\varepsilon(\varepsilon = \bar{\varepsilon}(\eta, \sigma))]. \qquad (5)$$

Supply and employment are determined as $YL = \eta \cdot \ln p(w) + \ln Z + \bar{\varepsilon}(\eta, \sigma)$ and $L(w) = YL/\pi_l$. F_ε is the cumulative distribution function of the demand shock ε. The optimal price depends through a log-linear function on unit labour costs, the mark-up is determined by the optimal probability of the supply constrained regime. This probability, in turn, is completely determined by the price elasticity of demand and the variance of demand shocks. In case of sufficient capacities, the price is independent of demand shifts, the firm adjusts quantities with respect to demand. The optimal price can also be expressed as

$$p(w) = \frac{w}{U_l(\eta, \sigma) \cdot \pi_l \cdot (1 + 1/\eta)}. \qquad (6)$$

The optimal price is determined by the price elasticity of demand, unit labour costs and the expected utilization of employment $U_l := E(Y)/YL$. An immediate adjustment of prices is contained as the limiting case $\sigma \to 0$. In this case, $U_l \to 1$, and the firm can achieve full utilization of employment. Introducing uncertainty reduces the expected utilization of employment and exhibits the same effect on prices and employment as higher variable costs.

The model extends the standard formulation of monopolistic competition by introducing uncertainty about demand and medium-run capacity constraints. The assumption of a delayed adjustment of prices and employment enhances the economic interpretation of the model:

– Ex ante, the firm sets prices and employment under uncertainty about demand, i.e. the firm chooses one point in the $\{p, Y\}$-diagram (see Figure 1). Uncertainty increases the optimal price and reduces employment through the costs of underutilization of employment. Relevant for the price setting is a capacity limit $YS = YL \leq YC$ and a minimum price $p(w)$ which is determined by unit labour costs, the price elasticity of demand and demand uncertainty.

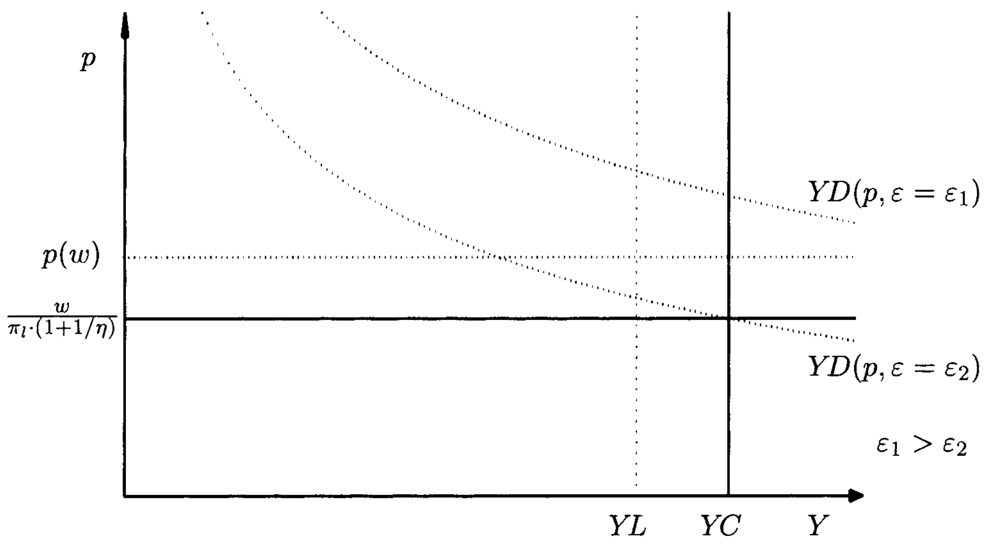


Figure 1. Optimal prices and employment.

In case of sufficient capacities, the regime probabilities are determined by the income distribution shares (see Equation (5)); the income distribution, in turn, is determined mainly by the price elasticity of demand (see Equation (6)).
- Ex post, rationing of demand or underutilization of capacities and labour can occur. In case of a positive demand shock $\varepsilon = \varepsilon_1$, the firm cannot satisfy all customers (delivery lags), in case of a negative demand shock $\varepsilon = \varepsilon_2$, underutilization of capacities and labour hoarding occur. Short-run demand shocks can be identified from the utilization of the production factors. The short-run demand situation can be identified from the utilization of employment at the firm level, the medium-run business-cycle situation can be identified from the utilization of capacities.

The model also provides a useful framework for the analysis of price rigidities and quantity adjustments during the business cycle. Suppose the stochastic process generating the demand shocks is autocorrelated. Then, a short-run demand shock affects the utilization of labour and capital today. The adjustment of the firm depends on the availability of capacities: In case of capacity constraints (in boom periods), the firm should adjust the price, and employment should remain unchanged; with sufficient capacities (in recession periods), the price should remain unchanged, and the firm should adjust employment. A similar asymmetry results in case of cost changes. In case of capacity constraints, prices and employment should remain unchanged; with sufficient capacities, prices and employment should adjust. That means, the model provides clear testable hypotheses about the effects of capacity utilization U on the direction Δp, ΔL and the frequency of price σ_p and quantity σ_L adjustments with respect to demand shocks (see Table I). The model can be understood as an error correction model for prices and employment: If the actual utilization of capacities differs from the optimum, prices and/or employment adjust.

The dynamic formulation of the model also provides a hypothesis about effects of the price elasticity of demand and demand uncertainty on the price and quantity adjustment.[7]

TABLE I
Capacity utilization and demand

	U	Z	$\lvert\eta\rvert$	σ
Δp	+	+	−	+
ΔL	+	+	+	−
σ_p	+		+	+
σ_L	−		−	+

- Demand uncertainty increases the variance of output and therefore increases average costs. Prices should be higher and employment should be lower. In addition, uncertainty should increase the necessity of price and employment adjustments; it becomes more difficult to achieve a high utilization of capacities and employment.
- A low price elasticity of demand $|\eta|$, i.e. less competition should result in higher prices and less employment. In addition less competition should favour quantity adjustments against price adjustments in case of demand shocks.

This means, the model also yields clear testable hypotheses about the impact of demand characteristics on price rigidities and price and quantity adjustments.

2.3. *Market behaviour, innovations and firm size*

Innovations affect the price and quantity adjustment through the demand curve and through marginal costs: Process innovations reduce production costs, and product innovations increase the quality of the product. Therefore, innovative firms should be more competitive and increase output and employment. On the other hand, firms introduce better products to achieve a monopolistic situation on the product market. Specialized products reduce the price elasticity of demand which can lead to higher prices and less output and employment. 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.[8]

Process innovations reduce production costs w/π_l which should result in lower prices and more output. The employment effect of process innovations is ambiguous due to substitution effects. Successful product innovations increase the quality of the product, and demand should increase. This need not result in higher prices: An increase of the level of demand Z with constant marginal costs in case of sufficient (or flexible) capacities should result in pure quantity effects and leave prices unchanged. On the other hand, it is also relevant for the price setting that innovations might change market behaviour. The intended change of competition is an important incentive for innovation activities: Firms develop differentiated products to become less dependent on the price and the behaviour of other firms on the market. The price elasticity of demand $|\eta|$ and demand uncertainty σ should be lower for specialized products.[9] If product innovations reduce the price elasticity of demand, innovations can result in higher prices and less output and employment; less demand uncertainty should result in lower prices and more employment. In addition, a lower price elasticity of demand should favour quantity adjustments against price adjustments, while less uncertainty about demand should reduce the necessity of both, price and quantity adjustments.

Demand also depends on the innovation behaviour of other firms on the market. First, more competition from other firms with better products and lower prices should lead to lower demand, and prices and quantities should adjust downwards. On the other hand, competitors' innovations also change demand characteristics and own market behaviour. It is expected that a market dominated by product innovators exhibits a lower price elasticity of demand. This should lead to higher prices, less employment, a lower volatility of prices, and a higher volatility of quantities. In addition, the variance of demand shocks might be lower. Each firm is protected from competition through specialized products. The cross-price elasticity of demand might be lower which should reduce the volatility of prices and quantities. On markets that are characterized by a large share of process innovators, on the other hand, more price competition, a higher price elasticity of demand, and more demand uncertainty is expected. Therefore, a larger volatility of prices is expected.

Market behaviour of firms should also depend on firm size. First, scale economies of large firms should reduce production costs which permits them to set lower prices and increase output and employment. Second, adjustment costs for prices and quantities could differ according to firm size. Third, large firms exhibit larger market shares which should be associated with a monopolistic situation on the product market, a lower price elasticity of demand and less uncertainty about demand shocks. Therefore, it is not clear whether large firms set lower prices, but the volatility of prices should be lower. A summary of the expected effects of innovations and firm size on the price and employment adjustment is contained in Table II.

– Product innovators should exhibit a higher level of demand Z, a lower price elasticity of demand $|\eta|$ and therefore increase prices Δp. The effect

TABLE II
Market behaviour, innovations and firm size

	Own innovations		Competitors innovations		Firm size
	Product	Process	Product	Process	
σ	?		–	+	–
$\|\eta\|$	–		–	+	–
Z	+		–	–	
w/π_l		–			–
Δp	+	–	?	–	?
ΔL	?	?	–	–	?
σ_p	?		–	+	–
σ_L	?		?	?	?

on employment ΔL and the volatility of prices σ_p and employment σ_L is ambiguous.
– Process innovators exhibit lower production costs w/π_l and should reduce prices. The effect on employment is ambiguous (substitution vs. scale effects).
– Competitors' product innovations should reduce the level of demand, the price elasticity of demand and demand uncertainty. Employment and the volatility of prices should be lower, the effect on the level of prices and the volatility of employment is ambiguous.
– Competitors' process innovations should reduce the level of demand and increase competition and demand uncertainty. Prices and employment should be lower and the volatility of prices should be higher.
– For large firms, the price elasticity of demand, demand uncertainty, and production costs should be lower. The volatility of prices should be lower, the net effect on prices and employment is ambiguous.

The aim of the empirical work is to test the hypotheses of the theoretical model and to estimate those effects which are ambiguous from theoretical arguments.

3. Empirical analysis

3.1. *Data and empirical specification*

The data source for the empirical investigation of the price and quantity adjustment is a unique panel of micro data from West German manufacturing firms. The data stem from the monthly business survey of the ifo institute, Munich. For the estimates here, the data set contains information from 2253 firms for the period 1980–1992. Data on price and demand changes are available monthly, data on capacity utilization and employment changes are available quarterly, and data on innovation behaviour are available annually. The firm-level data provide a valuable source for the analysis of price rigidities and the microeconomic adjustment of prices and quantities with respect to changes in demand and competition. The time-series dimension of the data permits the detailed analysis of the adjustment process, and the high frequency of the data permits the analysis of the volatility of price and quantity adjustments.

The data set firstly contains a monthly information about the price adjustment. Every month, the firms were asked whether they had increased p^+, decreased p^-, or left unchanged $p^=$ their prices (net prices), as compared with the preceding month.[10] The data reveal that the firms reported about one price increase per year and about one price reduction every second year, on average (see Table III).[11] However, the distribution of the annual number of price changes is quite uneven: In 27.5 percent of the observations, the firms reported constant prices during the year, in 33.2 percent of the observations, one change (mostly an increase) was reported.[12] In addition, in only 19.5 percent of the observations, the firms reported price reductions during the year. This can be seen as a first hint of price rigidities. Note that output changes were more frequent than price changes, i.e. the assumed adjustment structure is not rejected by the data.[13]

These results for the frequency of price changes can be compared with those from an interview study of Blinder (1991) for the United States. In Table V, those results are depicted together with the corresponding figures from the ifo firm panel. The table reveals a similar frequency of price changes in the U.S. sample: 37.5 percent of the U.S. firms reported 1 price change and 17.4 percent reported less than 1 price change per year, on average; in both samples, more than 50 percent of the firms reported not more than 1 price change per year, and more than 70 percent of the firms reported not more than 2 price changes per year. This confirms the results from the German sample.

These data indicate that the decision to change the price can be viewed, to a large extent, as an annual decision. Most firms change the price once a year or do not change prices at all during the year. This is taken into account for the empirical specification of the econometric model: In the empirical equations, it is tried to explain the annual price decision, i.e. it is explained whether and how often the firms increase, decrease, and change the price during the year. For this purpose, different binary probit models for *at least one* and *more than one* price increase, decrease and change during the year are estimated. In addition, ordered probit models for the frequency of increases, decreases, net increases,[14] and changes are estimated, and corresponding models for the

TABLE III
Frequency of price changes

Average number of price changes per year: 1.86
Average number of price increases per year: 1.28
Average number of price reductions per year: 0.57

Number of changes[a]	p^+		p^-		$p^=$	
	Obs	Share	Obs	Share	Obs	Share
0	7152	0.386	14902	0.805	75	0.004
1	6161	0.333	1371	0.074	92	0.005
2	2593	0.140	719	0.039	153	0.008
3	1036	0.056	429	0.023	200	0.011
4	556	0.030	304	0.016	226	0.012
5	332	0.018	258	0.014	318	0.017
6	214	0.012	162	0.009	425	0.023
7	143	0.008	140	0.008	609	0.033
8	103	0.006	91	0.005	835	0.045
9	71	0.004	66	0.004	1359	0.073
10	66	0.004	40	0.002	2977	0.161
11	40	0.002	20	0.001	6149	0.332
12	47	0.003	12	0.001	5096	0.275
Total number of observations					18514	

[a] Per year.

employment adjustments are specified. This should give an information about the determinants of the quantity adjustment as compared with the price adjustment. Corresponding data on employment changes are available quarterly.[15] Some measures of the data are reported in Table IV.

One may question the reliability of this qualitative information about the price and quantity adjustment. From the data set, no comparable quantitative data for prices at the firm level are available. However, the data set contains quantitative data on sales and employment growth for some of the firms. A simple OLS regression of quantitative sales changes on the number of price and output increases revealed that firms which more often report price (output) increases during the year exhibit more sales growth, and firms that more often report price (output) reductions exhibit less sales growth.[16] A corresponding result is revealed for employment. Therefore, the data appear to be consistent. Note that the data should not be interpreted as “inflation rates”, but they contain another relevant information about the price-setting behaviour of the firms.

TABLE IV
Frequency of employment changes

Number of changes[a]	l^+		l^-		$l^=$	
	Obs	Share	Obs	Share	Obs	Share
0	17800	0.837	14934	0.702	799	0.038
1	2137	0.100	3169	0.149	1458	0.069
2	798	0.038	1596	0.075	2479	0.117
3	376	0.018	969	0.046	4637	0.218
4	158	0.007	601	0.028	11896	0.559
Total number of observations					21269	

[a] Per year.

TABLE V
Price rigidities

How often do the prices of your most important products change in the typical year?

MEASURES OF PRICE STICKYNESS[a]

Frequency of price change[b]	Percent of companies
More than 12	10.1
4.01 to 12	4.3
2.01 to 4	10.1
1.01 to 2	20.3
1.0	37.7
Less than 1.0	17.4

[a] Based on 72 interviews completed as of mid-November 1990.
[b] Times per year.
Source: Blinder, A.S., AER 81/2, 1991, p. 93.

Number of price changes per year.

MEASURES OF PRICE RIGIDITIES[a]

Frequency of price changes[b]	Percent of firms[c]	Percent of observations
More than 12	0	0
More than 4	10.4	11.3
$2 < pc \leq 4$	18.2	11.9
$1 < pc \leq 2$	32.4	16.1
1	9.4	33.2
Less than 1	29.6	27.5

[a] Calculated form 18514 observations from 2253 firms, 1980–1992.
[b] Times per year.
[c] Averages per year.
Source: Ifo Firm Panel.

In the empirical model, the sequential decision structure of the theoretical model is exploited for the econometric specification. In the theoretical model, capacities and innovation behaviour are determined in the long run; therefore, they can be treated as predetermined for the medium-run price and employment decision. In addition, the specification of the adjustment model is based on the assumption that firm-specific demand shocks are autocorrelated. The firms exploit this autocorrelation when forming expectations about the development of demand. The model can be understood as an error correction model for the price and employment adjustment. These assumptions permit to interpret lagged values of capacity utilization and innovations as predetermined for the price and employment adjustment, and the identification of the model can be sought through lagged values of the explanatory variables. For the estimates, the data are pooled and an unbalanced panel is employed. Note that the endogenous variables are already specified as changes.

The first explanatory variable is the degree of capacity utilization U. This variable should reflect the relevance of capacity constraints for the price setting of the firms.[17] For the estimates, a binary specification of this variable is chosen to account for a non-linear effect of capacity constraints on the price and employment adjustment. Five dummy variables are calculated according to the average capacity utilization during the year. In about 17 percent of the observations, the average annual capacity utilization is above 95 percent;[18] those firms reported a capacity utilization of 100 percent at least once the year.

A measure of the volatility of demand shocks at the firm level is calculated as the relative frequency of demand changes σ_{YD}. In the questionaire, the firms are asked whether the demand situation for their product is better, unchanged, or worse, as compared with the preceding month. σ_{YD} is defined as the sum of the "better" and "worse" responses per year, relative to the total number of observations per year. A direct measure of demand expectations is contained annually (in December) in the business survey: The firms report the expected development of their product market in the medium-run (about 5 years). For the estimates, 2 dummy variables are calculated for a growing market Z^+ and for a shrinking market Z^-; a stagnating market is the reference case.

Once a year, in December, the business survey contains the information, whether within the year for the respective product an innovation was implemented. Innovations are defined as novelties or essential improvements of the product or the production technology; the answers are distinguished for product and process innovations. The data reveal that most firms innovate, at least in some years. The relative frequency of both, product and process innovations, is quite evenly distributed within the range {0, 1}; the average is about 0.5. For the estimates, dummy variables are defined for product and process innovators. The innovation behaviour of the other firms in the market is approximated by the average share of innovators in the sector; these shares are calculated excluding the respective firm.

Firm size is specified by dummy variables according to the average number of employees $\overline{L}$ of the firm over the sample. Although large firms are over-represented in the survey, as compared with total manufacturing, the sample consists mainly of small and medium-size firms. Only about 10 percent of the observations stem from firms with more than 1000 employees. Finally, a complete set of 11 time dummies is always included in the estimates; these dummies shall capture e.g. the development of factor costs; firm-level data on input costs are not available from the business survey.

3.2. *Estimation results*

In Tables VI and VII, the estimation results of the model are presented. In Table VI, the results of binary probit model for different specifications of the probability of price increases p^+, price reductions p^- and price changes *pc* per year are reported; p^+, p^- >0 denotes observations where the firms report both, increases and decreases, during the year. In Table VII, the results of ordered probit models for the frequency of price and employment adjustments are depicted. The sample means of the endogenous variables and the χ^2 statistic of the estimated equations are reported in the last rows; the sample means of the explanatory variables are reported in the last column of Table VI. The explanatory variables refer to the preceding year.

The estimation results firstly reveal that firms that exhibit a high capacity utilization in the preceding year more often increase prices: The probability that prices are increased more than once a year $p^+ > 1$ and at least once a year $p^+ \geq 1$ is higher, as compared with those firms that exhibit a very low capacity utilization, the reference group. Note that the probability of at least one price increase during the year hardly differs for those firms that exhibit a full utilization of capacities $U = 100$ as compared with those firms that exhibit an average capacity utilization. However, the probability of more than one price increase and the frequency of price increases p^+ increases steadily with the level of capacity utilization.

The estimation results also reveal that firms that exhibit a full utilization of capacities more often reduce prices; a capacity utilization beyond 100 percent hardly affects price reductions. That means, capacity constraints increase the probability and the frequency of both, price increases and price decreases. This is confirmed by the results for price changes *pc*: the volatility of prices increases steadily with the level of capacity utilization. The effect of capacity utilization on net price increases Δp is also positive; capacity constraints also increase the probability that prices are both, increased and decreased, during the year p^+, $p^- > 0$.

A high capacity utilization also increases the frequency of employment increases l^+ and reduces the frequency of employment reductions l^-; consequently, the effect on net employment increases Δl is also positive. In addition, a high capacity utilization significantly reduces the frequency of employment changes *lc*. This confirms the assumptions of the theoretical model of the price and quantity adjustment and shows that capacity utilization today is a useful predictor for price and employment changes tomorrow. In case of a positive autocorrelation of demand shocks, a high utilization of capacities indicates a positive demand shock today. The firm increases prices and/or employment. In addition, in case of a low utilization, employment should change often and in case of capacity constraints, prices should change often. Therefore, the model also supplies an argument for the higher probability of price reductions in case of capacity constraints.

A large volatility of demand in the preceding year σ_{YD} strongly increases the probability and the frequency of price increases, price decreases, and price changes, in addition to a high capacity utilization. It also strongly increases the frequency of employment increases, decreases, and changes. The effect on net price increase is positive and the effect on net employment increases is negative, i.e. uncertainty increases prices and reduces employment. These results are again consistent with the theoretical model of the price and employment adjustment: Uncertainty increases average costs which should result in higher prices and less employment. In addition, the necessity of price and employment adjustments is enhanced.

The medium-run demand expectations also

TABLE VI
Price adjustment: binary probit models

	p^+		p^-		pc		p^+, p^-	Mean
	> 1	≥ 1	> 1	≥ 1	> 1	≥ 1	> 0	
Capacity utilization U								
100	0.298	0.233	0.214	0.128	0.333	0.297	0.136	0.18
	(5.3)	(4.6)	(3.3)	(2.3)	(6.4)	(5.7)	(1.9)	
90	0.243	0.232	–0.009	–0.027	0.212	0.215	0.048	0.16
	(4.3)	(4.6)	(–0.1)	(–0.5)	(4.0)	(4.1)	(0.7)	
80	0.216	0.284	–0.016	–0.056	0.165	0.267	0.005	0.31
	(4.1)	(6.1)	(–0.3)	(–1.1)	(3.4)	(5.6)	(0.1)	
70	0.146	0.273	–0.018	–0.079	0.106	0.251	–0.021	0.22
	(2.7)	(6.1)	(–0.3)	(–1.5)	(2.2)	(5.1)	(–0.3)	
60	0.074	0.189	0.034	–0.051	0.086	0.154	0.021	0.08
	(1.2)	(3.4)	(0.5)	(–0.8)	(1.5)	(2.7)	(0.3)	
Demand uncertainty								
σ_{YD}	0.302	0.395	0.505	0.440	0.509	0.621	0.407	0.39
	(6.9)	(9.5)	(9.2)	(9.2)	(12.2)	(14.1)	(6.8)	
Demand expectations								
Z^+	0.130	0.163	–0.056	–0.054	0.076	0.140	0.013	0.44
	(5.1)	(6.7)	(–1.7)	(–1.9)	(3.1)	(5.5)	(0.4)	
Z^-	–0.035	–0.089	0.202	0.179	0.079	0.020	0.066	0.12
	(–0.9)	(–2.6)	(4.8)	(4.7)	(2.3)	(0.6)	(1.4)	
Own innovations								
Product	0.040	0.124	–0.202	–0.177	–0.048	0.055	–0.128	0.53
	(1.5)	(5.1)	(–6.3)	(–6.3)	(–2.0)	(2.2)	(–3.6)	
Process	–0.017	0.013	0.058	0.043	0.010	0.033	0.033	0.49
	(–0.7)	(0.5)	(1.9)	(1.6)	(0.4)	(1.3)	(1.0)	
Competitior's innovations								
Product	–0.669	0.312	–1.933	–1.754	–1.386	–0.393	–1.506	0.51
	(–6.9)	(3.4)	(–16.3)	(–16.8)	(–15.0)	(–4.1)	(–11.8)	
Process	–0.125	0.034	0.390	0.493	0.073	0.178	0.536	0.46
	(–0.9)	(0.2)	(2.2)	(3.1)	(0.5)	(1.2)	(2.8)	
Firm size								
$\overline{L} < 50$	0.222	–0.020	0.076	0.056	0.063	0.049	–0.058	0.33
	(0.9)	(–0.8)	(2.4)	(2.0)	(2.6)	(1.9)	(–1.7)	
$\overline{L} < 1000$	0.027	–0.011	0.085	0.046	0.023	0.015	0.013	0.12
	(0.7)	(–0.3)	(1.8)	(1.1)	(0.7)	(0.4)	(0.3)	
χ^2_{25}	563	677	960	1017	774	536	341	
Mean	0.27	0.61	0.12	0.19	0.38	0.72	0.08	

14961 observations.
Depicted are the coefficients and the *t*-statistics (in parantheses).
Time dummies were included (not reported).

TABLE VII
Volatility of prices and employment

	Price adjustment				Employment adjustment			
	p^+	p^-	pc	Δp	l^+	l^-	lc	Δl
Capacity utilization U								
100	0.272	0.146	0.311	0.147	0.373	–0.583	–0.270	0.484
	(6.5)	(2.7)	(7.8)	(3.7)	(5.8)	(–12.4)	(–6.3)	(11.6)
90	0.241	–0.020	0.199	0.181	0.338	–0.421	–0.194	0.385
	(5.7)	(–0.4)	(4.9)	(4.4)	(5.1)	(–8.9)	(–4.4)	(9.2)
80	0.240	–0.057	0.177	0.184	0.238	–0.271	–0.145	0.244
	(6.1)	(–1.1)	(4.8)	(4.9)	(3.8)	(–6.5)	(–3.7)	(6.4)
70	0.194	–0.065	0.139	0.146	0.160	–0.106	–0.039	0.104
	(4.8)	(–1.3)	(3.7)	(3.8)	(2.5)	(–2.5)	(–1.0)	(2.7)
60	0.120	–0.038	0.085	0.085	0.059	0.014	0.027	–0.012
	(2.5)	(–0.6)	(1.9)	(1.9)	(0.8)	(0.3)	(0.6)	(–0.3)
Demand uncertainty								
σ_{YD}	0.334	0.456	0.524	0.079	0.476	0.605	0.732	–0.170
	(9.4)	(9.5)	(15.2)	(2.3)	(10.3)	(15.2)	(20.9)	(–5.2)
Demand expectations								
Z^+	0.159	–0.056	0.113	0.137	0.381	–0.213	0.065	0.298
	(7.8)	(–2.0)	(5.7)	(7.0)	(14.2)	(–9.3)	(3.1)	(15.4)
Z^-	–0.062	0.203	0.079	–0.124	–0.175	0.320	0.231	–0.281
	(–2.1)	(5.8)	(2.9)	(–4.7)	(–3.9)	(10.6)	(8.1)	(–10.1)
Own innovations								
Product	0.069	–0.188	–0.032	0.114	0.166	0.047	0.116	0.041
	(3.3)	(–6.9)	(–1.6)	(5.8)	(6.0)	(2.1)	(5.6)	(2.1)
Process	–0.006	0.049	0.017	–0.026	0.011	0.047	0.043	–0.023
	(–0.3)	(1.9)	(0.9)	(–1.4)	(0.4)	(2.1)	(2.2)	(–1.3)
Competitior's innovations								
Product	–0.296	–1.814	–1.175	0.478	0.215	0.405	0.402	–0.120
	(–3.9)	(–17.7)	(–15.9)	(6.4)	(2.1)	(4.7)	(5.2)	(–1.6)
Process	–0.075	0.479	0.127	–0.309	–0.011	0.200	0.207	–0.145
	(–0.7)	(3.2)	(1.2)	(–2.9)	(–0.1)	(1.5)	(1.8)	(–1.3)
Firm size								
$\overline{L} < 50$	0.005	0.071	0.060	–0.015	–0.024	–0.284	–0.237	0.161
	(0.2)	(2.6)	(3.0)	(–0.8)	(–0.9)	(–12.0)	(–11.3)	(7.9)
$\overline{L} < 1000$	–0.008	0.076	0.026	–0.042	0.036	0.293	0.247	–0.188
	(–0.3)	(1.9)	(0.9)	(–1.4)	(1.0)	(9.4)	(8.7)	(–7.6)
χ^2_{25}	755	1187	964	875	1747	2294	1531	3203
Mean	1.28	0.57	1.86	0.71	0.26	0.55	0.81	–0.29

14961 observations for prices and 16751 observations for employment.
Depicted are the coefficients and the *t*-statistics (in parantheses).
Time dummies were included (not reported).

exhibit a consistent and well determined effect on the price and employment adjustment. Firms that expect a growing market for their product Z^+ more often increase and less often reduce prices and employment. Consequently, the effect on net price and employment increases is also positive. The opposite results are revealed for those firms that expect a shrinking market Z^-. Positive as well as negative demand expectations increase the necessity of both, price and employment adjustments *pc*, *lc*, as compared with those firms that report a stagnating market, the reference case. Note that positive demand expectations exhibit a stronger effect on price changes while negative demand expectations exhibit a stronger effect on employment changes. This points towards an asymmetry of the price and employment adjustment during the business cycle which should result in case of short-run capacity constraints.

These estimates reveal a consistent picture of the price and employment adjustment during the business cycle and confirm the hypotheses of the theoretical model. A high capacity utilization indicates a positive demand shock today. The firms adjust with more price and employment increases and less price and employment reductions. In addition, capacity constraints increase the volatility of prices and reduce the volatility of employment. In boom periods, quantity adjustments are restricted and the firms adjust prices. A high volatility of demand shocks increases prices and reduces employment. In addition, it increases the necessity of both, price and employment adjustments. Positive demand expectations exhibit a stronger effect on the price adjustment and negative demand expectations exhibit a stronger effect on the employment adjustment. This confirms the theoretical model with predetermined capacities and short-run capacity constraints.

The estimation results also reveal significant effects of innovations on the price and employment adjustment. The estimates firstly show that product innovators more often increase prices and less often reduce them. In addition, product innovators more often increase employment, and the effect of product innovations on net price and employment increases is positive. Product innovators are more successful and can set higher prices and increase employment. The estimation results also reveal that product innovations increase the probability that prices are increased and changed at least once a year, but reduce the probability that prices are changed more than once a year. In addition, the frequency of price changes is lower and the frequency of employment changes is higher. This is consistent with the conventional view of the price-setting behaviour of firms on monopolistic markets. Prices are changed (increased) once a year, and the firms more often adjust quantities. This is a first hint towards effects of innovations on market behaviour.

Process innovations exhibit only a small effect on the price setting and employment adjustments. Process innovators exhibit a slightly higher probability and frequency of price reductions, and the frequency of employment changes is slightly higher. That means, the estimation results are consistent with the interpretation that process innovators exhibit lower costs and face more demand uncertainty, but the effects are only weakly significant.[19]

A very strong effect on the price setting is revealed for product innovations of competitors on the market. In sectors with a large share of product innovators, the probability and the frequency of price reductions is much lower. In addition, in those sectors, the probability of more than one price increase per year and the frequency of price increases is also lower. Consequently, the volatility of prices is also much lower. Firms in those sectors increase prices once a year or do not change prices at all during the year. This kind of price-setting behaviour is again consistent with the conventional view of the price setting on monopolistic markets, where price competition is replaced by competition in innovation behaviour. A consistent result is revealed for the volatility of employment. Employment is changed more often in sectors with a large share of product innovators; when prices are sticky, quantity adjustments are more frequent.

Process innovations of competitors exhibits only a small effect on the price and employment adjustment. The estimates reveal that price and employment reductions are more frequent in those sectors.[20] In addition, prices and employment are changed more often. That means, the estimation results indicate more price competition in those sectors, i.e. they are consistent with the interpretation that in those sectors the price elasticity of demand and demand uncertainty is high. However, the estimated coefficients are only weakly significant.

Somewhat surprisingly, firm size exhibits only small effects on the price setting, ceteris paribus. Note however that small firms exhibit a lower probability of innovations. In addition, small firms exhibit a lower capacity utilization and face more demand uncertainty (see Table A4 and Table A5 in the Appendix). Price reductions of small and large firms are more frequent, as compared with medium-size firms, the reference group. In addition, small firms more often change prices, but these effects are only weakly significant. However, small firms less often reduce (change) employment and large firms more often reduce (change) employment. This could either indicate a higher price elasticity of demand which should favour price adjustments against quantity adjustments for small firms. It could also indicate higher adjustment costs for employment in small firms.

Finally, the relation of the microeconomic price adjustment and the sectoral development of wages, prices and productivity is explored. First tentative results suggest that sectoral inflation reduces the frequency of price reductions, but hardly increases the frequency of price increases.[21] Second, sectoral wage inflation increases the frequency of price increases but hardly affects the frequency of price reductions. Third, sectoral labour productivity growth reduces the frequency of price increases but hardly affects the frequency of price reductions. Consequently, sectoral inflation and sectoral labour productivity growth reduce the volatility of prices, and sectoral wage inflation increases the volatility of prices.

4. Conclusions

In this paper, a theoretical model of the microeconomic price adjustment under uncertainty about demand is developed. The model is based on the assumption of a delayed adjustment of prices and employment which is analysed within a framework of monopolistic competition on the product market. A special emphasis is devoted to the analysis of the role of capacity constraints and innovation behaviour for the price setting. The model yields testable hypotheses about the direction and the frequency of firms' price vs. quantity adjustments depending on capacity restrictions, demand characteristics and innovations.

The model is estimated with a unique data set of micro data from West German manufacturing firms. The firm-level data provide a valuable source for the analysis of price rigidities and the microeconomic adjustment of prices and quantities with respect to changes in demand and competition. The high frequency of the data permits the analysis of the volatility of the price and quantity adjustment. A prior inspection of the data revealed that the price setting can be viewed, to a large extent, as an annual decision. Most firms change prices once a year or do not change prices at all during the year. This can be seen as a first hint towards microeconomic price rigidities.

In the empirical model, it is tried to explain the annual price and quantity adjustment of the firms. The estimation results reveal that capacity constraints exhibit a very important effect on the price adjustment at the micro level. A high capacity utilization today increases prices and quantities tomorrow which indicates a positive autocorrelation of demand shocks and confirms the imposed adjustment structure of the theoretical model. A high utilization of capacities also increases the volatility of prices and reduces the volatility of quantitites which confirms the relevance of capacity constraints for the price and quantity adjustment. Demand uncertainty increases prices, reduces employment and increases the necessity of both, price and quantity adjustments. The price and quantity adjustment with respect to positive and negative demand expectations is asymmetric. Positive demand expectations exhbit a stronger effect on the price adjustment and negative demand expectations exhibit a stronger effect on the employment adjustment.

The price setting is also significantly affected by variables which are related to competition on the market. Product innovators less often reduce prices and more often adjust quantities. In addition, in sectors which are characterized by a large share of product innovators, prices are less often changed and quantity adjustments are frequent. This kind of price-setting behaviour is consistent with the conventional view of the price setting on monopolistic markets. In those sectors, prices are increased mostly once a year or are not changed at all during the year. Price competition is replaced by competition in innovation behaviour; when prices are sticky, quantities adjustments are frequent.

The price-setting behaviour of firms and the dynamic adjustment of prices with respect to changes in the economic environment is relevant for the short-run analysis of the business cycle as well as for the analysis of the long-run development of competition. Micro data for firms supply a valueable source for the empirical analysis of the price and quantity adjustment. These data are available from regular business surveys for many countries and for long periods, and cross-country comparisons of the adjustment process are feasible. A more detailed analysis of the adjustment speed of prices with respect to changes in costs, demand, and competition and the interdependence of the price setting of the firms should remain on the agenda of future research.

Acknowledgements

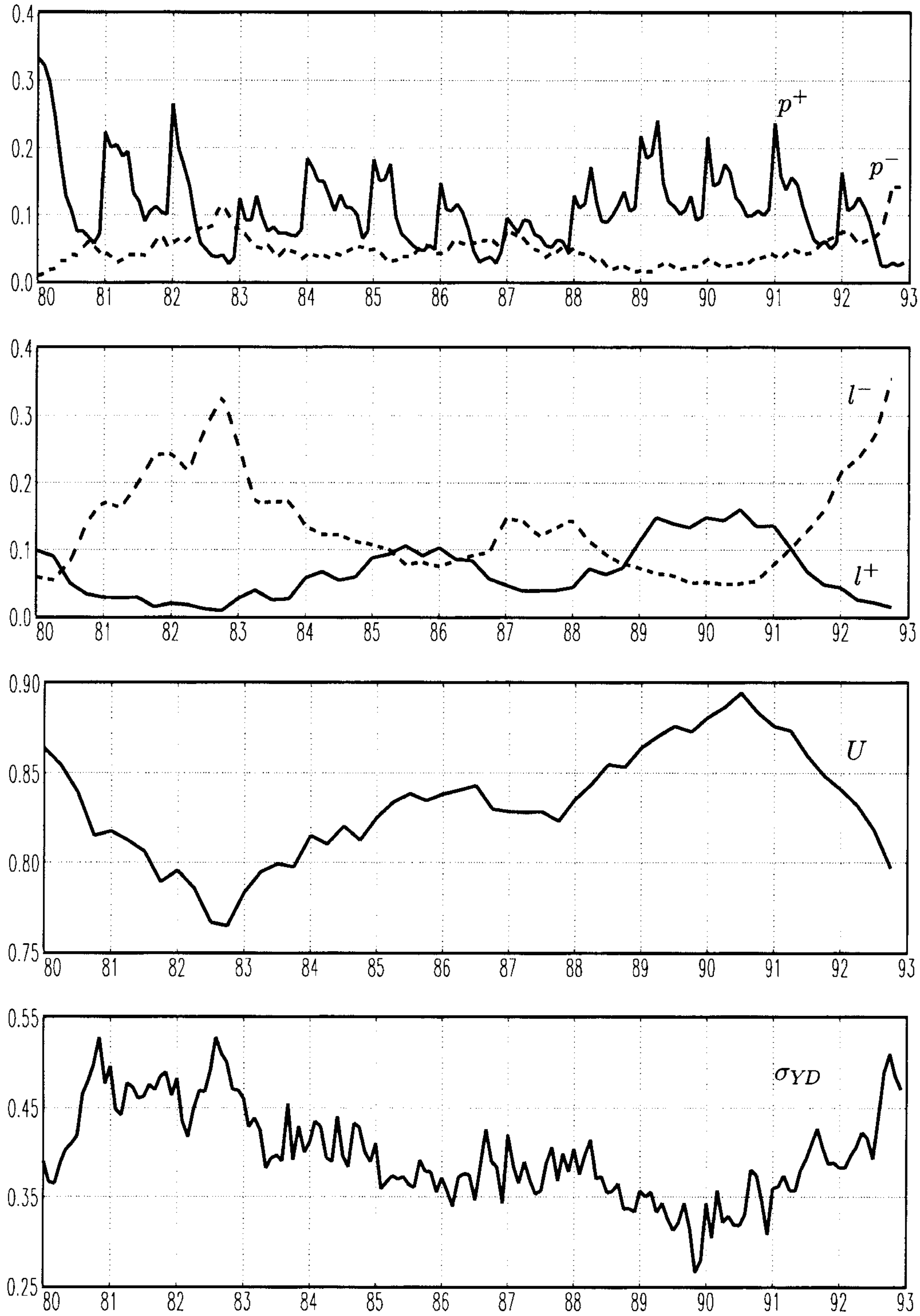
This paper is part of the research project "Growth and Innovations". I like to thank a referee of this journal for his helpful comments on an earlier version of this paper and W. Franz (ZEW and University of Mannheim), H. J. Ramser (University of Konstanz), and K. H. Oppenländer (ifo Institut, München) for their support. I also like to thank the Thyssen Stiftung for financial support of the project, the ifo Institut for providing the data and Thomas Schneeweis for his help with the construction of the data set.

Appendix

TABLE A1
Frequency of price changes

Number of changes	p^+												
	0	1	2	3	4	5	6	7	8	9	10	11	12
0	5096	5450	2243	835	430	263	168	117	84	66	64	39	47
1	699	326	157	81	48	21	16	9	8	3	2	1	
2	408	131	67	47	32	16	9	5	3	1	0		
3	236	80	36	26	17	14	9	5	5	1			
4	177	51	31	17	5	10	5	5	3				
5	164	43	19	8	13	5	4	2					
6	104	26	11	12	6	0	3						
7	90	23	13	7	4	3							
8	63	14	10	3	1								
9	50	11	5	0									
10	34	5	1										
11	19	1											
12	12												
p^-													

Number of observation in each category. 18514 observations.



Source: Ifo firm panel, time series 1980–1992, 2253 firms.

Figure A1: Price changes, employment changes, capacity utilization and demand volatility.

TABLE A2
Frequency of employment changes

Number of changes[a]	l^+ 0	1	2	3	4
0	11986	1803	713	364	158
1	2834	249	74	12	
2	1517	68	11		
3	952	17			
4	601				
l^-					

Number of observations in each category. 21269 observations.
[a] Per year.

TABLE A3
Qualitative and quantitative data

Dependent variable: Rate of change of sales, Δ ln *S*

	1	2, 3	4, 5	6, 7	8, 9	≥ 10	Constant
p^+	0.013	0.017	0.026	0.036	0.053	0.035	0.048
	(3.8)	(4.1)	(3.8)	(3.4)	(3.4)	(2.1)	(14.1)
p^-	–0.006	–0.013	–0.032	–0.035	–0.066	–0.064	
	(–1.0)	(–2.1)	(–3.9)	(–2.9)	(–4.2)	(–2.7)	
y^+	0.010	0.040	0.049	0.072	0.077	0.039	
	(2.5)	(10.4)	(10.3)	(9.5)	(5.3)	(1.3)	
y^-	–0.028	–0.055	–0.087	–0.101	–0.130	–0.126	
	(–6.4)	(–14.3)	(–18.5)	(–16.1)	(–11.6)	(–7.5)	

Obs	$\overline{R}^2$	SEE	Mean
8649	0.111	0.134	0.035

Dependent variable: Rate of change of employment, Δ ln *S*

	1	2	3	4	Constant
l^+	0.042	0.065	0.069	0.097	–0.002
	(13.2)	(12.7)	(9.7)	(9.0)	(–1.9)
l^-	–0.034	–0.055	–0.085	–0.084	
	(–12.5)	(–14.7)	(–19.1)	(–15.1)	

Obs	$\overline{R}^2$	SEE	Mean
12563	0.103	0.098	–0.008

OLS estimates.

TABLE A4
Capacity utilization and demand changes

	U	σ_{YD}	YD^+	YD^-
Own innovations				
Product	0.1084	0.056	0.116	–0.014
	(6.40)	(3.4)	(6.8)	(–0.8)
Product	0.1350	0.035	0.084	–0.029
	(8.19)	(2.2)	(5.2)	(–1.7)
Competitors' innovations				
Product	–0.0732	–0.021	–0.086	0.020
	(–1.16)	(–0.4)	(–1.4)	(0.3)
Product	–0.3494	0.042	–0.141	0.148
	(–3.58)	(0.5)	(–1.5)	(1.5)
Firm size				
Product	–0.3819	0.089	–0.040	0.122
	(–23.31)	(5.6)	(–2.5)	(7.6)
Product	0.0731	–0.046	0.076	–0.132
	(2.68)	(–1.9)	(2.9)	(–5.0)
χ^2_{17}	2105	612	872	2261
Mean		4.79	2.04	2.74

20642 observations for demand changes, 20273 observations for capacity utilization. Results of ordered probit models. σ_{YD},YD^+, YD^- are defined correspondingly to the variables for price changes, U is defined as an ordered variable from the dummy variables in Tables VI and VII.

TABLE A5
Innovations and firm size

	$\bar{L} \leq 100$	$100 < \bar{L} < 1000$	$\bar{L} \geq 1000$	All
Product innovations	0.325	0.581	0.743	0.497
Process innovations	0.322	0.519	0.690	0.459

Depicted are the average shares of innovators according to firm size.

Notes

1 For a discussion of adjustment delays, see Kydland and Prescott (1982).

2 A delayed adjustment of prices is analysed by Maccini (1981) and Smolny (1998a). Adjustment delays for employment can be justified with legal and contractual periods of notice and search, screening, or training time. See e.g. Blanchard and Diamond (1992) and Hamermesh and Pfann (1996).

3 See e.g. Dixit and Stiglitz (1977) and Blanchard and Kiyotaki (1987).

4 The assumption of a limitational productions technique is not neccessary but helpful and appears plausible for the short run model. Nothing of substance depends on this assumption, but capacities can be defined in a pure technological sense.

5 Expected output is determined as $E(Y) = E[\min(YD, YS)] = \int_{-\infty}^{\bar{\varepsilon}} YD \cdot f_\varepsilon d\varepsilon + \int_{\bar{\varepsilon}}^{\infty} YS \cdot f_\varepsilon d\varepsilon$. f_ε is the probability distribution function of the demand shock ε.

6 Equation (4) results from the first order condition of Equation (3) with respect to the price. A more detailed discussion of the theoretical model is contained in Smolny (1998a). Note that the model is basically a variant of the model of Hall (1986).

7 For a discussion, see Barro (1972), Hall (1986), Carlton (1986) and Blanchard and Kiyotaki (1987).

8 See Aghion and Howitt (1992). For a discussion of the relation of market structure and innovations, see Kamien and Schwarz (1975) and Dixit and Stiglitz (1977). A more detailed

analysis of the effects of innovations on supply and demand is contained in Smolny (1998b).

[9] The introduction of a new product might also increase uncertainty about demand.

[10] All questions in the business survey refer to a specific product XY of the firm.

[11] Note that the data on price increases exhibit a strong seasonal pattern: Most price increases take place in the first half of the year. See Figure A1 in the appendix.

[12] The sample is constrained to those observations where the complete annual information is available, i.e. those firms that answered the corresponding question every month.

[13] In a corresponding question, the firms reported about 2 output increases and 2 output decreases during each year, on average. In addition, a corresponding concentration mass on observations with 0 or 1 change is not revealed. Detailed data are available on request.

[14] Net increases are defined as number of increases minus number of decreases during the year. Note that most firms reported either only increases or only decreases or reported that they had not changed prices and employment at all during the year. See Tables A1 and A2 in the Appendix.

[15] For employment, the firms are asked to report expected (planned) changes for the next 3 months, as compared with realized changes for prices.

[16] The results are reported in Table A3 in the Appendix.

[17] The business survey data are classified in steps of 5 percent from 30 percent to 100 percent. For about 15 percent of the observation, the degree of utilization is 100 percent. The firms can also report a degree of capacity utilization above 100 percent. This was the case for about 2 percent of the observations.

[18] The sample means of the variables are depicted in Table VI together with the estimation results.

[19] Note that both, product and process innovations, increase demand and capacity utilization. See Table A4 in the appendix.

[20] Note that competitors' innovations tend to reduce demand and capacity utilization. See Table A4 in the Appendix.

[21] The estimation results are available on request.

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