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Time- or State-Dependence? An Analysis of Inflation Dynamics using German Business Survey Data[☆]

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Abstract

This paper evaluates the predictions of different price setting theories using a new dataset constructed from a large panel of business surveys of German retail firms over the period 1970-2010. The dataset contains firm-specific information on both price realizations and expectations. Aggregating the price data we find clear evidence in favor of state-dependence; for periods of relatively high and volatile inflation not only the size of price changes (intensive margin) but also the fraction of price adjustment (extensive margin) is important for aggregate inflation dynamics. Moreover, at the business cycle frequency, variations in the extensive margin explain a large fraction of inflation variability even for moderate inflation periods. This holds both for price realizations and expectations suggesting a role for state-dependent sticky plan models. Moreover, results from a structural sign-restriction VAR model show that the extensive margin reacts significantly to a monetary policy shock and is more important for the response of overall inflation than the intensive margin conditional on the shock. These findings confirm the validity of state-dependent pricing models that stress the importance of the extensive margin - even for low inflation periods.

Keywords: Price setting behavior, time dependent pricing, state dependent pricing, monetary policy transmission
JEL: E31, E32, E50

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1. Introduction

This paper offers new insights on the relationship between aggregate inflation dynamics and price setting at the level of the individual firm using a novel constructed from a large panel of business surveys of German retail firms over the period 1970-2010. The paper contributes to the literature in various important ways. First, the dataset allows us to assess the implications of different models of both price setting as well as price *updating* because our survey dataset contains firm-specific information on both realized price changes and price expectations. Decomposing aggregate inflation into the size of price changes (*intensive margin, IM*) and the frequency of price adjustment (*extensive margin, EM*), we find that not only the intensive margin matters for aggregate inflation dynamics. For periods of relatively high and volatile inflation, variations in the extensive margin are important for the variability of the overall rate of inflation as well. Importantly, for our German sample we do not need inflation rates of more than 5% to achieve such an outcome[3], which contrasts existing studies for different countries during high and low inflation periods of Gagnon (2009) or Wulfsberg (2009). These findings also hold for price *expectations* suggesting an important role of state-dependent sticky plan models. Moreover, we explicitly analyze the importance of the extensive margin at different frequency ranges. To the best of our knowledge, a thorough assessment of the role of the extensive margin at, for instance, the business cycle frequency has not been forthcoming. We find that at lower frequency ranges the EM comoves much more strongly with the rate of inflation and accounts for a large share of inflation's variance - even in periods of moderate inflation. Second, we further assess the dynamics of the extensive and intensive margin, respectively, using a structural VAR (SVAR) model with theory-based sign restrictions for the German economy over the period 1995-2009. We find that the extensive margin as well as the frequency of price increases and decreases show a significant reaction following a monetary policy shock confirming that the predictions of time-dependent theories are not supported by the data. Third, the setup of our SVAR model allows us to additionally assess the importance of fluctuations in the EM for overall inflation *conditional* on observing a monetary policy shock by decomposing variations in the impulse response functions. This allows an even more explicit assessment of the validity of different pricing models. Overall, our results suggest that the timing of price changes should be endogenized in models of price setting if they are to realistically predict the dynamics of the frequency and magnitude of price changes. In particular, menu cost models stressing the role of the extensive margin in the transmission of monetary shocks seem to be more realistic than those solely emphasizing the intensive margin.

Competing models of price setting tend to have very different implications for the nature of price adjustment. In standard time-dependent models à la Taylor (1980) or Calvo (1983), the timing of price adjustment is exogenous implying that the frequency of price adjustment is invariant over time. In contrast, state-dependent theories assume the timing of price changes to

[3] In particular, the average annual rate of consumer price inflation in Germany has been 4.6% for the period 1970-1985.

be the outcome of a profit maximization problem of firms.[4] Hence, the frequency of price adjustment is endogenously determined and may vary with economic conditions. Evaluating these two alternative mechanisms to investigate which of them more closely reflects the true underlying price adjustment process is important for two reasons. First, an assessment of these different theories has important implications for modeling price stickiness. While the fraction of price changes is fixed in time-dependent models and price responses to a shock therefore occur due to an increase in the average size of price changes, in state-dependent models it is either the *size* or the *fraction* of price changes that react, or both. In state-dependent models like Dotsey et al. (1999), the reason for the faster reaction of prices to shocks is due to fluctuations in the frequency of price adjustment. By contrast, in the model of Golosov and Lucas (2007), which contains large idiosyncratic shocks, it is mainly the size of the price changes that react to the shock while the frequency of price adjustment is relatively unaffected. Analyzing the behavior of the extensive and intensive margins of price setting, therefore, should reveal to which extent the implications of state-dependent pricing theories are supported by the data relative to time-dependence. Moreover, if state-dependence is important, such an analysis also allows evaluating the divergent features of different state-dependent models. Second, and related, an analysis of competing price setting models is relevant for policy-making because of their diverging implications for the transmission of monetary policy.[5] Related to the above-mentioned frameworks are sticky plan models, where firms set entire pricing plans instead of individual prices at every period. The distinction between time- and state-dependence also applies to these models. On the one hand, in so-called sticky information models a delayed price adjustment is the consequence of information costs preventing continuous price revisions.[6] These models predict that every period a fixed fraction of firms updates an entire sequence of future prices implying that the frequency of expected future price changes is constant over time. On the other hand, the sticky plan model of Burstein (2006) constitutes an example of state-dependent price updating. In this model firms' updating of pricing plans is constrained by a menu cost - the frequency of price updating is thus endogenous and adjusts once accumulated shocks to the economy are large enough.[7]

Even though the implications of state-dependent models seem to be more plausible, so far, it has been difficult to find clear evidence in favor of these models. On the one hand, empirical studies analyzing microdata underlying the CPI and PPI for the Euro area, respectively, find support

[4] Examples of such models are Caplin and Spulber (1987), Dotsey et al. (1999), Gertler and Leahy (2008) and Golosov and Lucas (2007).

[5] For instance, Dotsey and King (2005) show that prices tend to react faster to monetary policy shocks in state-dependent frameworks as compared to time-dependent models leading to a less persistent effect on real output in the former models.

[6] Examples include Bonomo and Carvalho (2004), Caballero (1989), and Mankiw and Reis (2002, 2006). While in Bonomo and Carvalho (2004) time-dependent price reviewing is due to the simultaneous occurrence of both menu and information costs, in Mankiw and Reis (2002, 2006) imperfect information is assumed to follow from a fixed cost of observing the state of the economy. See also Mankiw and Reis (2010) for an overview.

[7] Related to this model are recent contributions by, for instance, Alvarez et al. (2010) and Bonomo et al. (2010) modeling the mechanism underlying the price reviewing process. Due the inclusion of both menu and information costs these models assume state-dependent price reviews.

for both time- and state-dependent elements.[8] On the other hand, however, Eichenbaum et al. (2010), using a dataset from a large U.S. retailer, find evidence that the most common prices (*reference prices*) closely comove with costs. In Lein (2010) this evidence for state-dependence is confirmed by evaluating business surveys for Swiss manufacturing firms with special emphasis on the relationship between the probability of price adjustment and costs. Using aggregate U.S. CPI data Klenow and Kryvtsov (2008) follow a different approach. They decompose monthly inflation into the fraction of products with price changes and their average size and find the extensive margin to be rather stable and relatively uncorrelated with inflation, while the intensive margin was volatile and showed almost perfect comovement with inflation. Moreover, the intensive margin accounted for almost all of inflation's variance. While the unimportance of the extensive margin is in line with time-dependence, some state-dependent frameworks such as the model of Golosov and Lucas (2007) are also able to match these results. Gagnon (2009) finds similar results for low-inflation episodes using Mexican CPI data; the average frequency (size) of price changes is weakly (strongly) correlated with inflation due to offsetting movements in the frequency of price increases and decreases. When inflation increases to 10-15%, however, price increases are dominant and thus both the extensive and intensive margins are important for inflation dynamics. Wulfsberg (2009) reports similar findings for Norwegian price data for low- and high-inflation periods.

We argue that, complementary to the existing approach to the analysis of the different components of price setting, it is important to examine the role of the extensive and intensive margins for aggregate inflation dynamics not only at a month-on-month basis but also at lower frequencies. With sticky prices, the fraction of firms that decide to change their prices due to changes in the economic environment might be relatively stable in the very short run, but as economic shocks accumulate over time, firms may gradually decide to adjust their prices. Thus, the extensive margin might be invariant and not so important for variations in inflation month-on-month, but may be rather variable and more relevant in explaining aggregate inflation dynamics at the business cycle frequency. Using spectral analysis we show that fluctuations in aggregate inflation are dominated by low-frequency components of the data, and that this is largely driven by the dynamics of the extensive margin. Moreover, we find that the dynamic correlation between the frequency of price adjustment and inflation is high at low frequencies, while it declines with decreasing cycle durations. The driving forces of aggregate inflation dynamics are then examined by, following Klenow and Kryvtsov (2008), decomposing the variance of the rate of inflation into terms involving variation in the intensive margin (time-dependent terms) and terms that include the variance of the extensive margin (state-dependent terms). While during low-inflation episodes the extensive margin is of little relevance for variations in inflation, for periods of relatively high inflation the importance of the extensive margin for inflation dynamics is more pronounced - even at the monthly frequency. Over the period 1970-1985, the extensive margin's share of overall inflation variability is about 15%. Moreover, our results indicate that the role of the extensive

[8] See Dhyne et al. (2005) and Vermeulen et al. (2007). Hoffmann and Kurz-Kim (2006) offers corresponding evidence for German CPI data.

margin for aggregate inflation dynamics is much more important once analyzed at the appropriate frequency; at the business cycle frequency the extensive margin accounts for between 26% and 32% of inflations's variance for the full sample period. Furthermore, when analysing the extensive and intensive margins of *expectations* on price changes we find very similar results. To further analyze the relative importance of time- versus state-dependence for price adjustment, the responses of the two components of inflation to a monetary policy shock are analyzed in a theory-based sign restriction SVAR model for Germany over the period 1995:01-2009:06. More precisely, next to a vector of standard macroeconomic variables the intensive and extensive margins are included as endogenous variables. The impulse-response analysis shows that, following a contractionary policy shock, the extensive margin increases significantly and strongly indicating that the frequency of price changes reacts to a shock to the economy. Moreover, conditional on the identified monetary policy shock variations in the extensive margin are much more important for the implied response of overall inflation than fluctuations in the intensive margin. These observations confirm that standard time-dependent theories do not reflect the true mechanism of price adjustment. Rather, models of price setting should endogenize the timing of price adjustment and stress the role of the extensive margin in order to predict realistic dynamics, as is done for instance in the menu cost model of Dotsey et al. (1999).

The rest of the paper is organized as follows. Section 2 describes the survey dataset, explains the statistics calculated for the analysis and gives the main price setting facts. In Section 3, a spectral assessment of the time series is given followed by a variance decomposition of aggregate inflation. Section 4 explains the VAR framework and Section 5 reports and discusses the results thereof. Finally, Section 6 concludes.

2. Price Setting Facts from Business Survey Data

2.1. Data Description and Discussion

The dataset we use contains monthly firm-level price data of a large panel of business surveys for the retail sector conducted by the Ifo Institute for Economic Research.[9] The firm-specific survey data is available for the period January 1990 to June 2009 covering around 2000 West German retail firms. For the period prior to 1990 and after 2009:06 only aggregated time series concerning the percentage of firms that increased or decreased their prices is available[10]. Each retail firm can be allocated to one of the following sectors according to the 4-digit WZ08 classification of the Federal Bureau of Statistics: Automobile, Food and Beverages, Communication and Information Technology, Household Products, Recreational Products, Other Industrial Products and Products

[9]Next to retail firms the business survey also contains wholesale and manufacturing firms as well as the service and construction sector. See Becker and Wohlrabe (2008).

[10]For more details concerning the availability of the different data sources see Appendix A.2.

not in Store. Thus, the composition of the products is similar to that of the Consumer Price Index. Missing items relative to the CPI are Services including housing rents as well as Energy goods such as oil products as well as gas and electricity. Amongst other questions, firms are asked whether they changed the price of their products in the last month. The answers are coded as 1 ("increased"), 0 ("not changed") and -1 ("decreased").[11] Moreover, firms are asked about their *expectations* concerning the setting of prices in the future. More specifically, they are asked whether they plan to change the price of their products in the coming three months; answers are again coded as 1 ("plan to increase"), 0 ("plan not to change") and -1 ("plan to decrease").

Relative to other data sources, the survey dataset offers several advantages. First, in contrast to detailed quantitative price data for specific *products* underlying CPI calculations as used by e.g. Bils and Klenow (2004), Klenow and Kryvtsov (2008) or Dhyne et al. (2005), our dataset contains *firm*-specific information on prices, which is a clear advantage.[12] Second, the business survey data contain information on firms' price expectations allowing to assess the validity of different sticky plan models, which is not possible using item-level price data. A third advantage of the dataset at hand is that firms are not asked directly on their pricing strategies as it is the case for the one-time interview studies conducted by, for instance, Blinder (1991) for the U.S. and Fabiani et al. (2006), for the Euro area. To the extent that firms may be unwilling to respond truthfully to questions regarding their pricing strategies, such an interview method could lead to biased responses. Despite these advantages it should be kept in mind that due to the qualitative nature of the questionnaires, the data does not contain information concerning the size of price changes. However, Figure 1 reveals that the survey data largely reflects the official retail price index.[13] The figure displays the comovement of the fraction of price increases minus the fraction of price decreases in the survey data with the rate of change of the German retail price index constructed by the Federal Bureau of Statistics.[14] A further limitation of the dataset is that the survey data contains both single- and multi-product firms without providing any information on how the latter firms answer the question concerning their prices. This problem is mitigated by the fact that firms are asked to fill in different questionnaires for their respective product groups. Nevertheless, firms still have to cluster the price development of several sub-products within the same category resulting in a certain degree of aggregation of individual prices.[15]

A number of authors stress that the macroeconomic implications of price adjustment, especially of consumer prices, is conditional on the particular type of these price changes (Klenow and Malin,

[11]For more details on the questionnaires as well as on the respondents see Appendix A.1. and Abberger et al. (2009).

[12]Moreover, the data contains idiosyncratic information on key economic measures such as business volume, demand or the expected business development. This allows an assessment of the price setting behavior of firms at the micro level; see Schenkelberg (2011).

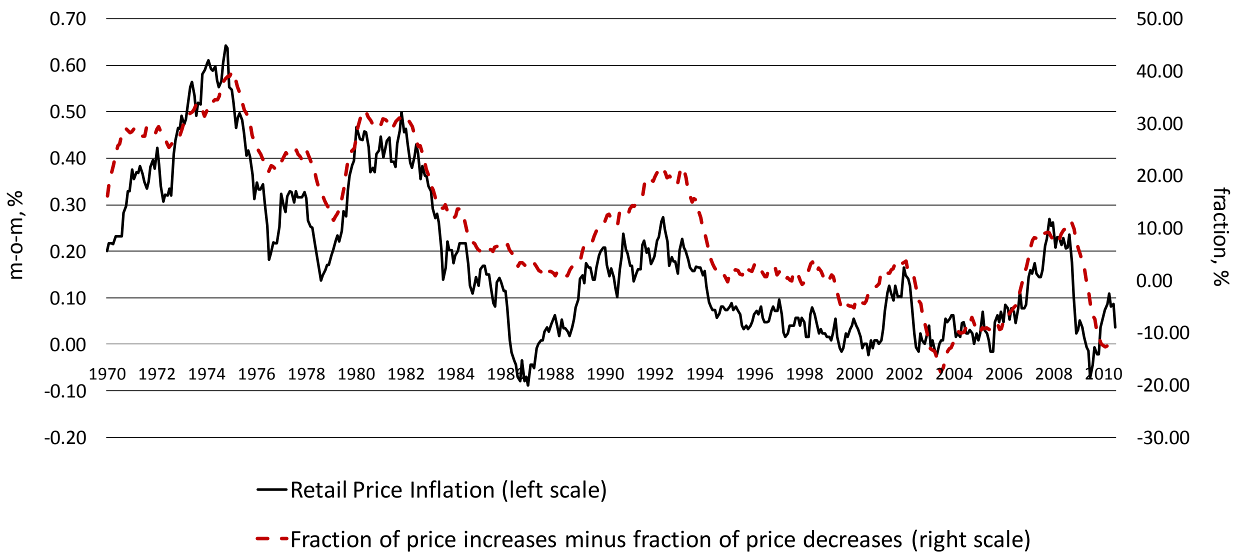
[13]Similarly, the aggregated microdata comoves quite strongly with the official price indexes for the respective sectors, as is shown in Appendix B.

[14]Both series are displayed as 12-month moving averages.

[15]However, a recent meta-study on the survey provides some details on how multi-product firms tend to fill in the questionnaires. See Appendix A for more details.

2010; Nakamura and Steinsson, 2008). For instance, the transient nature of price changes due to end-of-season sales implies that the extent of aggregate price adjustment is reduced (Kehoe and Midrigan, 2007). Moreover, sales prices may be independent of macroeconomic conditions (Taylor, 1999) implying that the coexistence of different types of price changes may conceal the true adjustment mechanism underlying regular price setting. Thus, in order to draw unbiased conclusions concerning the price setting behavior of regular prices, sales should be filtered out of the data. Unfortunately, in the business survey, firms are not asked whether a price change results from a "sale" or is a "regular" price change. Therefore, following Nakamura and Steinsson (2008), we identify "V-shaped" price changes using a sale filter for the period 1990-2009 (see Appendix A.3.). Apparently, the occurrence of sales in the data is relatively limited. Thus, results are robust to the exclusion of these temporary price changes, which is not surprising given the relatively lower importance of sales for the Euro area compared to the U.S. as documented in Dhyne et al. (2005). While we can account for sales in the survey data, it is, however, not possible to identify price changes related to product substitutions.

Figure 1: Aggregated Micro Retail Price Data and Retail Price Index



2.2. Decomposing the Rate of Inflation

Because the survey data does not contain information on the size of price changes, defined as the intensive margin throughout the paper, we have to construct this statistic from the data available. As a first step, note that the rate of inflation can be decomposed into the fraction of price changes and the average size of these changes (Klenow and Kryvtsov, 2008). Thus, inflation can be expressed as (more details are given in Appendix C.):

$$\pi_t \approx \pi_t^K \cdot fr_t = IM_t \cdot EM_t, \tag{1}$$

where π_t^K denotes the average rate of inflation of those items with price changes in period t and fr_t indicates the fraction of price changes in period t. The extensive margin is constructed by aggregating the idiosyncratic price information:[16]

$$EM_t = \frac{\sum_{i=1}^n y_t^+ + \sum_{i=1}^n y_t^-}{\sum_{i=1}^n y_t^+ + \sum_{i=1}^n y_t^- + \sum_{i=1}^n y_t^0}, \tag{2}$$

where y_t^+, y_t^- and y_t^0 denote price increases, decreases and observations for which the price has not been changed in a certain period. Using this aggregated time series, the implied intensive margin can be constructed as:

$$IM_t \approx \frac{\pi_t}{EM_t}, \tag{3}$$

where π_t denotes the monthly rate of change of the retail price index for Germany, obtained from the Federal Bureau of Statistics. The extensive margin can be further decomposed into the fraction of price increases and decreases:

$$F_t^+ = \frac{\sum_{i=1}^n y_t^+}{\sum_{i=1}^n y_t^+ + \sum_{i=1}^n y_t^- + \sum_{i=1}^n y_t^0}$$

$$F_t^- = \frac{\sum_{i=1}^n y_t^-}{\sum_{i=1}^n y_t^+ + \sum_{i=1}^n y_t^- + \sum_{i=1}^n y_t^0}.$$

Tables 1 and 2 contain summary statistics for the components of inflation calculated as described above. In order to be able to relate our results to those found in the literature we also report the main statistics for the U.S. dataset used by Klenow and Kryvtsov (2008) over the period 1988 to 2004. For better comparison Table 1 displays the statistics for the German data over this period as well. The monthly rate of retail price inflation is 0.09% (or about 1% annually). The average monthly frequency of price changes is 24.9% with a standard deviation of 7.7%; the implied average duration of a price spell is thus about 4 months.[17] This is comparable to the

[16]Since the dataset does not contain information concerning the importance of the respective products, we implicitly assume that all products have equal weights.

[17]The term implied average duration refers to the inverse of the monthly frequency of price changes: $d = 1/fr$. See e.g. Dhyne et al. (2005) for a discussion of different measures of the duration of price spells.

U.S. statistics.[18] The intensive margin averages 0.3% with a standard deviation of 0.8%. It is highly correlated with the rate of retail price inflation, while the extensive margin is relatively uncorrelated with inflation (.94 versus .19). Importantly, this high correlation of the intensive margin and the rate of inflation is not only due to it's construction; correlations reported for the U.S. data are very similar. Moreover, similarly to the U.S. statistics, we observe a higher correlation with inflation as soon as the frequency of price changes is separated into the frequency of increases and decreases (.42 and -.24). The asymmetry between both statistic's correlations with inflation is documented in the literature as well. Finally, even though the EM is not so correlated with inflation, regression results from a simple OLS regression in column five of the table show that the relation between the extensive margin as well as the frequency of price increases are significantly related to overall inflation.

Table 1: Summary Statistics - Comparison with U.S. Data

	German data, period 1988 - 2004				U.S. data, period 1988 - 2004		
	Mean (%)	StDev (%)	Corr π	Regression on π	Mean (%)	StDev (%)	Corr π
π_t	0.09	0.21			0.27	0.36	
IM_t	0.33	0.88	0.94	3.79***	0.98	1.19	0.99
EM_t	24.88	7.71	0.19	6.86***	26.6	3.2	0.25
Fr_t^+	13.88	7.61	0.42	14.92***	15.0	2.6	0.69
Fr_t^-	11.00	7.01	-0.24	-8.07***	11.5	2.5	-0.41

Notes: German sample runs from 1988:01 to 2004:12 with monthly frequency. The retail price index is obtained from the Federal Bureau of Statistics. The last column in the left panel contains OLS regression coefficients from the following regressions: $x_t = \alpha + \beta\pi_t + u_t$.

Table 2 displays the summary statistics for the full sample as well as several subsamples. We separate the full sample in three periods. While the first runs from 1970:01 to 1985:12 thus including a period of relatively high and volatile inflation in Germany and Europe, the second starts in 1986:01 and ends in 1998:12, just before the European Monetary Union (EMU) came into force. The last period starts with the beginning of the EMU in 1999:01 and runs until 2010:07. As is shown in the table, when the 1970's and early 80's are included in the sample, both the rate of retail price inflation and the intensive margin are relatively high and more volatile. While the average annualized rate of inflation is about 2.2% for the full period, it reaches 4.1% for the period 1970-1985. Similarly, including this period in the sample leads to a larger average frequency of price changes. On average, 28.9% of the firms change their prices in a given month during the

[18]The relatively high frequency of price changes stands, however, in contrast to similar measures for the Euro area and Germany. Generally, with an average frequency of only 15%, price adjustments are less frequent in the Euro area compared to the U.S. (Dhyne et al., 2005). For Germany, Hoffmann and Kurz-Kim (2006) report the monthly frequency of price changes to range between 10.1 - 11.3%. However, this difference can be explained by the fact that, in contrast to the survey dataset used for this paper, the CPI data includes categories characterized by a relatively infrequent price adjustment such as electricity and gas as well as rents and other services.

full sample, while during the period 1970-1985 the average frequency is even 33.4%. Moreover, the extensive margin is more strongly correlated with the rate of inflation (.41 and .42 for the periods 1970-2010 and 1970-1985, respectively). Accordingly, the frequency of price increases is much larger during these periods and correlation with the rate of inflation is higher. By contrast, the fraction of price decreases becomes less important during that times both in terms of size and comovement with inflation. In the period prior to the EMU, 1986-1998, the average rate of inflation as well as the EM and IM are quite similar to the statistics for the Klenow/Kryvtsov period, while, however, the extensive margin and the frequency of price increases are somewhat more correlated with inflation (.39 and .46, respectively). By contrast, during the most recent period, 1999-2010, both the EM and the fraction of price increases are only weakly correlated with inflation (.08 and .26, respectively). Accordingly, the asymmetry between the frequency of price increases and decreases is less pronounced. The results displayed in Tables 1 and 2 are in line with previous studies of the dynamics of inflation and it's components during periods of high and low inflation. In particular, using Mexican CPI data over the period 1994-2004 Gagnon (2009) finds that once high-inflation periods are excluded from the sample correlation between the two series decreases sharply. Similarly, Wulfsberg (2009) reports a high correlation between the EM term and inflation for high-inflation periods using Norwegian data.

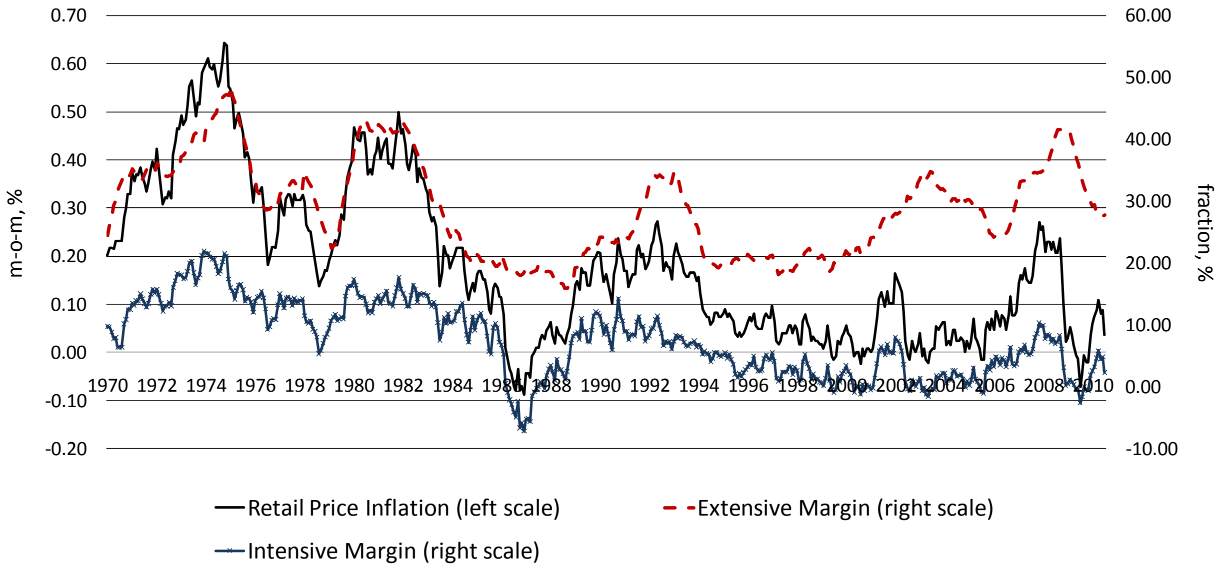
Table 2: Summary Statistics - Different Sample Periods

	1970-2010			1970-1985		
Variable	Mean (%)	StDev (%)	Corr π_t	Mean (%)	StDev (%)	Corr π_t
π_t	0.18	0.31		0.34	0.34	
IM_t	0.55	1.02	0.92	0.97	1.00	0.90
EM_t	28.87	9.98	0.41	33.39	10.63	0.42
Fr_t^+	19.62	11.47	0.55	28.39	10.90	0.45
Fr_t^-	9.24	6.66	-0.32	5.00	3.13	-0.14
	1986-1998			1999-2010		
Variable	Mean (%)	StDev (%)	Corr π_t	Mean (%)	StDev (%)	Corr π_t
π_t	0.09	0.21		0.07	0.26	
IM_t	0.34	0.98	0.93	0.22	0.88	0.97
EM_t	22.51	7.50	0.39	29.76	7.50	0.08
Fr_t^+	14.60	8.17	0.46	13.16	6.82	0.26
Fr_t^-	7.92	4.37	-0.19	16.60	6.31	-0.19

Notes: Samples run from 1970:01 to 2010:07, 1970:01 to 1985:12, 1986:01 to 1998:12 and 1999:01 to 2010:07, respectively. Frequency is monthly. The retail price index is obtained from the Federal Bureau of Statistics.

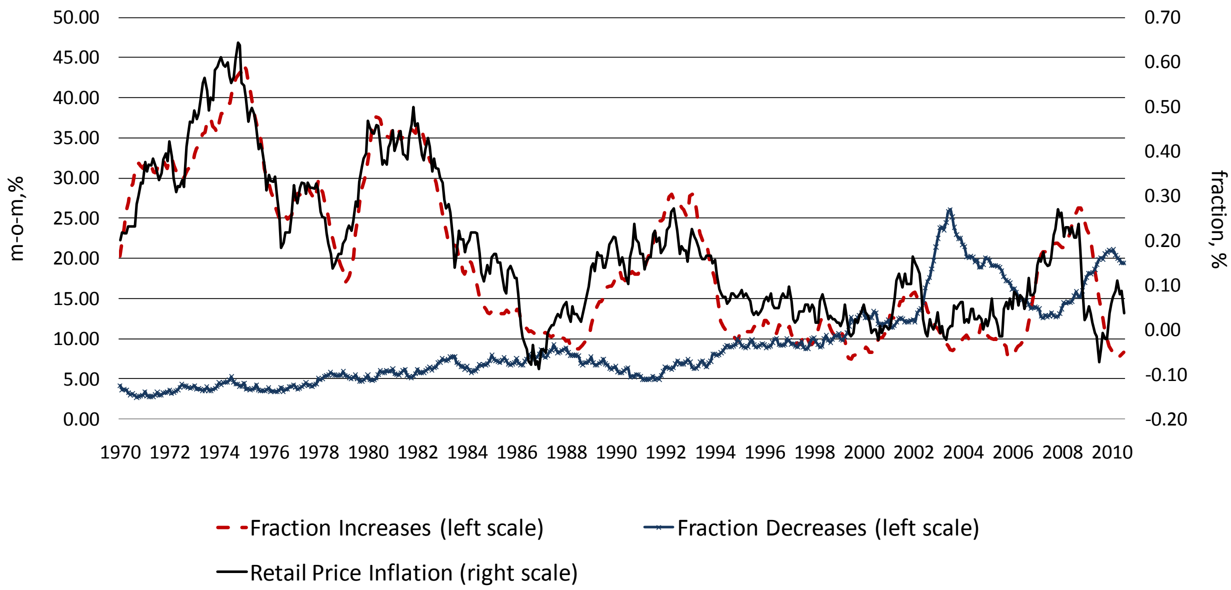
Figure 2 plots the evolution of the retail price inflation as well as the extensive and the intensive margin of price adjustment. As expected, the intensive margin reflects the evolution of retail price inflation over time. However, the figure also shows that the extensive margin is not completely stable but seems to comove with the rate of inflation as well. Figure 3 displays the frequency of price increases and decreases, respectively, as well as the rate of retail price inflation. The figure clearly shows the comovement between the rate of inflation and the frequency of price increases.[19] Thus, both figures suggest that the frequency of price changes is not invariant over time as predicted by time-dependent theories.

Figure 2: Retail Price Inflation, Extensive and Intensive Margins



[19]Both figures display year-on-year changes of the retail price index. The extensive and intensive margins (divided by ten) as well as the frequency of price increases and decreases enter as 12-month moving averages.

Figure 3: Retail Price Inflation, Fraction of Price Increases and Decreases



2.3. Price Expectations

Due to the information on firms' expectations included in the business survey dataset, the frequency of changes in price expectations can be calculated analogously to that of price realizations. The calculation of the intensive margin, however, is slightly more complicated and involves additional assumptions. We start by calculating the extensive margin of price expectations as:

$$EM_t^{exp} = \frac{\sum_{i=1}^n y_t^{exp,+} + \sum_{i=1}^n y_t^{exp,-}}{\sum_{i=1}^n y_t^{exp,+} + \sum_{i=1}^n y_t^{exp,-} + \sum_{i=1}^n y_t^{exp0}}. \tag{4}$$

Using the formula for the expected value of a sum of two random variables, the expected rate of inflation can be expressed as:

$$\begin{aligned} E_t[\pi_{t+j}] &\approx E_t[IM_{t+j} \cdot EM_{t+j}] \\ &= E_t[IM_{t+j}] \cdot E_t[EM_{t+j}] + cov[IM, EM]. \end{aligned}$$

From this expression, the intensive margin of price expectations can be calculated as:

$$E_t[IM_{t+j}] \approx \frac{E_t[\pi_{t+j}] - cov[IM, EM]}{E_t[EM_{t+j}]}. \tag{5}$$

The first assumption necessary in order to compute a measure of the size of expected price changes concerns the expectation horizon of the firms. In fact, firms are asked for their expectations over the following *three* months. Because our analysis is based on a monthly frequency, however, we have to control for this. Assuming that the information firms provide on this horizon mainly reflects expectations concerning the middle of this range, i.e. month 2, the extensive margin of expected price changes can be written as $E_t[EM_{t+j}] \approx E_t[EM_{t+2}]$.[20] The second assumption concerns the formation of inflation expectations, $E_t[\pi_{t+j}]$. As baseline we construct this measure by assuming perfect foresight in expectation formation, i.e. $E_t[\pi_{t+j}] = \pi_{t+j}$. Relaxing this assumption by using static expectations, i.e. $E_t[\pi_{t+j}] = \pi_{t-1}$ does not alter the main results. Finally, the covariance between the IM and EM is calculated using the statistics based on realized price changes. The measure is calculated separately for the respective sample periods.

Figure 4: Extensive Margin - Realized and Expected Price Changes

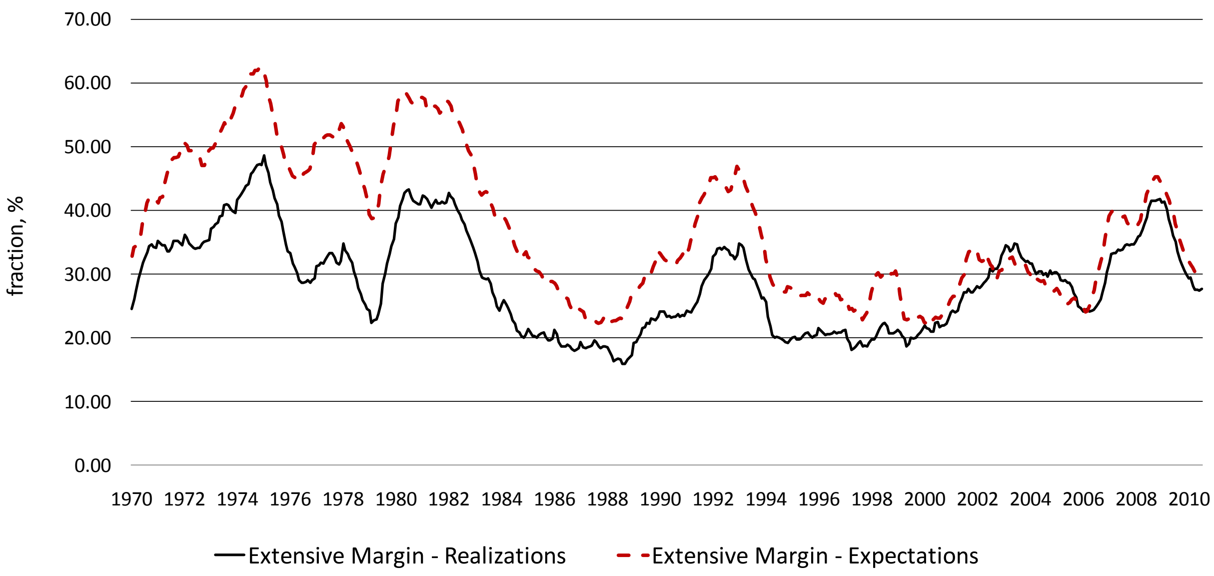


Figure 4 shows the extensive margin constructed from realized and expected price changes, respectively. The frequency of expected price changes is almost always higher than the frequency of realized price adjustments indicating that firms' expectations are less sticky than actual price changes. Moreover, in times of higher inflation variability, for instance during the 1970's, or in periods of increased uncertainty, for instance during the financial crisis of 2007/2008 or after 9/11, the gap between price expectations and realizations increases. Overall, however, the figure shows that the comovement between the two series is large. A spike in the frequency of expected price changes always coincides with a peak in the extensive margin of realized price changes suggesting that, following a shock to the economy, not only pricing plans but also actual prices change. This is not in line with sticky plan models that imply a reaction of price updating but not of realized prices in a given period.

[20] Of course, this assumption can be varied by assuming, for instance, that firms truly report expectations concerning the subsequent month only or that they give some sort of average measure of the coming three months. Results are largely invariant to changing this assumption.

Table 3: Summary Statistics - Price Expectations

	1970-2010			1970-1985		
Variable	Mean (%)	StDev (%)	Corr. $E_t[\pi_{t+2}]$	Mean (%)	StDev (%)	Corr. $E_t[\pi_{t+2}]$
$E_t[\pi_{t+2}]$	0.18	0.31		0.33	0.34	
IM_t^{exp}	0.34	0.81	0.93	0.65	0.73	0.95
EM_t^{exp}	37.39	13.02	0.46	47.36	11.60	0.33
$Fr_t^{+,exp}$	30.78	15.44	0.49	44.17	12.15	0.35
$Fr_t^{-,exp}$	6.60	4.93	-0.32	3.20	1.83	-0.28

	1986-1998			1999-2010		
Variable	Mean (%)	StDev (%)	Corr. $E_t[\pi_{t+2}]$	Mean (%)	StDev (%)	Corr. $E_t[\pi_{t+2}]$
$E_t[\pi_{t+2}]$	0.09	0.21		0.07	0.26	
IM_t^{exp}	0.20	0.75	0.95	0.19	0.85	0.97
EM_t^{exp}	30.36	9.77	0.36	31.41	8.49	0.15
$Fr_t^{+,exp}$	24.40	10.55	0.37	19.29	9.03	0.18
$Fr_t^{-,exp}$	5.96	2.87	-0.14	12.12	4.99	-0.07

Notes: Samples run from 1970:01 to 2010:05, 1970:01 to 1985:12, 1986:01 to 1998:12 and 1999:01 to 2010:05, respectively. Frequency is monthly. The retail price index is obtained from the Federal Bureau of Statistics.

Table 3 shows summary statistics for price expectations. Compared to the statistics calculated from price realizations (Tables 1 and 2), the moments of the expected rate of inflation and the expected size of price changes as well as their correlation are quite similar. However, the mean of the extensive margin is larger (37.4 % for the full sample period) suggesting that price updating occurs more often than actual prices changes. Furthermore, the frequency of expected price increases is much larger than that of expected price decreases (30.8% and 6.7 % for the period 1970-2010); this asymmetry is not that pronounced for price realizations. Thus, apparently, firms expect to increase their price more often than they actually do. Related, the correlation between the expected rate of inflation and the extensive margin as well as the frequency of price increases, respectively, is higher than for price realizations (.46 and .49). Apart from these differences, the general tendency of the extensive margin showing a higher correlation with the rate of inflation during periods of relatively high inflation is also present for price expectations. The correlation between the frequency of expected price changes and the expected rate of inflation is 0.15 for the ”low-inflation” period 1999-2010, while it is 0.46, 0.33 and 0.36 for the full period and for the periods 1970-85 and 1986-98, respectively. Moreover, the average value of the extensive margin is much higher during the period 1970-85 (47.4%) suggesting that during periods of high expected inflation a much larger share of firms expects to change prices in the future. Thus, these statistics point towards a state-dependent interpretation; firms seem to adjust pricing plans in line with economic developments, which accords with the sticky plan model of Burstein (2006).

3. The Importance of the EM and IM for Aggregate Inflation Dynamics

3.1. Spectral Analysis

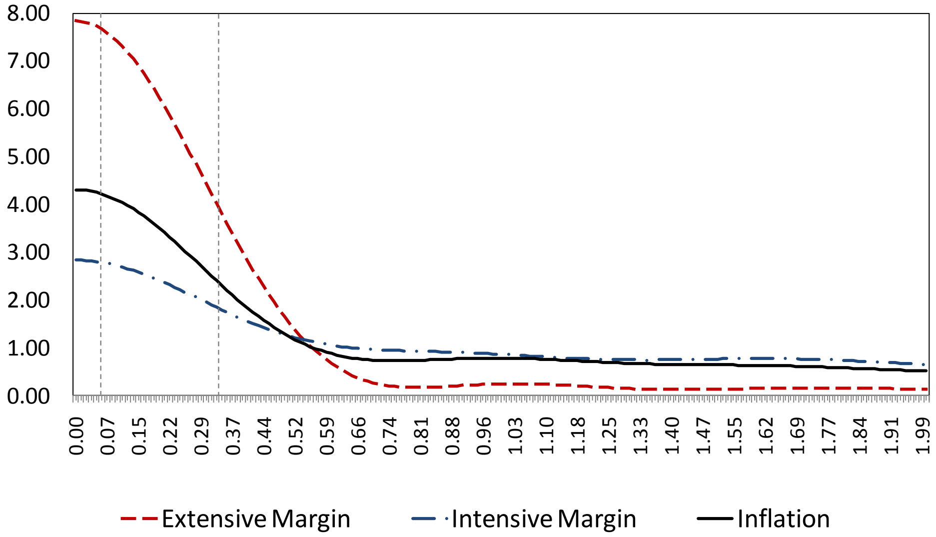
In this section we employ spectral analysis for the time series of interest in order to determine the cycle component dominant for the variability of the respective series. Empirical studies concerning price adjustment as e.g. Dhyne et al. (2005) find a considerable degree of price stickiness for the Euro area implying that the frequency of price changes does not adjust immediately. We therefore argue that the unimportance of variations in the extensive margin for aggregate inflation dynamics during low-inflation regimes reported by e.g. Klenow and Kryvtsov (2008) and Gagnon (2009) may be due to the fact that the analysis is done at the monthly frequency even though the extensive margin is relatively stable at high frequencies. Thus, we convert the series of interest from the time domain into the frequency domain using a Fourier transform. In particular, the spectral density function of a time series y_t with autocovariance function γ_k can be expressed as $f_y(\omega) = \frac{1}{2\pi}\sum_{j=-\infty}^{\infty}\gamma_k e^{-jk\omega}$ (Granger and Watson, 1984). The spectral density functions of the rate of inflation, the extensive and intensive margins are shown in Figure 5. The figure shows that while the spectral density function of the intensive margin is relatively flat over the range of frequencies, the spectral shape of the extensive margin is much more concentrated at very low frequencies. The vertical lines in the figure mark the frequencies corresponding to one and a half and eight years, which accords with the NBER business cycle definition. For all three series the business cycle interval contains the main mass of the spectral density; this pattern is clearest for the extensive margin. This implies that, following changes in the economic environment, in the very short run it is mainly the *size* of the price changes that reacts, while the fraction of firms that additionally decide to adjust prices only changes gradually if shocks to the economy accumulate.

In order to analyze the patterns of comovement between the rate of inflation and the extensive and intensive margins at the business cycle frequency the time series are smoothed using a symmetric two-sided band-pass filter suggested by Baxter and King (1999) to isolate the low-frequency components.[21] The filtered series are then used to calculate cross correlations, displayed in Table 4. As expected, the extensive margin is more strongly correlated with inflation at the business cycle frequency ($Corr(EM_t, \pi_t) = .66$). Furthermore, the correlation with lagged values of the rate of inflation is even higher (e.g. $Corr(EM_t, \pi_{t-2}) = .69$) suggesting stickiness in the response of the frequency of price changes to changes in the rate of aggregate inflation. In line with state-dependent models, the frequency of price changes reacts gradually as changes in aggregate inflation accumulate. Accordingly, the correlation between the rate of inflation and the frequency of price increases and decreases, respectively, is much larger at the business cycle frequency. The

[21] In particular, the series are produced using the Baxter-King filter with 36 leads and lags. The filter weights are chosen to obtain an optimal approximation to the 18-96 month band-pass filter.

frequency of increases is highly correlated with the rate of inflation ($Corr(Fr_t^+, \pi_t) = .74$), while the correlation between decreases and inflation is less pronounced ($Corr(Fr_t^-, \pi_t) = -.24$). This asymmetry is also documented in Klenow and Kryvtsov (2008) and Gagnon (2009) at the monthly frequency. By contrast, the intensive margin is somewhat less correlated with the rate of inflation at the business cycle frequency ($Corr(IM_t, \pi_t) = .83$).

Figure 5: Spectral Densities of the Rate of Inflation, the IM and EM



Notes: The spectral densities are constructed using the following estimator: $\hat{f}_y(\omega) = \frac{1}{2\pi}\left(\omega_0\hat{\gamma}_0 + 2\sum_{j=1}^{M_T}\omega_k\hat{\gamma}_k cos(\omega_k)\right)$. We use a standard Bartlett window procedure with window size 10.

Table 4: Cross Correlations with Inflation - $Corr(x_t, \pi_{t+k})$

k (+ /-)	EM_t		IM_t		Fr_t^+		Fr_t^-	
	lag	lead	lag	lead	lag	lead	lag	lead
0	0.658	0.658	0.826	0.826	0.739	0.739	-0.242	-0.242
1	0.680	0.618	0.791	0.816	0.762	0.693	-0.245	-0.126
2	0.688	0.565	0.727	0.775	0.769	0.634	-0.244	-0.144
3	0.680	0.502	0.638	0.707	0.759	0.564	-0.238	-0.164
4	0.668	0.430	0.531	0.617	0.732	0.486	-0.225	-0.186
5	0.622	0.353	0.412	0.512	0.690	0.402	-0.206	-0.207
6	0.576	0.273	0.288	0.398	0.635	0.317	-0.180	-0.226

Notes: The cross-correlations are calculated using the filtered series. We use a symmetric two-sided Baxter-King filter filtering frequencies corresponding to 18-96 months with 36 lags and leads. Sample period is 1970:01-2007:07.

3.2. Dynamic Correlations

In order to further analyze the underlying comovement between the extensive and intensive margin with the rate of retail price inflation at different frequencies, we employ the concept of dynamic correlation proposed by Croux et al. (2001). This measure is calculated directly in the frequency domain and allows therefore to capture the correlation between two series of interest at any cycle duration. Thus, relative to calculating the static correlation of two series at a certain frequency band, this dynamic procedure offers additional insights. Dynamic correlation between two variables can be defined as:

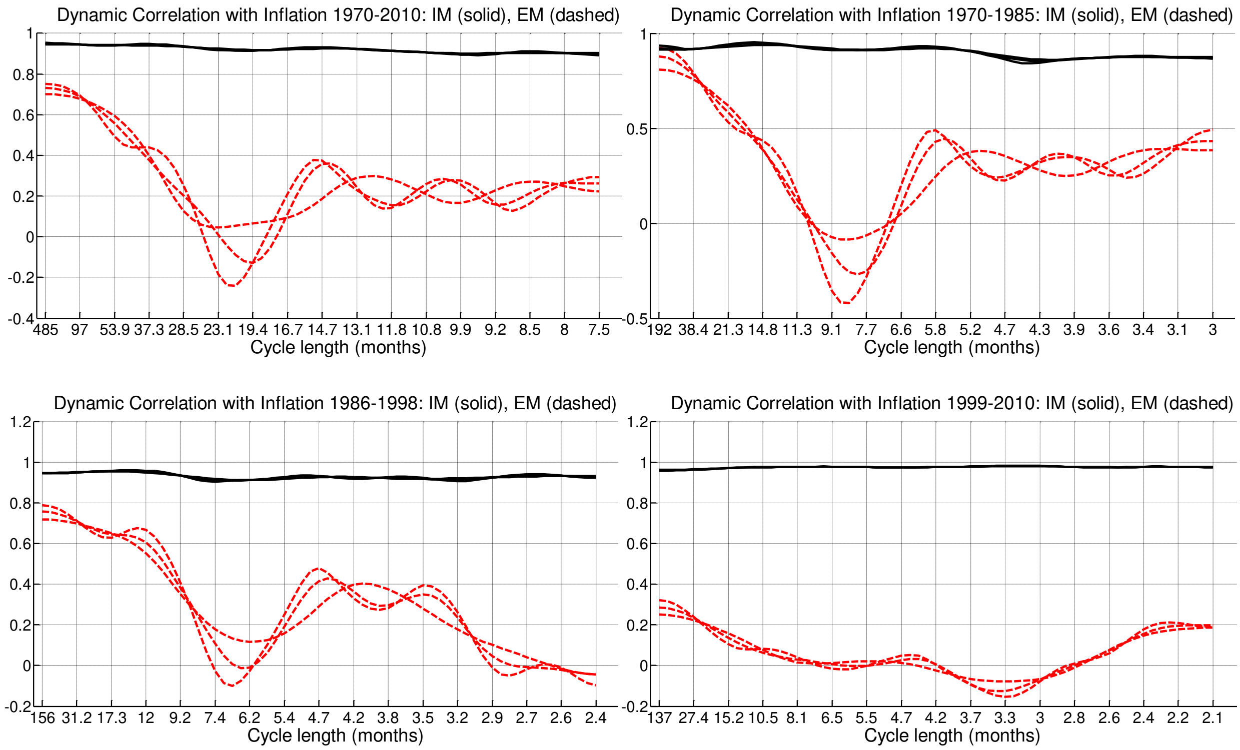
$$\rho_{xy}(\omega) = \frac{C_{xy}(\omega)}{\sqrt{S_x(\omega)S_y(\omega)}},$$

where $S_x(\omega)$ and $S_y(\omega)$ are the spectral density functions of x and y as defined in the last subsection, $-\pi \leq \omega < \pi$ denotes the frequency, and $C_{xy}(\omega)$ is the co-spectrum of x and y.

Figure 6 shows the dynamic correlations of the extensive and intensive margin with the rate of retail price inflation.[22] Because we want to evaluate whether state-dependence is present in the data, we are mostly interested in the comovement of the EM with inflation. In line with the spectral densities of the respective variables shown above, the dynamic correlation between the EM and inflation increases with cycle duration. In particular, for the full sample period, correlation is above .70 at cycle durations of more than 96 months (eight years). Furthermore, in line with the summary statistics for the different subsamples given in the last section, the dynamic correlation between the EM and inflation is higher for periods of higher overall inflation. While for the period 1970-1985 correlation between the EM and inflation is almost as large as that between the IM and inflation (around 0.90) for very low frequencies, the comovement between the two series is substantially reduced for the period 1999-2010. While the dynamic correlation still increases with cycle duration, its absolute value is smaller staying below .40 at any frequency. The descriptive evidence offered by the figure is thus in line with the static cross-correlations of the Baxter-King filtered series given above in that it suggests that the EM is not stable over time. Instead, in a higher and more variable inflation regime, the EM shows an increased reagibility with respect to overall inflation dynamics.

[22] The correlations calculated using the filtered series given in Table 3 are not equal to a simple average of the dynamic correlations over the corresponding frequencies. See Croux et al. (2001) for more details. However, the order of magnitude of the different measures is still comparable.

Figure 6: Dynamic Correlation with Inflation



Notes: The figure displays measures of dynamic correlations according to $\rho_{xy}(\omega) = C_{xy}(\omega)/\sqrt{S_x(\omega)S_y(\omega)}$. Samples run from 1970:01 to 2010:07, 1970:01-1985:12, 1986:01-1998:12 and 1999:01-2010:07. We use a Bartlett window with smoothing parameters 8, 10 and 12.

3.3. Variance Decomposition

In order to assess the relative importance of the frequency and size of price adjustment for aggregate inflation dynamics, following Klenow and Kryvtsov (2008), the variance of retail price inflation is decomposed into terms involving the variance of the intensive and extensive margin, respectively:

$$var(\pi_t) = \underbrace{var(IM_t) \cdot \overline{EM}^2}_{\text{"}IM\ term\text{"}} + \underbrace{var(EM_t) \cdot \overline{IM}^2 + 2 \cdot \overline{IM} \cdot \overline{EM} \cdot cov(EM_t, IM_t)}_{\text{"}EM\ terms\text{"}} + O_t. \tag{6}$$

In this expression, O_t are high-order terms that are functions of the extensive margin. The IM term involves the variance of the intensive margin, while the EM terms contain the variance of the extensive margin as well as the covariance of the EM and IM. In standard time-dependent theories such as the fixed probability model of Calvo (1983) or the staggered price model of Taylor (1980), the extensive margin is inactive implying that the intensive margin terms account for all of inflation's variance. State-dependent models typically predict that the frequency of price changes varies according to the economic environment faced by firms, which implies that the EM terms account for a relatively large fraction of overall inflation variability.[23] However, some state-dependent menu-cost models as, for instance, the model of Golosov and Lucas (2007) including large idiosyncratic shocks, imply a relatively important IM term relative to the EM component. For the U.S. Klenow and Kryvtsov (2008) report that the IM term explains almost all variations in the rate of inflation, while the EM terms are small (95% versus 5%). Similarly, for the Mexican CPI dataset Gagnon (2009) finds that the EM terms are relatively unimportant during periods of low inflation, while the IM term accounts for about 90% of inflation's variance. Only if the rate of inflation increases to 10 - 15% does the IM term fall to about 35% implying a larger role for the frequency of price changes.

Tables 5 and 6 show the results of the variance decomposition for our dataset for price realizations and expectations, respectively. Using the unfiltered data, in accordance with the previous literature for low-inflation periods, the IM term represents a rather large fraction of the variance of retail price inflation for both realized price changes and expectations for the Klenow/Kryvtsov-period 1988-2004 and for the EMU sample 1999-2010 (100.0% and 99.9% for price realizations and 102.8% for expectations). Correspondingly, the EM terms are relatively unimportant for the variance of inflation (0.6% and 2.6% as well as 1.6%, respectively). In line with the results reported by Gagnon (2009), however, the EM terms become more important once we regard periods of relatively high inflation. For the period 1970-1985, the EM terms account for more than 15% of inflation's variance for price realizations, while for price expectations it is 10%. Thus, it is mainly the higher-inflation episode during the 1970's and early 80's that drives the relatively high share of the EM terms for the full sample period (10.0% and 10.2% for realized and expected price changes, respectively).

The descriptive evidence offered above suggests that the comovement between the overall rate of inflation and the frequency of price adjustment becomes important at lower frequencies. Thus, we would expect the share of the EM terms to become even larger once analyzed at the appropriate cycle length. Therefore, we conduct the variance decomposition additionally using the Baxter-King filtered series to isolate the business cycle component of the respective time series.[24] Tables 5 and 6 reveal that the EM terms become more important at the business cycle frequency. For instance, isolating the components with cycle duration of 1.5-8 years, the percentage of inflation's

[23]Thus, Klenow and Kryvtsov (2008) label the respective components "time-dependent term" (TDP term) and "state-dependent terms" (SDP terms).

[24]We use a symmetric two-sided Baxter-King filter with frequencies corresponding to 18-96 and 36-96 months, respectively, with 36 lags and leads. Because the Baxter-King filter applies a weighted moving average procedure with weights summing to zero (Baxter and King, 1999), to calculate the variance shares, we first add back the mean of the time series over the respective sample periods.

variance explained by the EM terms rises to about 10% over the KK-sample for price realizations. For the full sample period, the EM terms now account for about 26.4% and 23.2% for price realizations and expectations, respectively, while for the period 1970-1985 the shares rise to even about 69.6% for price realizations and 35.3% for expectations. Relative to the small percentages for the unfiltered series, those shares are clearly substantial. For cycle durations of between 3 and 8 years, this increase in the importance of the extensive margin for overall inflation dynamics is even more pronounced. Over the full sample period, the shares of the EM terms increase to 32.3% and 33.9% for price realizations and expectations, respectively, while the importance of the IM term is reduced (66.0% and 77.1%, respectively). For price realizations, the EM terms are even dominant vis-à-vis the IM term over the higher-inflation period 1970-1985 (77.7% versus 41.2%).

Table 5: Variance Decomposition - Price Realizations

	Share of Inflation Variance (%)		
Unfiltered Data			
	IM Term	EM Terms	HO Terms
1970-2010	0.898	0.100	0.002
1970-1985	0.955	0.153	-0.108
1986-1998	1.057	0.064	-0.121
1999-2007	0.999	0.006	-0.004
1988-2004	1.000	0.026	-0.025
Baxter-King Filter, 1.5-8 years			
	IM Term	EM Terms	HO Terms
1970-2007	0.804	0.264	-0.067
1970-1985	0.629	0.696	-0.324
1986-1998	1.029	0.125	-0.153
1999-2007	1.136	-0.012	-0.124
1988-2004	0.913	0.098	-0.011
Baxter-King Filter, 3-8 years			
	IM Term	EM Terms	HO Terms
1970-2007	0.660	0.323	0.017
1970-1985	0.412	0.777	-0.189
1986-1998	1.105	0.126	-0.231
1999-2007	0.799	0.060	0.141
1988-2004	0.880	0.128	-0.009

Notes: Samples run from 1970:01 to 2007:07, 1970:01-1985:12, 1986:01-1998:12, 1999:01-2007:07 and 1988:01-2004:12. See equation (6) for a definition of the IM, EM and HO terms. For the filtered series, we use a symmetric two-sided Baxter-King filter with frequencies corresponding to 18-96 and 36-96 months, respectively, with 36 lags and leads.

Table 6: Variance Decomposition - Price Expectations

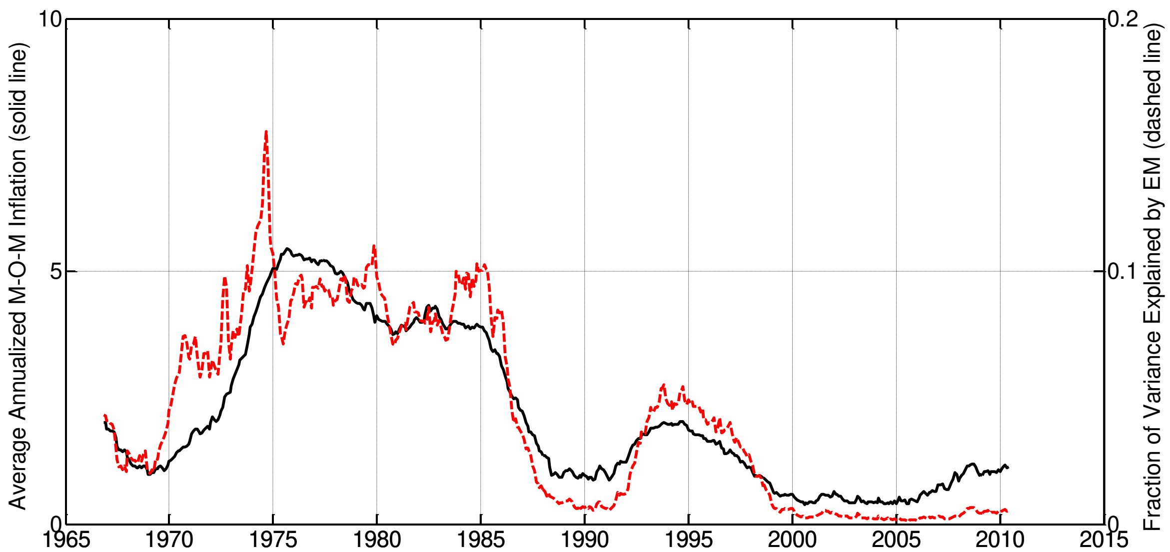
	Share of Inflation Variance (%)		
Unfiltered Data			
	IM Term	EM Terms	HO Terms
1970-2010	0.963	0.102	-0.065
1970-1085	1.045	0.100	-0.146
1986-1998	1.131	0.046	-0.177
1999-2007	1.028	0.016	-0.043
Baxter-King Filter, 1.5-8 years			
	IM Term	EM Terms	HO Terms
1970-2007	0.978	0.232	-0.210
1970-1085	0.884	0.353	-0.237
1986-1998	1.010	0.083	-0.093
1999-2007	1.275	0.142	-0.417
Baxter-King Filter, 3-8 years			
	IM Term	EM Terms	HO Terms
1970-2007	0.771	0.339	-0.110
1970-1085	0.604	0.512	-0.116
1986-1998	0.901	0.191	-0.092
1999-2007	1.047	0.157	-0.205

Notes: Samples run from 1970:01 to 2007:05, 1970:01-1985:12, 1986:01-1998:12, and 1999:01-2007:05. See equation (6) for a definition of the IM, EM and HO terms. For the filtered series, we use a symmetric two-sided Baxter-King filter with frequencies corresponding to 18-96 and 36-96 months, respectively, with 36 lags and leads.

Figures 7 visualizes the increasing importance of the EM terms for periods of higher inflation. The figure displays a rolling variance decomposition, where the EM shares for each month have been calculated on the basis of the respective previous 72 months. For instance, the share of the EM term in January 1980 reflects it's importance over the period January 1974 to December 1979. The figure relates the shares of the EM terms to the respective average annualized rate of retail price inflation at every point in time. The two lines in the figure show a clear comovement of the two series. This reflects the finding that with decreasing rates of inflation the extensive margin becomes less important for overall inflation dynamics.

A number of interesting conclusions emerge from the above exercises. First, the results presented above for the German data are in line with Gagnon (2009), who finds a much more pronounced role of the extensive margin for inflation dynamics for high-inflation episodes. This result is remarkable because even for the episode 1970-1985, the average annualized rate of inflation is low (about 4%) compared to the Mexican high-inflation episodes, where CPI inflation reached 41% in 1995. Thus, while for the Mexican sample annual inflation needs to be at 10-15% for the EM terms to become important, we find this tendency also for lower inflation rates. Second, we find much higher shares of the EM terms at lower frequencies suggesting that, even during periods of low inflation, the frequency of price changes is not invariant over time as standard time-dependent models predict. Instead, the fraction of firms that decide to adjust prices changes gradually over time. This is consistent with menu-cost models implying that firms adjust prices once the costs of having implemented a non-optimal price due to accumulated change in the economic environment exceeds the adjustment cost (see e.g. Cecchetti (1986)). Third, results are quite similar for price expectations implying that price updating adjusts slowly over time, too. Time-dependent sticky plan models in the spirit of Mankiw and Reis (2002) imply that the frequency of firms that update their price expectations is invariant. Our results show, however, that the extensive margin of expected price changes is important for inflation dynamics at the business cycle frequency. These results accord with state-dependent sticky plan models in the spirit of Burstein (2006) or Alvarez et al. (2010) postulating a menu-cost of changing plans of future prices.

Figure 7: Rolling Variance Decomposition - EM Term over Time



4. A VAR Model for Germany

4.1. The Basic VAR Model

To analyze the effects of a monetary policy shock on the respective components of inflation, the following reduced-form VAR model is estimated:

$$Y_t = c + A(L)Y_{t-1} + u_t, \tag{7}$$

where Y_t is a vector of endogenous variables, c is a vector of intercepts, $A(L)$ is a matrix of autoregressive coefficients of the lagged values of Y_t and u_t is a vector of error terms. In our benchmark regression we include the following six variables in the system:

$$Y_t = [IP_t,\ PPI_t,\ EM_t,\ IM_t,\ M1_t,\ R_t]. \tag{8}$$

As equation (8) above shows, the vector Y_t of endogenous variables contains the German industrial production IP_t, the producer price index PPI_t, the extensive (EM_t) and intensive (IM_t) margin of retail price inflation, the monetary aggregate $M1_t$[25] and the three-month Euribor R_t.[26] Except for the Euribor, all variables are seasonally adjusted. German industrial production, the producer price index and M1 are included as log-levels, while the extensive and intensive margin and the Euribor enter in percentages. All variables are linearly detrended. In the benchmark case, six lags of the endogenous variables are included in the estimation, which seems to be sufficient to capture the dynamics of the model.[27] The VAR model is estimated by means of Bayesian methods using monthly data over the period 1995:01-2009:06. The sample period only starts in 1995 in order to exclude any shocks resulting from the German reunification that could possibly be confused with a monetary policy shock. The ongoing convergence process in the mid-90's towards stage three of the monetary union may justify that our sample period starts several years before the official start of the EMU (Surico, 2003). Moreover, Chow breakpoint tests do not reject the null hypothesis of structural stability during this period. In any case, results are robust to changing the sample period to 1999:01-2009:06.[28] As in Uhlig (2005), Canova and Nicolo

[25]Following Smets and Peersman (2001), we use M1 instead of M3 as measure of the monetary aggregate. Since a restrictive monetary policy shock may lead to a substitution effect away from liquidity towards other components of M3, such as time deposits or mutual funds, responses of this measure might not reflect the actual response of narrow money.

[26]Our results are robust to including the oil price as an additional variable to account for changes in world economic conditions (Smets and Peersman, 2001).

[27]While different lag length criteria lead to different suggestions concerning the number of lags to include, all of them tend to propose shorter lag lengths. Our main results are, in fact, robust to varying the lag length.

[28]Additionally, we estimated the model for the period prior to the German reunification; 1973-1989. While the qualitative results concerning the extensive margin are robust, we encounter, however, a price puzzle. Moreover, Chow breakpoint tests indicate structural instability in the early 1980's at the 5% level. We therefore only report results for the period 1995-2009, where structural stability is given. Regression results for different sample periods as well as results of the Chow breakpoint tests are available upon request.

(2002) and Peersman (2005) we identify the monetary shock by imposing sign restrictions on the impulse response functions[29]. Identification is achieved by imposing the standard assumptions that a contractionary monetary policy shock has a non-positive effect on industrial production, on the producer price index and on the monetary aggregate as well as a non-negative effect on the short term interest rate. These restrictions are implied by a wide range of DSGE models and have been applied in a VAR framework by, for instance, Canova et al. (2007). Because we are mainly interested in the response of the intensive and extensive margin to the monetary shock, we do not restrict these variables. In the baseline case, restrictions are binding for twelve months following the shock.[30] The restriction setup is summarized in Table 7:

Table 7: Identifying sign restrictions

Variable	Response to monetary shock
Industrial Production	$\leq 0, \quad k = 0, ..., 11$
PPI	$\leq 0, \quad k = 0, ..., 11$
Extensive Margin	
Intensive Margin	
M1	$\leq 0, \quad k = 0, ..., 11$
Euribor	$\geq 0, \quad k = 0, ..., 11$

Numerically, following e.g. Canova and Nicolo (2002) or Uhlig (2005), the sign restriction approach is implemented by taking draws for the VAR parameters from the Normal-Whishart posterior, constructing an impulse vector for each draw and calculating the corresponding impulse responses for all variables over the specified horizon.[31] If all these responses meet the sign restrictions, the draw is kept, otherwise it is discarded. The impulse response functions for the respective variables are then calculated as the median of all "successful" draws. For the analysis at hand, the procedure is repeated until 1000 draws are found satisfying the restrictions. In contrast to other identification strategies the sign restriction approach offers some advantages. Compared to the traditional Cholesky ordering identification, the sign restriction approach allows for more explicit, transparent, and in particular model-based identification. Thus, zero-restrictions on contemporaneous interactions may not hold in reality (Faust, 1998). At the same time imposing zero restrictions on long-run impulse responses is avoided. Faust and Leeper (1997) show that long-run restrictions may be biased in small samples.

[29] In contrast, for instance, Canova and Nicolo (2002) and Peersman (2005) identify several shocks which should also help to identify the monetary shock. However, identifying all shocks comes at the cost of making more assumptions. Therefore, and because we are merely interested in the effects of a monetary shock, we only identify the Euribor shock.

[30] Scholl and Uhlig (2005) use a similar restriction horizon.

[31] Estimation was performed by using Fabio Canova's Matlab codes bvar.m, bvar_chol_impulse.m and bvar_sign_ident.m which can be downloaded from his website http://www.crei.cat/people/canova/.

4.2. Variance Decomposition of Impulse Responses

In order to assess the validity of different price setting models, it is important to analyze the relative importance of variations in the extensive and intensive margin for overall inflation dynamics *conditional* on a monetary policy shock. We would thus like to disentangle the importance of the extensive margin for the response of the rate of retail price inflation to a contractionary monetary policy shock. This amounts to asking "how wrong" those models are that predict a response of the intensive margin to a monetary policy shock only as is done by, for instance, the time-dependent models of Taylor (1999) and Calvo (1983). In contrast, the menu cost model of Dotsey et al. (1999) predicts a more important role for the response of the extensive margin for the transmission of monetary shocks. However, despite of modeling state-dependent price setting, the framework of Golosov and Lucas (2007) implies that the role of the extensive margin is less pronounced. To evaluate these different predictions, we first calculate the response of the rate of retail price inflation that is implied by the responses of the extensive and the intensive margin. This can easily be done by multiplying the response of the two margins:

$$R^{\pi}_{t+k} = R^{EM}_{t+k} \cdot R^{IM}_{t+k}, \tag{9}$$

where R^{EM}_{t+k} and R^{IM}_{t+k} denote the cumulative impulse responses at period k of the extensive and intensive margin, respectively, to a monetary policy shock at time t and R^{π}_{t+k} indicates the implied response of the rate of inflation to the same shock. The relative importance of variations in the responses of the extensive and intensive margin can then be calculated using these measures and equation (6) that has been employed in the last section.

4.3. Alternative Specification: Increases versus Decreases

We additionally estimate a further specification that includes the fraction of price increases and decreases, respectively, instead of the extensive margin. Thus, the overall fraction of price changes is split up into these two separate components. This allows us to analyse the respective responses of these measures to a monetary shock and thus to learn more about the driving forces underlying the reaction of the extensive margin. The modified specification is given by:

$$Y_t = [IP_t,\ PPI_t,\ FRI_t,\ FRD_t,\ IM_t,\ M1_t,\ R_t], \tag{10}$$

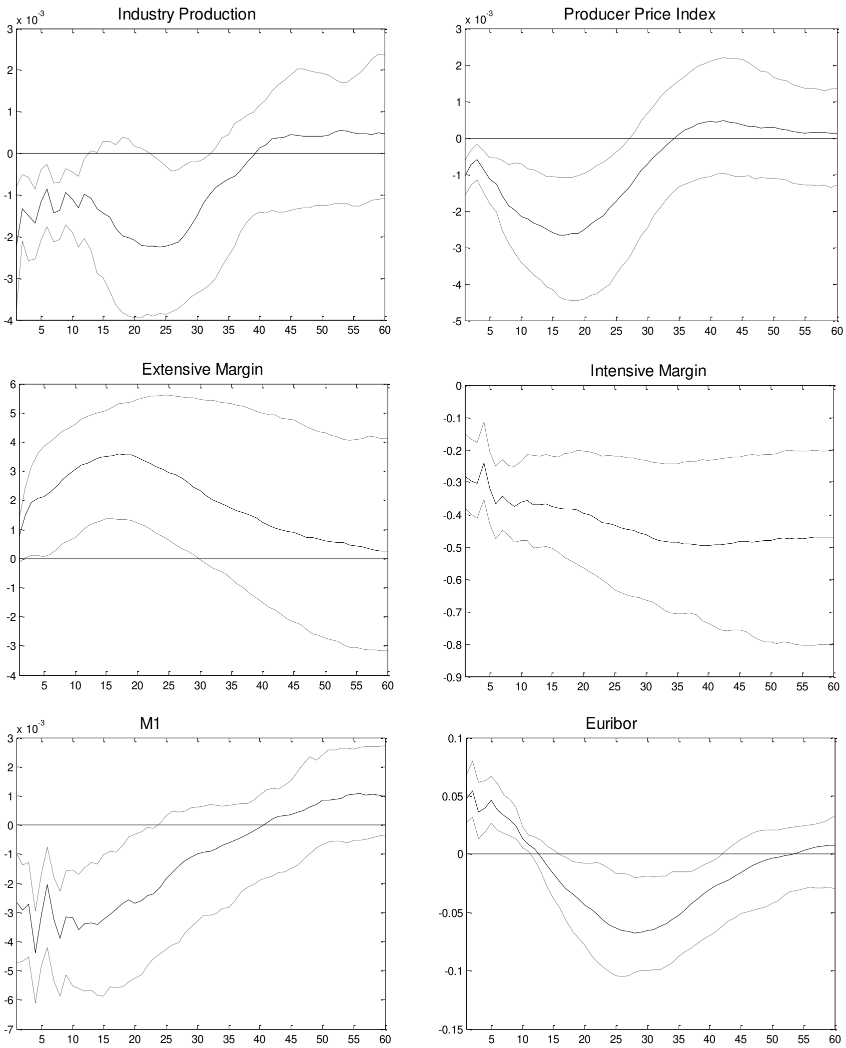
where FRI_t and FRD_t denote the fraction of price increases and decreases, respectively. The shock is identified using the same identification scheme as given above. The two components of the extensive margin as well as the intensive margin are left unrestricted in order to be able to analyze the reaction of these variables to a monetary shock.

5. Results of the SVAR Model

5.1. The Benchmark Specification

Figure 8 displays impulse responses of the variables included in the SVAR to a contractionary monetary policy shock that is identified according to the scheme described in the last section. In the figure, the solid lines denote the median impulse responses identified from a Bayesian vector-autoregression with 1000 draws using sign restrictions. The dashed lines are the 68% confidence intervals. Since the signs of the responses of industry production, the producer price index, M1 as well as the Euribor have been restricted, there is no need to extensively interpret the direction of these adjustments. As preset, industry production falls as a reaction to the shock and remains below the zero line for about 30 months. Similarly, the producer price index shows a decrease by about 0.2% and stays below benchmark for more than two years. As specified, M1 decreases on impact and stays below zero for about 24 months, while the Euribor increases and remains above baseline somewhat longer than restricted. To evaluate the response of the size and frequency of price adjustment separately, we leave the extensive and intensive margins unrestricted. Figure 8 shows that the extensive margin increases significantly on impact and reaches its maximum response of around 3.5% after one and a half years. The direction of the response is as expected; the fraction of firms that decides to adjust prices rises. The increase is temporary; after several years the cumulative response reaches the zero line. As expected, the average size of price adjustment, the intensive margin, decreases following a contractionary monetary shock; the maximum response is around -0.5% after about three years. However, the impulse response function returns to the zero line after only five months following the shock. Overall, the significant and relatively strong reaction of the extensive margin to a monetary policy shock clearly contradicts the implications of time-dependent models that the frequency of price changes is inactive and does not depend on economic conditions.

Figure 8: VAR Model with Sign Restrictions: Impulse Responses to a Monetary Shock

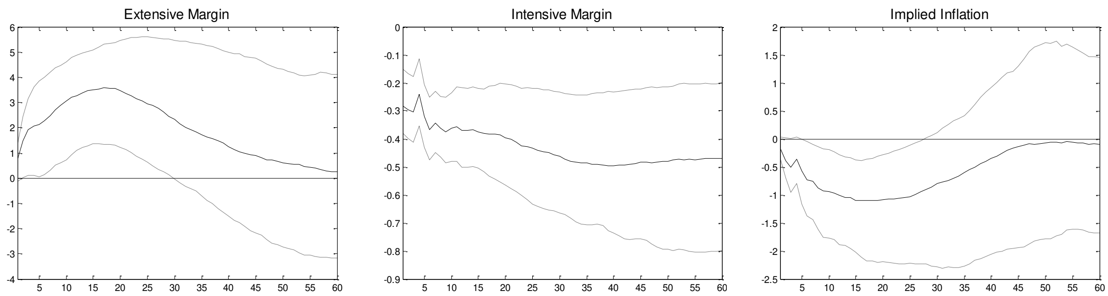


Notes: The solid lines denote the median of the impulse responses following a contractionary monetary shock. The dotted lines refer to the 68% confidence intervals. All impulse response functions are identified from a Bayesian vector autoregression with 1000 draws using sign restrictions with a restriction horizon of 12 months. While the impulse responses of industrial production, the PPI, M1 and the Euribor are changes in the (log) levels of the variables, the impulse responses of the IM and EM are cumulative responses.

5.2. Implied Rate of Inflation and Variance Decomposition of Impulse Responses

Figure 9 displays again the impulse responses of the extensive and intensive margin. Moreover, the implied response of the rate of retail price inflation, calculated according to equation (9) above, is shown in the figure. Following the contractionary monetary policy shock the implied rate of retail price inflation decreases by up to 1% after about 18 months. The implied negative response is temporary and lasts for about 24 months. Such a reaction of the rate of inflation to the monetary shock is in line with economic theory and previous studies, which indicates that also the responses of the extensive and intensive margin are reasonable. Calculating the implied response of the rate of inflation additionally allows us to assess the relative importance of variations in the extensive and intensive margin for overall inflation dynamics *conditional* on a monetary policy shock. Applying formula (6) to the impulse response functions, we find that while fluctuations in the response of the intensive margin are relatively unimportant for the response of the implied rate of inflation, variations in the extensive margin's response are much more important. The share of the intensive margin in the variance of the response of overall inflation is only 9.6%, while the share of the extensive margin amounts to 109.3%.

Figure 9: The Extensive and Intensive Margin and the Implied Rate of Inflation



Notes: The solid lines denote the median of the impulse responses following a contractionary monetary shock. The dotted lines refer to the 68% confidence intervals. The impulse response functions for the extensive and intensive margin are identified from a Bayesian vector autoregression with 1000 draws using sign restrictions with a restriction horizon of 12 months. The impulse response function for the implied rate of inflation is calculated from these impulse responses according to $R^{\pi}_{t+k} = R^{EM}_{t+k} \cdot R^{IM}_{t+k}$.

5.3. Fraction of Increases and Decreases

Figure 10 shows impulse responses of the modified specification of the VAR model given in equation (10). Instead of the extensive margin, the model now includes the frequency of price increases and decreases separately. The sign restrictions are defined as before with the latter variables as well as the intensive margin remaining unrestricted. As expected, the cumulative response of the fraction of price decreases is significantly positive following the shock. The cumulative response of the frequency of price increases reacts with a delay and is negative thereafter. Thus, as expected, the significantly positive reaction of the overall frequency of price changes is due to a rise in the share of firms that decrease their price following the contractionary shock that offsets the negative reaction of the frequency of price increases in the short-run.[32]

5.4. Robustness

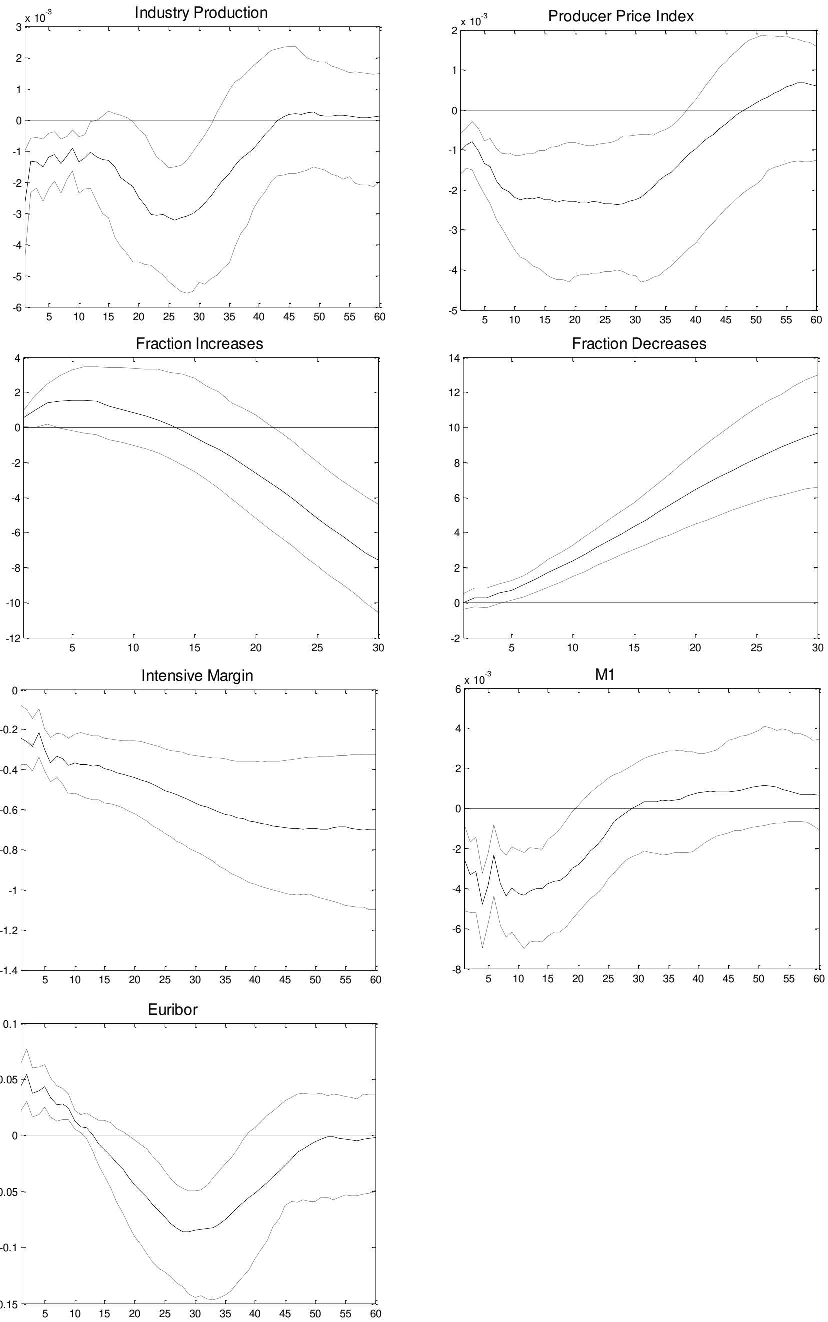
As has been mentioned above, the sign restriction approach involves specifying the restriction horizon K. Uhlig (2005) offers a discussion on the effects of the transmission of a monetary shock on real GDP for U.S. data when varying the restriction horizon K. In order to check the sensitivity of the impulse responses to variations of the restriction length, we estimate the SVAR additionally choosing different values for K. Figure 11 shows the impulse responses of the variables of interest, the EM and IM, to the monetary policy shock identified under different restriction horizons. While the first row displays results for K=9, the second and third rows show impulse responses under K=12 and K=15, respectively. Figure 11 reveals that for K=9 the response of the extensive margin to the monetary shock is insignificant, while the intensive margin decreases significantly.[33] In contrast, for shocks affecting the economy for 15 months, the extensive margin shows a strong and significant reaction, as can be seen in the third row of the figure.[34] This suggests that the reaction of the frequency of price changes to a monetary shock is stronger, the more persistent it's effects are on the economy. By contrast, the response of the intensive margin is similar in all cases.

[32] Arguably, with positive trend inflation, the rise in the frequency of price increases should be larger than the fall in the frequency of price decreases. However, we control for a time trend in our VAR model.

[33] Similar results are obtained for a restriction horizon of six months or eight months.

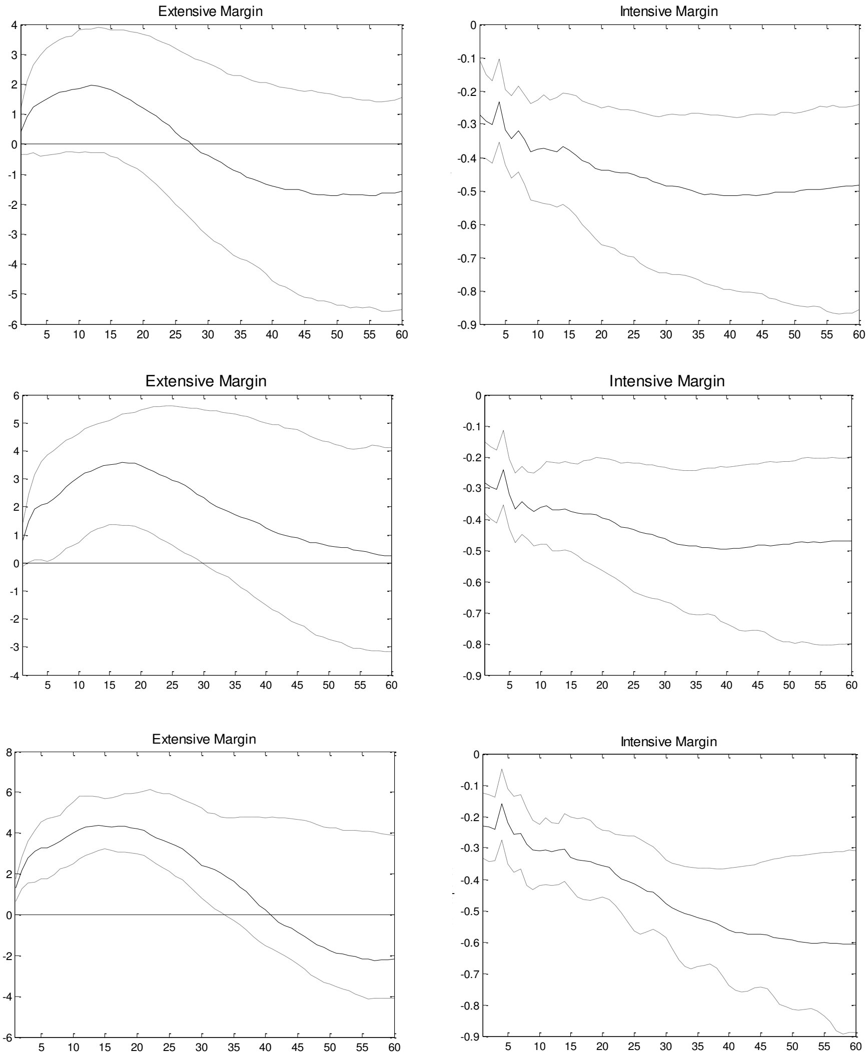
[34] Results are very similar for even longer restriction horizons of 18 or 24 months.

Figure 10: VAR Model with Sign Restrictions: Fraction of Price Increases and Decreases



Notes: The solid lines denote the median of the impulse responses following a contractionary monetary shock. The dotted lines refer to the 68% confidence intervals. All impulse response functions are identified from a Bayesian vector autoregression with 1000 draws using sign restrictions with a restriction horizon of 12 months.

Figure 11: VAR Model with Sign Restrictions: Varying the Restriction Horizon



Notes: The solid lines denote the median of the impulse responses following a contractionary monetary shock. The dotted lines refer to the 68% confidence intervals. All impulse response functions are identified from a Bayesian vector autoregression with 1000 draws using sign restrictions with a restriction horizon of 12 months. Rows one, two and three display impulse responses to a monetary shock identified with a restriction horizon of 9 months, 12 months and 15 months, respectively.

6. Conclusion

In this paper we provide new evidence on the relationship between aggregate inflation dynamics and the extensive margin of price adjustment in order to evaluate the relative importance of time- versus state-dependent pricing. This is done using a new firm-level dataset constructed from a large panel of business surveys of German retail firms over the period 1970-2010. Additionally, the dataset includes price expectations allowing to analyze the setting and updating of price plans. Following Klenow and Kryvtsov (2008), we decompose the variance of inflation into terms involving the extensive and intensive margin, respectively. We find that for periods of relatively high and volatile inflation such as the sample period including the 1970's and early 1980's not only the intensive margin matters for aggregate inflation dynamics but variations in the extensive margin are important for the variability of the overall rate of inflation as well. In contrast to existing evidence for Mexico and Norway reported by Gagnon (2009) and Wulfsberg (2009), respectively, for Germany we do not need annual inflation rates of more than 5% to observe these results. Moreover, our findings suggest that at the business cycle frequency the extensive margin comoves much more strongly with the rate of inflation and accounts for a large share of inflation's variance - even in periods of very low inflation. This is a new result and is clearly at odds with standard time-dependent pricing models implying an inactive role of the extensive margin. Furthermore, estimating a structural VAR model with theory-based sign restrictions for the German economy over the period 1995-2009, we find that the extensive margin as well as the frequency of price increases and decreases, respectively, show a significant reaction following a monetary policy shock. Thus, the extensive margin clearly responds to economic conditions, which provides further evidence in favor of state-dependent pricing. Calculating the implied response of the rate of retail price inflation to the monetary shock and constructing measures of the importance of the responses of the extensive and intensive margin, respectively, shows that the extensive margin is also important *conditional* on a monetary shock.

The results outlined in this paper have important implications for the modeling of price stickiness. Overall, our findings suggest that the timing of price changes should be endogenized in models of price setting if they are to realistically predict the dynamics of the frequency and magnitude of price changes. More specifically, results imply that models predicting an important role for the extensive margin for overall inflation dynamics and thus for the transmission of a monetary shock such as the framework of Dotsey et al. (1999) are more realistic than models emphasizing the intensive margin such as standard time-dependent models or certain state-dependent models such as Golosov and Lucas (2007) - even for relatively moderate inflation regimes. Moreover, the finding that also the extensive margin of price updating is important for overall inflation variability is in line with sticky plan models containing state-dependent elements such as Burstein (2006) or Alvarez et al. (2010). To the extent that these respective models lead to diverging predictions concerning the speed and persistence of monetary policy transmission these results have interesting policy implications.

Appendix A. Data

Appendix A.1. Business Survey Data

Since 1949 the Ifo Institute for Economic Research has been analyzed economic developments in Germany using monthly business surveys (see Becker and Wohlrabe (2008) for more details on the variables contained in the survey). In the questionnaires firms are asked about the development of certain key measures such as the number of orders and business volume, the perceived state of business as well as the development of prices. A distinct feature of the survey data is that it contains firm-specific information on expectations concerning the future business development as well as future prices. While the data is mainly used for the construction and analysis of business tendency indicators, the fact that the survey contains economic measures characterizing the idiosyncratic state of the firms allows to analyze a variety of other issues at well. As has been emphasized in the main text, in this paper we only analyze data concerning the retail sector. In 2003, the average number of retail firms surveyed each month was 900, while the average response rate was about 70%. The participating firms' share of total revenues generated in the retail sector was about 10%.

For the questions asked in this paper, we only use information on the price development as well as on price expectations for firms within the retail sector. As far as price realizations are concerned, firms are asked to answer the following question:

Development in reporting month:
Relative to the previous month, our sales prices were (1) increased, (2) not changed, (3) decreased

Concerning their price expectations, firms are asked the following question:

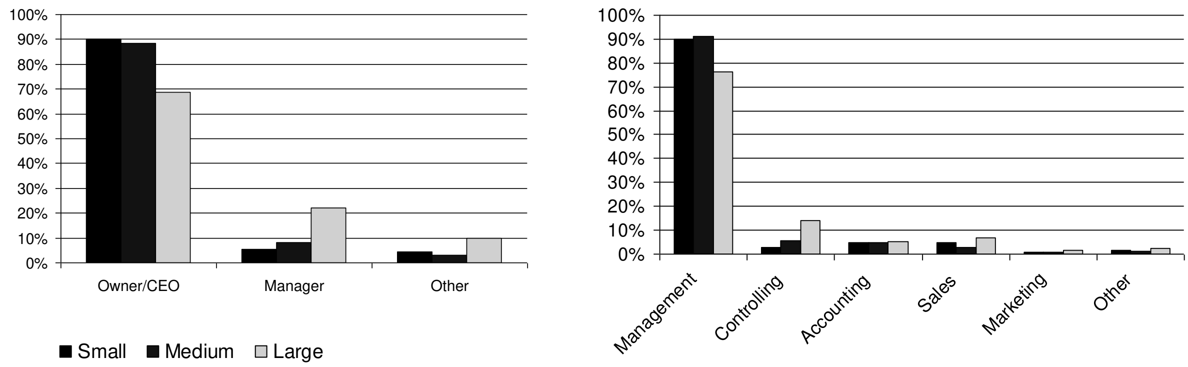
Plans and Expectations:
In the next three months we expect our sales prices to (1) increase, (2) not change, (3) decrease

It is explained in the main text how we account for the fact that expectations are reported for the next *three* months.

In order to judge the extent to which the business surveys capture the price developments actually realized by the firms, it is important to know who actually answers the questionnaires. According to Abberger et al. (2009), for small and medium-sized firms, in almost 90% of the cases the surveys are answered by the firm owner, the CEO or another member of the company's board. In the case of large firms, almost 70% of the survey are answered by the latter group while in about 20% of the cases the questions are answered by department managers (see Figure A.14, left panel). Moreover, as can be seen in the right panel in figure, if firms are asked in which department of the company the questionnaires are filled out, about 90% of small and medium-sized firms report "management". For large firms, the questionnaires are answered within the management department in almost 80% of the cases. Thus, overall, the questionnaires are answered at a very high level of expertise suggesting that they reliably report actual price developments.

A final issue concerns the price development reported by multi-product firms. Arguably, the inclusion of multi-product firms in the survey may lead to an upward bias of the frequency of price changes. For instance, in an extreme case, a firm may report a price change even though only the price of one major product has been adjusted. In the survey, this problem is mitigated because multi-product firms are asked to fill out several questionnaires for different product groups. To the extent that firms still have to cluster several sub-products within the same reporting category, about half of the respondents report the average price development of all their products (43.3%) or give information on prices of their most important products in terms of business volume (44.6%). Only 10% report the price devlopment of their main product, while 3.7% use other practices in reporting their price development (Abberger et al., 2009).

Figure A.12: Position of the person and department in charge of answering the questionnaires



Left panel, question asked : *Which position does the person in charge of answering the questionnaire have in your company?* Right panel, question asked: *In which department of your company is the survey usually answered?.* Since firms may report several departements, percentages don't always add up to 100.

Appendix A.2. Data Availability

Table A.8: Availability of Business Survey and Retail Price Data

Data	Period of availability	Source
Disaggregated survey data, West	1990:01 - 2009:06	Ifo Institute
Disaggregated survey data, East	1998:01 - 2009:06	Ifo Institute
Aggregated survey data, West	1960:01 - 2006:01	Ifo Institute
Aggregated survey data, West&East	1991:01 - 2010:07	Ifo Institute
Retail price index, 1995=100	1950:01 - 1990:12	Federal Bureau of Statistics
Retail price index, 2005=100	1991:01 - 2010:07	Federal Bureau of Statistics

Appendix A.3. Accounting for Sales

The survey dataset does not contain information on whether a price change is related to temporary sales. We account for the existence of temporary sales in the data by using a "sales filter" proposed in the literature. In particular, we identify such price changes by looking for "V-shaped" patterns in the data using a "sale filter" similar to the one proposed by Nakamura and Steinsson (2008). In particular, we label a price change "sale" if there is a one-time price decrease that is followed by a price increase. We define different windows for the time it takes for a decrease to be followed by an increase; in particular, we consider one to three months, labeled as window 1, 2 and 3, respectively. Once price changes related to sales are identified by the filter, they are removed by assigning these observations to the group of "no changes". Observations indicating a price decrease (-1) due to a sale are thus replaced by (0).

As pointed out in Nakamura and Steinsson (2008), this approach has several disadvantages relative to a direct identification of sales. First, clearance sales are not defined as sales using the filter; the measure adopted here may thus underestimate the true frequency of sales. Second, since we work with monthly data, very short-lived sales that are followed by price increases in the same month are not observable in the data and can thus not be identified by the filtering procedure. For instance, a firm that decreases its price at the beginning of the month, and increases it again two weeks later would probably not report these price changes when answering the questionnaire. Third, Nakamura and Steinsson (2008) mention the possibility for the sales filter to confuse sales with "regular" price changes in categories with very volatile price changes such as gasoline. However, since the share of these products in our dataset is very small, this is unlikely to cause any bias. An additional problem for the survey data, however, results from the fact that we do not have idiosyncratic information on the size of price changes. Thus, we do not observe whether prices actually return to the original price or stay low relative to before the sale and are thus not able to distinguish asymmetric and symmetric V-shaped patterns as is done in Nakamura and

Steinsson (2008). An additional problem is that we can only account for sales during the period 1990-2009 but not for the full sample period, since we only have aggregate price series for the years prior to 1990.

Table A.9 displays the mean frequencies, standard deviations as well as the correlation with the overall rate of retail price inflation of price changes for the original data as well as for the filtered data using the sales filter with different window sizes. As can be seen in the table, removing sales from the data does not cause changes in the statistics related to the extensive margin. The mean frequency of price changes only decreases slightly from 27.32% for the original data to 26.7%, 26.2% and 25.86% for the filtered data using window 1, 2 and 3, respectively. Similarly, the standard deviations for the different series are almost the same decreasing only slightly for the filtered data. Thus, the occurrence of sales as identified by the procedure described above is not a frequent phenomenon in our data as compared to the U.S. data reported in, for instance, Nakamura and Steinsson (2008). Moreover, using the filter does not influence the correlation with the rate of inflation indicating that the exclusion of sales does not alter the macroeconomic interpretation of the results.

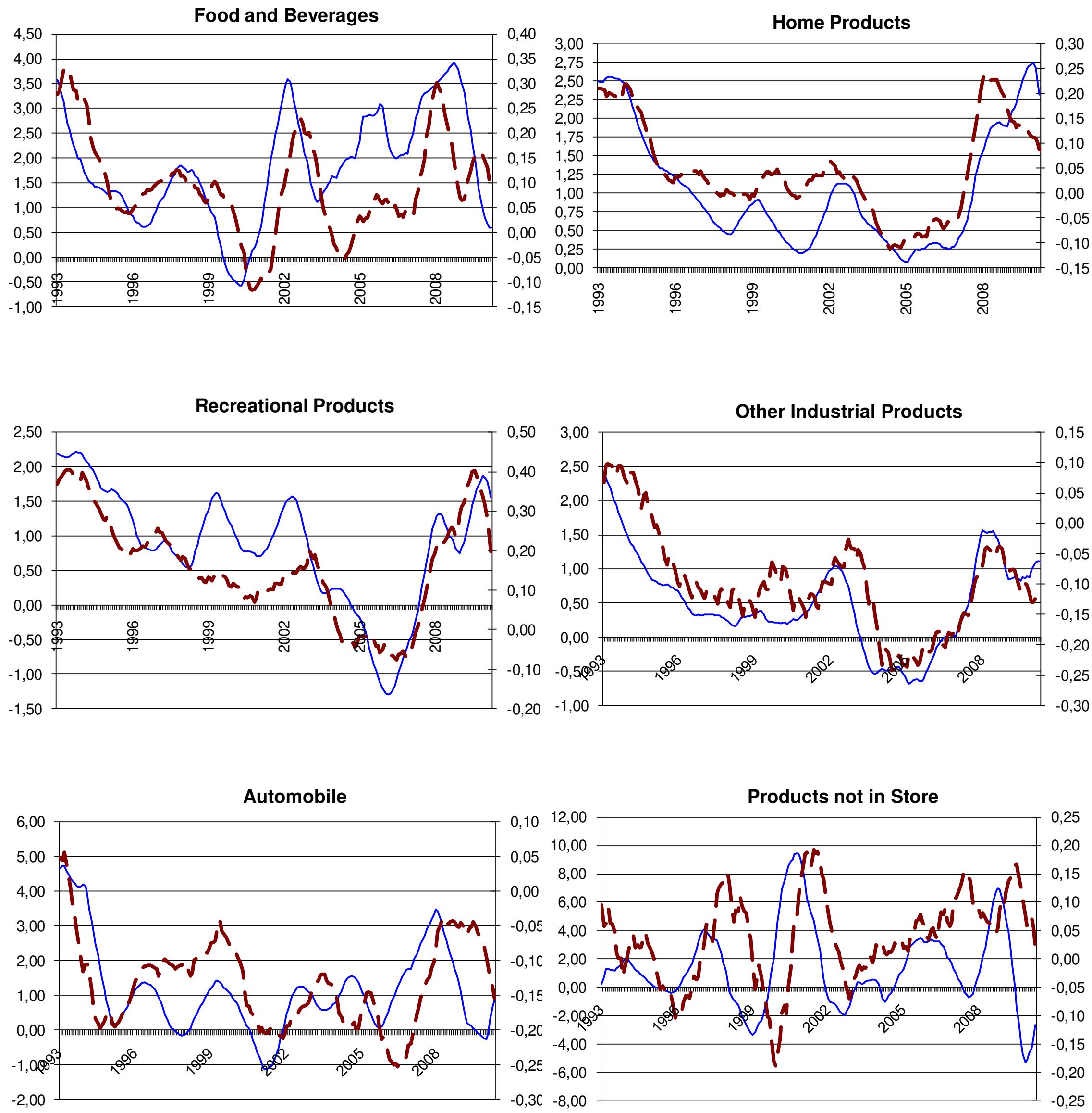
Table A.9: Summary Statistics for the Extensive Margin- Excluding Sales

Variable	Mean (%)	Std. dev. (%)	Corr. with π_t
Original data	27.32	7.26	0.18
Sale filter, window 1	26.70	7.09	0.17
Sale filter, window 2	26.20	7.02	0.18
Sale filter, window 3	25.86	7.08	0.19

Notes: Sample runs from 1990:01 to 2009:06 with monthly frequency. The retail price index is obtained from the Federal Bureau of Statistics. Lines 2-4 show results from filtered data, where observations coded as price decreases (-1) identified as "sale" are replaced by "no change" (0).

Appendix B. Tables and Figures

Figure B.13: Aggregated Micro Retail Price Data and Retail Price Index - Sectors



Appendix C. Decomposing the Rate of Inflation

The rate of inflation in a certain period can be expressed as

$$\begin{aligned}\pi_t &= \frac{P_t}{P_{t-1}} - 1 \\ &= \frac{\sum_i q_i(P_{it} - P_{it-1})}{\sum_i q_i P_{it-1}},\end{aligned} \tag{C.1}$$

where P_t is a price index that can be written as a weighted average of the individual prices with individual weights q_i. The share of firm-products with price changes can be expressed as:

$$\frac{1}{n}\sum_{i=1}^{n} 1_{\Delta P_{it} \neq 0} = \frac{K_t}{n},$$

with K_t denoting the number of price changes in a given period: $K_t = \sum_{i=1}^{n} 1_{\Delta P_{it} \neq 0}$. Thus, the average rate of change of the "price changers" is given by:

$$\pi_t^K = \frac{\sum_{i \in K} q_i \Delta P_{it}}{\sum_{i \in K} q_i P_{it-1}}. \tag{C.2}$$

Now the overall rate of inflation can be expressed as a function of the average rate of inflation of the "changers":

$$\begin{aligned}\pi_t &= \frac{\sum_i^n q_i \Delta P_{it}}{\sum_i^n q_i P_{it-1}} \\ &= \frac{\sum_{i \in K} q_i \Delta P_{it}}{\sum_{i \in K} q_i P_{it-1} + \sum_{i \notin K} q_i P_{it-1}} \\ &= \frac{\sum_{i \in K} q_i \Delta P_{it}}{\sum_{i \in K} q_i P_{it-1}} \cdot \frac{\sum_{i \in K} q_i P_{it-1}}{\sum_i^n q_i P_{it-1}}.\end{aligned} \tag{C.3}$$

The first term in the last equation above denotes the rate of inflation of items with price changes given in equation (2), while the second term is approximately equal to the fraction of price changes:

$$\frac{\sum_{i \in K} q_i P_{it-1}}{\sum_i^n q_i P_{it-1}} \approx \frac{\sum_{i \in K} q_i}{\sum_i q_i} = fr_t.$$

We implicitly weight all products equally, since the dataset does not contain information concerning the relative importance of the different products. Moreover, we assume that the price set last period is approximately the same across firms $P_{it-1} \approx P_{jt-1}$. Therefore, the rate of inflation can be expressed as the product of two terms, namely the size of price adjustment, the intensive margin, and the fraction of price changes (extensive margin):

$$\pi_t \approx \pi_t^K \cdot fr_t = IM_t \cdot EM_t. \tag{C.4}$$

The extensive margin can be further decomposed into terms due to price increases and decreases. With $K_t^+ = \sum_{i=1}^n 1_{\Delta^+ P_{it} \neq 0}$ and $K_t^- = \sum_{i=1}^n 1_{\Delta^- P_{it} \neq 0}$ denoting the number of price "increasers" and "decreasers" respectively, equation (4) can be written as

$$\begin{aligned} \pi_t &\approx \pi_t^K \cdot \left(\frac{\sum_{i \in K^+} q_i}{\sum_i q_i} + \frac{\sum_{i \in K^-} q_i}{\sum_i q_i} \right) \\ &= IM_t \cdot \left(EM_t^+ + EM_t^- \right). \end{aligned} \tag{C.5}$$

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