The Micro-level Price Response to Monetary Policy[†]

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Abstract

We estimate the effects of monetary policy on price-setting behavior in administrative micro data underlying the German producer price index. After expansionary monetary policy, the increase in the frequency of price change is economically small, the average absolute size across all price changes falls, and the aggregate price level hardly adjusts as a result. These estimates imply a strong degree of monetary non-neutrality because they rule out quantitative structural models that generate small and transient effects of monetary policy through selection on large price adjustments.

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1 Introduction

The real effects of monetary policy depend critically on the extent to which prices adjust and absorb changes in the interest rate. The contribution of this paper is to directly estimate this conditional moment in German administrative micro-level producer price data. After expansionary monetary policy, the increase in the frequency of price change is economically small and the average absolute size across all price changes falls up to -1%. As a result the aggregate price level hardly adjusts. Indeed, our empirical estimates imply a strong degree of monetary non-neutrality. First, they rule out quantitative structural models that generate small and transient effects of monetary policy through selection on large price adjustments. Second, we empirically confirm that monetary policy accounts for about 20% of aggregate output fluctuations.

We obtain these results by running Jordà (2005)-type local projections of German administrative micro price data on Euro Area monetary policy shocks. We use Jarociński and Karadi's (forthcoming) shock series, which builds on high frequency identification to recover monetary policy shocks from interest rate movements in narrow time intervals around European Central Bank (ECB) press events. This series also controls for the information channel of monetary policy, according to which markets may respond to new information about the economy's outlook released at press events above-and-beyond any monetary surprise.

At the extensive pricing margin, we find that the frequency of price increases rises by less than three percent following a three basis points (one standard deviation) cut in the policy rate, i.e. expansionary monetary policy. The frequency of price decreases falls by similar amounts but returns faster to normal, leaving the overall frequency of price change initially unchanged before it slightly increases. At the intensive margin, the average size of price changes increases by about half a percent. This finding primarily reflects a composition change towards more price increases. The average absolute size of a price change per adjuster actually decreases over time, reaching about minus one percent after nine months, which dampens inflationary pressures.[1]

These estimates provide a new benchmark to discriminate among structural models that seek to determine the degree of monetary non-neutrality. One prominent example of these models are menu-cost models. Up to now, a common strategy to calibrate menu cost models is to match the unconditional frequency of price adjustment and the unconditional average absolute size of a price change. The real effects of monetary policy are either small and transient (Caplin and Spulber, 1987; Golosov and Lucas, 2007; Karadi and Reiff, forthcoming) or large (Midrigan, 2011; Gertler and Leahy, 2008; Nakamura and Steinsson, 2010; Alvarez and Lippi, 2014), even though these models match the unconditional moments equally well. The difference comes from additional empirical targets used in model calibration. Crucially, these extra moments implicitly determine model price-setting behavior *conditional* on monetary policy shocks and hence the degree of monetary non-neutrality. On the one hand, Golosov and Lucas (2007) argue that selection on large price adjustments induces a strong response of the aggregate price level in reaction to monetary easing. On the other hand,

[1] We obtain very similar findings when we study the effects of expansionary Jarociński and Karadi (forthcoming)-central bank information shocks, which capture the information channel of monetary policy. While not the focus of this paper, we find these results interesting because they attest to a forward-looking component in price-setting behavior independent of monetary policy.

Midrigan (2011) argues that small price changes become more important, and the real effects of monetary policy stronger. According to our results, the average absolute size of a price change falls after a rate cut, providing evidence against the selection effect. Indeed, our findings imply that the slope of the Phillips curve lies between 0.09 and 0.26. This estimate compares well to the slope coefficient of 0.25 in the quantitative structural model of Nakamura and Steinsson (2010), in which monetary policy accounts for about 23% of aggregate output fluctuations.

This paper is the first to study the monthly Federal Statistical Office micro data underlying the German producer price index.[2] The sample covers the period 2005:M02 to 2016:M12. It comprises information on the frequency of price adjustment (the extensive margin) and the average size per price adjustment (the intensive margin) for granular manufacturing items at the 4-digit product level. In addition to this administrative data, we study independent product-level survey data on price-setting behavior from the IFO Business Climate Survey in the German manufacturing industry. This data is also available at the monthly frequency, covers only the extensive pricing margin, provides information on other outcomes and expectations which we can use as control variables, and captures the entire period since 1999 when the ECB took charge of Euro Area monetary policy. Overall, the extensive margin pricing results we obtain are very similar across both data sources.

Our findings add to other empirical work on price-setting behavior at the micro level.[3] A pair of highly-influential papers in this area, Nakamura and Steinsson (2008); Klenow and Kryvtsov (2008) document unconditional statistics, i.e., average pricing behavior over time, using US consumer and producer micro price data. Our estimates significantly expand on this evidence by conditioning on monetary policy shocks as the reason for price adjustment. This step allows to discriminate amongst structural models that explain unconditional pricing behavior equally well, but differ in their implied degree of monetary non-neutrality. Carvalho and Kryvstov (2018) measure price selection in US consumer price data and show that high inflation tends to derive from large price adjustments from low levels relative to the average. These estimate are also unconditional. The paper closest to the present one is Hong et al. (2019). Following Alvarez et al. (2016), these authors estimate the effects of monetary policy on US producer prices, conditioning on the kurtosis of price changes and other related sufficient statistics for the degree of monetary non-neutrality. The advantage of our approach is that we can also evaluate models for which no sufficient statistics are available.[4] Moreover, it does not require measurement of kurtosis which is biased upward in the presence of heterogeneous price-setting behavior across goods, whereas the frequency of price change is not.[5]

The paper also relates to the vast empirical literature that investigates the effects of monetary policy on the economy.[6] Relative to existing research, which is generally based on aggregate time series data, this paper studies micro-level behavior and the extensive and intensive margins of price setting. Other recent examples that investigate monetary policy transmission at the firm include Ottonello and Winberry (2018); Jeenas (2019); Lakdawala and Moreland (2019); Cloyne et al. (2018);

[2] Using an early, discontinued version of the data, Stahl (2006) provides descriptive statistics of unconditional price-setting behavior. These statistics are sometimes cited in the literature, but in private conversation he confirmed that there exists no accompanying paper. Bachmann et al. (2019) use quarterly statistics aggregated at the manufacturing level.

[3] See Klenow and Malin (2010) for a survey.

[4] For example, models with strategic complementarity in price setting such as Nakamura and Steinsson (2010).

[5] See the discussion in Alvarez et al. (2016, Section I.A).

[6] See Ramey (2016) for a recent survey.

Howes (2019) for investment spending, Bahaj et al. (2018) for employment, and Enders et al. (2019) for expectations about output prices and production.

2 Data Description

Our sample comprises identified monetary policy shocks, administrative data on price-setting behavior, and product-level survey data with information on the extensive pricing margin.

Monetary Policy Shocks We use a series of identified Euro area monetary policy shocks due to Jarociński and Karadi (forthcoming). The identification strategy relies on high frequency financial markets data around ECB policy announcements. Specifically, the main measure of monetary surprise is the price difference in Eonia interest swaps with 3-month maturity in 30-minute windows around press statements and 90-minute windows around press conferences.[7] The identifying assumption is that any price movements within these narrow time windows are due to monetary surprises revealed at the press event. The idea of using interest rate swaps rather than raw changes in the Eonia is that the former are assumed to have priced in any expected changes in monetary policy.

Relative to existing literature building on high frequency identification of monetary policy shocks, Jarociński and Karadi (forthcoming) deconstruct these monetary surprises further into two components: monetary policy shocks as such and central bank information shocks. Central bank information shocks refer to all novel information regarding the central bank's assessment of the economic outlook and released during the press events. If previously private to the central bank, financial markets may respond to this new information above-and-beyond the monetary policy surprise. Jarociński and Karadi (forthcoming) separate these components based on co-movement restrictions in a sign-identified vectorautoregression (VAR). A contractionary monetary policy shock raises interest rates and lowers stock prices, while an increase in interest rates and stock prices is associated with an expansionary central bank information shock.

Against this background, higher interest rates have expansionary effects conditional on central bank information shocks or contractionary effects conditional on monetary policy shocks. Because they move the economy in opposite directions, mixing these shocks results in biased estimates and makes prices appear less responsive to monetary policy. For this reason, we study the effects of pure monetary policy shocks and central bank information shocks on price-setting behavior in separation.

Pricing-Setting Data We use administrative data at the product level from the Federal Statistical Office (FSO) underlying the producer price index. The German producer price index is a weighted average of Elementary Price Indices (EPIs) for all major industrial products. Each EPI refers to a particular or, in some cases, several products at the 9-digit level of the GP 2009 production classification. The EPIs are unweighted averages of individual price quotes reported by a sample of products. For reasons of data disclosure, the FSO only provides statistics aggregated at the 4-digit product level.[8]

[7] The Euro Overnight Index Average (Eonia) measures interest on uncollateralized, overnight, interbank lending.

[8] For example, Processed and Preserved Potatoes, Footwear, or Metal Forming Machinery are product categories at the 4-digit GP 2009 level.

The sample excludes EPIs with very few observations to ensure data confidentiality and includes product price quotes imputed by the FSO. We consider individual product price changes below the 1st percentile or above the 99th percentile of all observed price changes (across EPIs) in a given month as measurement error or outlier, respectively, and remove them from the analysis.[9]

Our measurements are formally defined as follows. In each EPI, inflation equals the average of product inflation rates, i.e., $\pi_{j,t} = \frac{1}{N_{j,t}} \sum_i (p_{i,j,t} - p_{i,j,t-1})$, where $p_{i,j,t}$ denotes the log of the price of product i in EPI j at time t, and $N_{j,t}$ is the number of products for which the inflation rate is observable at time t. Equivalently, $\pi_{j,t}$ can be expressed as the product of the frequency of price change, the extensive margin, and the average size of those price changes, the intensive margin (Klenow and Kryvtsov, 2008):

$$\pi_{j,t} = \frac{1}{N_{j,t}} \sum_i (p_{i,j,t} - p_{i,j,t-1}) = \underbrace{\sum_i \frac{I_{i,j,t}}{N_{j,t}}}_{fr_{j,t}} \underbrace{\frac{\frac{1}{N_{j,t}} \sum_i (p_{i,j,t} - p_{i,j,t-1})}{\sum_i \frac{I_{i,j,t}}{N_{j,t}}}}_{\tilde{\pi}_{j,t}} \tag{1}$$

where $I_{i,j,t}$ equals one if an individual product price adjusts, $fr_{j,t}$ is the frequency of price change, and $\tilde{\pi}_{j,t}$ is average inflation of price changers. Klenow and Kryvtsov (2008) further decompose $fr_{j,t}$ into terms due to price increases and price decreases:

$$fr_{j,t} = \frac{1}{N_{j,t}} \sum_i I_{i,j,t} = \underbrace{\frac{1}{N_{j,t}} \sum_i I^+_{i,j,t}}_{fr^+_{j,t}} + \underbrace{\frac{1}{N_{j,t}} \sum_i I^-_{i,j,t}}_{fr^-_{j,t}} \tag{2}$$

where $I^+_{i,j,t}$ $\left(I^-_{i,j,t}\right)$ equals one if a price increases (decreases), $N^+_{j,t}$ $\left(N^-_{j,t}\right)$ is the number of price increases (decreases), and $fr^+_{j,t}$ $\left(fr^-_{j,t}\right)$ is the frequency of price increases (decreases). Similarly, $\tilde{\pi}_{j,t}$ can be decomposed into terms due to price increases and price decreases:

$$\begin{aligned} \tilde{\pi}_{j,t} &= \frac{\frac{1}{N_{j,t}} \sum_i (p_{i,j,t} - p_{i,j,t-1})}{\sum_i \frac{I_{i,j,t}}{N_{j,t}}} \\ &= \frac{\sum_i I^+_{i,j,t}}{\sum_i I_{i,j,t}} \underbrace{\frac{1}{\sum_i I^+_{i,j,t}} \sum_i (p_{i,j,t} - p_{i,j,t-1})^+}_{\tilde{\pi}^+_{j,t}} + \frac{\sum_i I^-_{i,j,t}}{\sum_i I_{i,j,t}} \underbrace{\frac{1}{\sum_i I^-_{i,j,t}} \sum_i (p_{i,j,t} - p_{i,j,t-1})^-}_{\tilde{\pi}^-_{j,t}} \end{aligned} \tag{3}$$

Note that the average size of price changes ($\tilde{\pi}_{j,t}$) includes the composition of the extensive margin, i.e., the share of price increases ($\frac{\sum_i I^+_{i,j,t}}{\sum_i I_{i,j,t}}$) and the share of price decreases ($\frac{\sum_i I^-_{i,j,t}}{\sum_i I_{i,j,t}}$). Define the absolute size of price changes as $\tilde{\pi}^{abs}_{j,t} \equiv \frac{1}{\sum_i I_{i,j,t}} \sum_i |p_{i,j,t} - p_{i,j,t-1}|$. The extensive pricing margin ($fr_{j,t}$, $fr^+_{j,t}$, and $fr^-_{j,t}$) and the intensive pricing margin ($\tilde{\pi}_{j,t}$, $\tilde{\pi}^{abs}_{j,t}$, $\tilde{\pi}^+_{j,t}$, and $\tilde{\pi}^-_{j,t}$) are the main outcomes of interest in this paper.

In addition to FSO micro data, we also use independent survey data on price-setting behavior available at the product level. The IFO Business Climate Survey (IFO-BCS) is a monthly survey with

[9] Additionally, Vavra (2014, footnote 21) excludes small price changes for which the absolute price change is smaller than half of the respective sample average in a given month. This extra criterion delivers results very similar to our baseline sample selection and are available upon request.

mostly qualitative questions, predominantly filled out by executives (Sauer and Wohlrabe, 2019). For a meaningful comparison with the administrative producer price data, we focus on the manufacturing sector. Relative to the FSO micro data, the IFO-BCS only provides data on the extensive margin. Specifically, our analysis of pricing behavior uses a question on whether the price of a product remained constant, increased, or decreased relative to the preceding month.[10] Formally, this information corresponds to $I_{i,j,t}$, $I^+_{i,j,t}$, and $I^-_{i,j,t}$, but for a different sample. We only consider complete price spells which start and end with a price change, and no missing values in between.

The monthly frequency of price adjustment in aggregate manufacturing displays similar dynamics across the FSO and IFO samples. The correlation coefficient is 0.62. For price increases, the correlation across samples equals 0.77; and 0.27 in the case of price decreases. Across EPIs, the correlation between the two samples equals 0.36 for price changes, 0.38 for price increases, and 0.27 for price decreases. Despite the lower correlation at the EPI level, we obtain very similar estimates using either data source.[11]

Covariates The IFO-BCS includes several other qualitative questions about product-specific outcomes and expectations. We use the responses to these questions in order to control for other factors that affect price-setting behavior. These questions include: current business situation, 6-month-ahead business expectations, orders, and 3-month ahead employment expectations. Similar to the question about price-setting behavior, there are three answer categories for each question: increase, decrease, and no change. Again, we use the individual survey responses, compute separately for each question and answer category the fraction of positive and negative responses, and merge these variables as controls to the FSO data.

Baseline Sample and Summary Statistics Our baseline sample in which monetary policy shocks and price-setting data are jointly available starts in 2005:M02. The FSO data is not available before then. The sample ends in 2016:M12. In the Appendix, we provide additional results estimated on the sample 1999:M01–2016:M12. This sample covers the entire period since the ECB manages Euro area monetary policy. In this full sample, we can only consider the extensive pricing margin available from the IFO-BCS.

The standard deviation of monetary policy shocks and central bank information shocks is small and equals about 3 basis points each.[12] Based on 14,381 EPI-month observations, we find that on average 17% of prices increase and 15% of prices decrease, which adds up to 32% of individual product prices changing per month. The average size of a price change is small and amounts to about 2.2 % in absolute terms. Price increases are slightly larger than decreases.[13] The mean of

[10] Bachmann et al. (2019) use the IFO-BCS for the manufacturing industry to study the relation between uncertainty and price setting. Carstensen and Schenkelberg (2011) use the retail portion of the IFO-BCS to study price-setting behavior for several items in the consumer price index.

[11] After controlling for month fixed effects, the correlation coefficient for price changes in aggregate manufacturing increases to 0.68. At the quarterly frequency, it is 0.72. The fact that aggregation in the cross-section and in the time dimension results in larger correlation coefficients is consistent with a measurement error interpretation.

[12] Small shocks are a common feature in high frequency identification of monetary shocks.

[13] There is rich heterogeneity in price-setting behavior across EPIs. For example, the standard deviation of the frequency of price changes per EPI equals 0.1653 in our sample. Nakamura and Steinsson (2008) document substantial heterogeneity in United States consumer and producer price-setting behavior.

month-on-month inflation in our sample is roughly 0.1%, which compares nicely to official producer price inflation.[14] Table A.1 in the Appendix shows all summary statistics for the baseline sample.

As for the IFO-BCS sample, there are more than 140,000 product-month observations available for estimation. On average 18% of prices increase and 14% of prices decreases, which add up to 32% of products changing their price every month. Notice that the frequency of price change and the share of price increases and price decreases are almost the same as in administrative data, even though both data sources are independent. This observation corroborates the high quality of the IFO-BCS.[15]

3 Price Adjustment in Response to Monetary Policy

This section presents estimates for the level effect of monetary policy on pricing behavior.

3.1 Baseline Specification

We estimate Jordà (2005)-local projections of the following form:

$$y_{j,t+h} = \alpha_{m,h} + \alpha_{j,h} + \psi_h \, \varepsilon_t^s + u_{j,t+h} \tag{4}$$

Here, $y_{s,t+h}$ denotes an outcome of interest on the extensive pricing margin ($fr_{j,t}$, $fr_{j,t}^+$, and $fr_{j,t}^-$) or the intensive pricing margin ($\tilde{\pi}_{j,t}$, $\tilde{\pi}_{j,t}^{abs}$, $\tilde{\pi}_{j,t}^+$, and $\tilde{\pi}_{j,t}^-$), ε_t^s is the identified monetary policy shock ($s = MP$) or the identified central bank information shock ($s = CBI$), $\alpha_{m,h}$ are month fixed effects, and $\alpha_{j,h}$ are 4-digit EPI fixed effects. In our baseline specification, we do not include any control variables because identification of ε_t^m is tight and plausible.[16] That said, month and EPI fixed effects in Equation (4) reduce residual variation due to seasonality and heterogeneity across sectors and thus improve estimation efficiency.[17] The object of interest is ψ_h, the dynamic effect of identified monetary policy shocks at horizon h. We normalize the sign of ε_t^m so that a positive value corresponds to a cut in rates, i.e. an expansionary monetary policy shock. We estimate separately all coefficients at each horizon h. For statistical inference, we compute standard errors following Driscoll and Kraay (1998) which allow for a rich residual correlation structure both in the time and in the cross-sectional dimension.

3.2 Main Results

We begin the discussion of our main results on micro-level price adjustment patterns with the pure monetary policy shock and the extensive margin. In this case, we separately run Equation (4) with

[14] The official producer price inflation includes EPIs unobserved in our sample for reasons of confidentiality and uses EPI weights in the aggregation, while we report an unweighted average.

[15] Table A.2 in the Appendix contains all summary statistics for the IFO-BCS baseline sample. Table A.3 in the Appendix reports the same statistics aggregated at the 4-digit industry level. This table also includes descriptive statistics for the covariates available from the IFO-BCS.

[16] To mitigate concerns about endogeneity, we add controls in a robustness check below. Our results remain unchanged.

[17] Following Jordà (2005, p.166), we recursively include the forecast errors from horizon $h-1$ in the local projection at horizon h to further increase estimation efficiency.

the frequency of prices that change ($fr_{j,t}$), increase ($fr^{+}_{j,t}$), or decrease ($fr^{-}_{j,t}$) as dependent variables. The panels in the second and third row of Figure 1 show that there are more price increases and less price decreases when monetary policy becomes expansionary. On impact, the frequency of price change hardly moves because the responses of price increases and decreases offset each other. Relative to their standard deviation, price increases and price decrease rise by about 4%. Four to seven months after the shock, price increases outweigh price decreases and the number of price changes increases by about 0.5 percentage points, or about 0.03 standard deviations. Overall, the effects on the extensive pricing margin are precisely estimated but very small in economic terms.

Next, we study the intensive pricing margin response. The bottom-four panels in Figure 1 display the cumulative change in the average size of price changes ($\tilde{\pi}_{j,t}$), the average absolute size of price changes ($\tilde{\pi}^{abs}_{j,t}$), and a breakdown by price increases ($\tilde{\pi}^{+}_{j,t}$) and price decreases ($|\tilde{\pi}^{-}_{j,t}|$). The size of an average price change ($\tilde{\pi}_{j,t}$) grows over time reaching 0.5 percent, or a little less than a third of a standard deviation increase, after 9 months. Does this result reflect the fact that there are now more price increases and less price decreases, or does price setting along the intensive margin change as well? In the right panel, second-to-last row of Figure 1, we see that the average absolute size of a price change slowly *decreases* over time reaching about minus 1 percent after 9 months, which equals a 0.85 standard deviation decline. Thus, the change in composition of the extensive margin drives the increase in $\tilde{\pi}_{j,t}$ mechanically. Behind this result hides an actual decrease in the average absolute size of price changes. The bottom row shows that the size of both price increases and price decreases fall in size in a similar fashion.

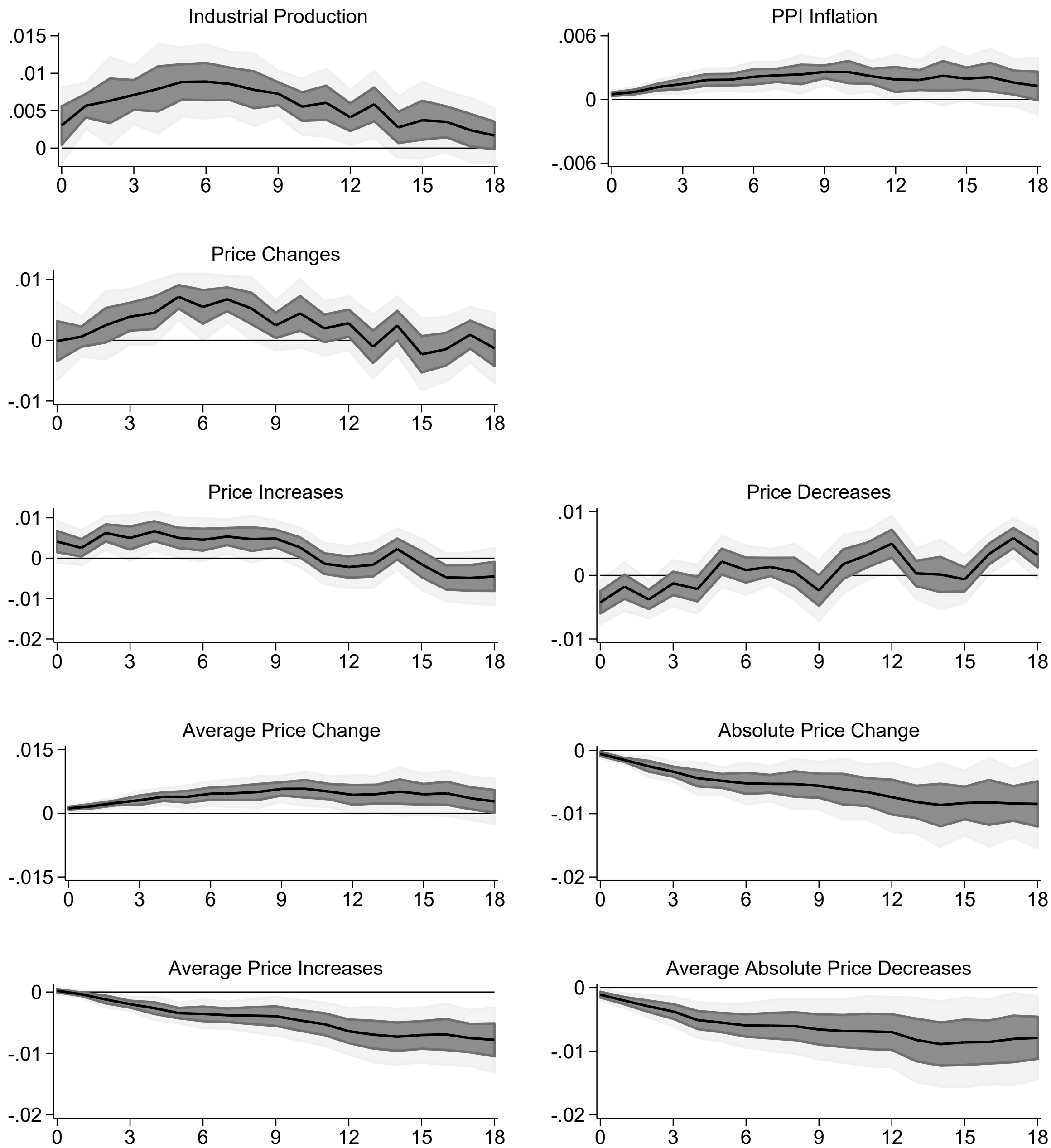
Finally, the first row of Figure 1 documents the response of production and inflation. The left panel shows the effect on the natural logarithm of industrial production, $\ln(IP_{i,t+h})$, the right panel the effect on cumulative producer price inflation, $\ln(PPI_{i,t+h}) - \ln(PPI_{i,t-1})$. Consistent with a vast empirical literature exploiting time series variation, the response of output is also hump-shaped across EPIs on average. The effect is economically mildly significant: at the peak, after 6 months, production expands by about 1 percent, or about 0.12 standard deviations of the month-on-month growth rate. The right panel shows that prices increase up to 0.2% after 9 month, which corresponds to about a third of the standard deviation of month-on-month producer price inflation. Hence, expansionary monetary policy generates producer price inflation.

Central bank information shocks affect pricing decisions in a very similar way.[18] If anything, there are three minor differences relative to monetary policy shocks. First, the effects on output and the intensive pricing margin appear somewhat stronger. Second, price increases now do not respond significantly and, as a result, the frequency of price change goes down. Third, the responses of inflation and average price changes is less persistent and dies off after about 9 months. The fact that the responses to monetary policy shocks and central bank information shocks are very similar confirms the importance of controlling for the information channel of monetary policy. Otherwise, these shocks would offset each other which would lead to the wrong conclusion that monetary policy has no significant effects on price-setting behavior.

Following Gorodnichenko and Lee (2019), we compute the forecast error variance decomposition of each outcome of interest with respect to the monetary policy shocks and central bank information shocks. Across all outcomes, both shocks explain a similar proportion of the forecast error variance.

[18] See Figure A.1 in the Appendix.

Figure 1 – Responses of Output, Inflation, and Pricing Setting: Monetary Policy Shocks



Notes: This figure shows impulse response functions to a three basis points (one standard deviation) expansionary monetary policy shock over 18 months obtained from estimating Equation (4) on 4-digit EPI-level German manufacturing data. The top row displays the response of industrial production in natural logarithms and of cumulative producer price inflation. The second an third row show the responses of the frequency of price change, the frequency of price increases, and the frequency of price decrease. The fourth and fifth row contain responses of the average size of a price change, the average absolute size of a price change, the average size of a price increase, and the average absolute size of a price decrease. All price changes in cumulative growth rates. Monthly data from Federal Statistical Office. Pure monetary policy shock from Jarociński and Karadi (forthcoming) with sign normalized so that a positive value corresponds to a cut in rates. Driscoll and Kraay (1998) standard errors. Solid lines are point estimates, light-shaded and dark-shaded gray areas are one and two standard error confidence bands, respectively. Sample period: 2005:M02-2016:M12.

Taken together, they account for only a small portion of the overall variation in industrial production as well as in the extensive pricing margin, for about 20% of the variation in price increases, and for about 40% of the variation of price decreases. Overall, they explain about 10% of PPI inflation.

3.3 Aggregate Effects on Inflation and Output

What are the macroeconomic implications of the micro-level price adjustment patterns shown in Figure 1? We next estimate the effects on aggregate manufacturing. Specifically, we run a variant of Equation (4) without EPI fixed effects using aggregate data from the Federal Statistical Office on industrial production and producer prices.[19]

The top two panels in Figure 2 contain the estimated responses to a one standard deviation expansionary monetary policy shock. The left panel shows the effect on the natural logarithm of industrial production, $\ln(IP_{t+h})$, the right panel the effect on cumulative producer price inflation, $\ln(PPI_{t+h}) - \ln(PPI_{t-1})$. In line with the empirical literature on the effects of monetary policy, the response of output is hump-shaped.[20] At the aggregate manufacturing level, the effect is also quantitatively significant: at the peak, after 6 months, production expands by about 1 percent, or about two thirds of the month-on-month growth industrial production growth rate. The large output response is noteworthy because it suggests strong amplification of small monetary policy shocks; a one standard deviation monetary policy shock corresponds to 3 basis points. The right panel shows that prices increase up to 0.15% after 9 month, which corresponds to about half the standard deviation of month-on-month producer price inflation. Hence, expansionary monetary policy generates mild producer price inflation.[21]

The results for central bank information shocks are again very similar, as the bottom two panels in Figure 2 document. Quantitatively, the real effects of monetary policy are somewhat stronger as output increases by almost 2 percent after about 5 month. On the other hand, the inflation response dissipates faster and there is no discernible effect after 6 months at standard significance levels. Overall, the differential effects of pure monetary policy shocks and central bank information shocks in aggregate manufacturing mirror those observed across EPIs.

Again, we compute the contribution of both shocks to fluctuations in output and prices, now at the aggregate level, following Gorodnichenko and Lee (2019). We find that monetary policy shocks account for about 22.5% of variations in industrial production and for approximately 15% of volatility in producer price inflation. Central bank information shocks explain about 30% of real output fluctuations and approximately 15% of producer price inflation.

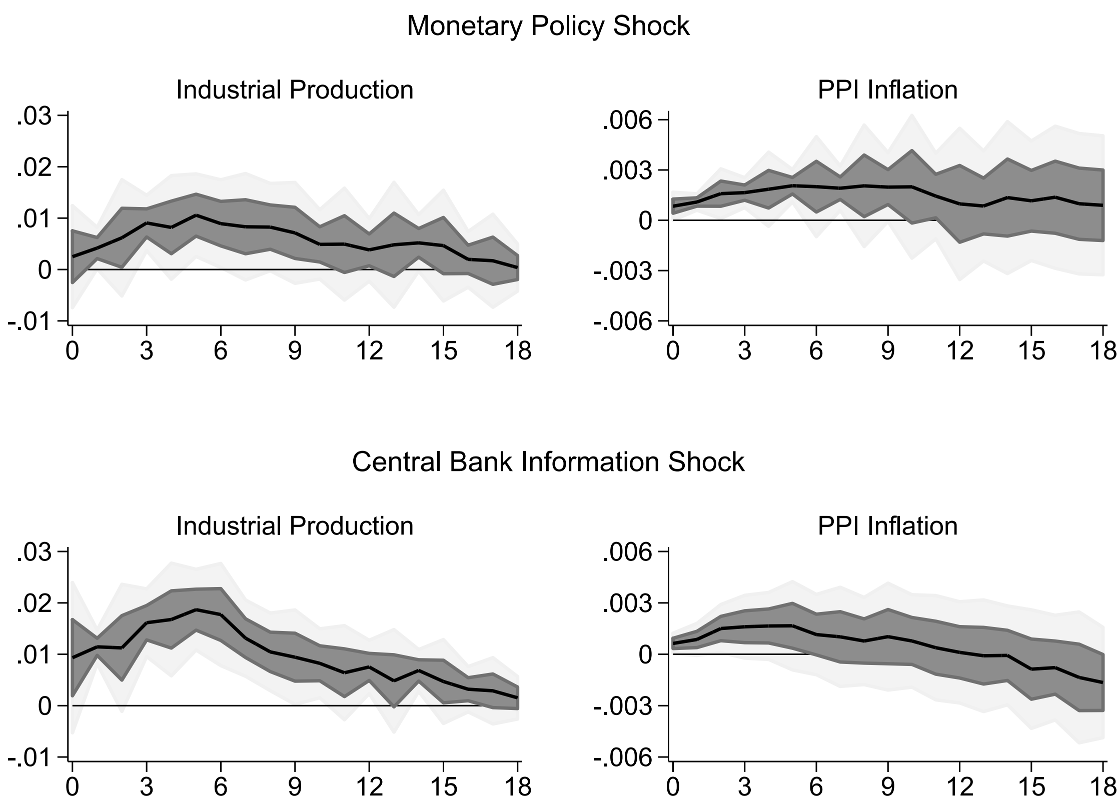
A back-of-the-envelope calculation for the inflation-output trade-off, the Philips curve, implied by our estimates gives a slope equal to 0.26 for monetary policy shocks and 0.09 for central bank information shocks. We obtain these figures by computing the average change in producer price inflation (not cumulated) per change in industrial production over the 12 months following each

[19] Here we compute Newey and West (1987) standard errors for statistical inference. The maximum lag order of autocorrelation at each horizon h equals $h + 1$.

[20] The ragged confidence bands are an artifact of including recursively the forecast errors from horizon $h - 1$ in the estimation of Equation (4) at horizon h for estimation efficiency. Intuitively, a large forecast error at horizon $h-1$ helps to reduce the horizon h forecast error. In turn, a small forecast error at horizon h does not help to reduce the horizon $h+1$ forecast error, and so on.

[21] In the full sample 1999:M01-2016:M12, the responses are somewhat larger and more precisely estimated. See Figure A.4 in the Appendix.

Figure 2 – Responses of Output and Inflation at the Aggregate Level



Notes: This figure shows impulse response functions to three basis points (one standard deviation) expansionary monetary policy shocks (top panels) and central bank information shocks (bottom panels) over 18 months obtained from estimating Equation (4) on aggregate German manufacturing data. Left panel displays response of industrial production in natural logarithms. Seasonally and calendar adjusted monthly data on production in manufacturing from Federal Statistical Office. Right panel displays response of cumulative producer price inflation. Monthly data on PPI in manufacturing from Federal Statistical Office. Pure monetary policy shock and central bank information shock from Jarociński and Karadi (forthcoming) with sign normalized so that a positive value corresponds to a cut in rates. Newey and West (1987) standard errors. Solid lines are point estimates, light-shaded and dark-shaded gray areas are one and two standard error confidence bands, respectively. Sample period: 2005:M02-2016:M12.

shock. This estimate lies at the upper end of empirical estimates for the slope of the Phillips curve reported by Mavroeidis et al. (2014). It is also consistent with to the slope of the Phillips curve generated in Nakamura and Steinsson (2010).[22]

3.4 Implications for Menu Cost Models

These estimates allow to distinguish between menu cost models with different degrees of monetary non-neutrality. In general, menu cost models typically match the unconditional frequency of price change and the unconditional average absolute size of a price change. Yet their implications differ vastly, depending on the choice of additional empirical targets used in calibration. For example, Caplin and Spulber (1987); Golosov and Lucas (2007); Karadi and Reiff (forthcoming) estimate small and transient effects of monetary policy, while Gertler and Leahy (2008); Nakamura and Steinsson (2010); Midrigan (2011); Alvarez and Lippi (2014) find a large degree of monetary non-neutrality. Crucially, these models differ in their predictions for the price-setting response to monetary policy. Our conditional estimates provide guidance to discriminate amongst these models that match the same set of unconditional statistics equally well.

In the presence of a menu cost, managers decide whether to change prices and, if so, by how much. The fixed cost introduces (i) a gap between the current price and the optimal price and (ii) thresholds that trigger price adjustment if this gap becomes too large. Moreover, production units are subject to idiosyncratic productivity shocks which generate heterogeneity in price gaps. Now consider the effects of expansionary monetary policy under this setup. Given demand, the price gap distribution shifts because the optimal price increases for all firms. Paying the menu cost and increasing the price becomes profitable for the marginal firm with a price gap just below the adjustment threshold before the shock. Conversely, it becomes unprofitable to decrease the price for the marginal firm with a price gap just above the adjustment threshold. Thus, there will be more price increases and fewer price decreases after an expansionary monetary policy shock, which is consistent with our empirical results. The net effect on the extensive margin is then determined by the relative mass of marginal firms at each adjustment threshold in the steady state price gap distribution. Our results document that the fraction of price adjusting firms increases only weakly after an expansionary monetary policy shock, in line with models that find a strong degree of monetary non-neutrality (Nakamura and Steinsson, 2010, for example).

On the intensive margin, i.e. the average size of a price change, two effects are in operation. First, the composition of the extensive margin shifts towards more price increases and less price decreases which mechanically drives up the intensive margin and hence inflation–even if the average size of price increases and price decreases remains the same (see Equation (3)). Second, the intensive margin responds to changes in the average absolute size of a price change. Golosov and Lucas (2007) argue that production units adjusting prices in response to monetary policy have large price gaps. Selection on large price changes generates small and transient real effects of monetary policy as mainly the price level adjusts. Our empirical findings reveal that the average absolute size of a price change *falls* after an expansionary monetary policy shock. Hence, there is selection, but towards *smaller* price

[22] See Mongey (2019) for a comprehensive comparison of Phillips curve slopes in various macroeconomic models.

changes, consistent with the results in Midrigan (2011). This dampens the intensive margin response and inflation responds weaker as a consequence.

To understand this result through the lens of a menu cost model, decompose the average size of a price increase into an inframarginal component and a marginal component:

$$\tilde{\pi}^{+}_{j,t} = \frac{\sum_i I^{+,infra}_{i,j,t}}{\sum_i I^{+}_{i,j,t}} \underbrace{\frac{1}{\sum_i I^{+,infra}_{i,j,t}} \sum_i (p_{i,j,t} - p_{i,j,t-1})^{+,infra}}_{\tilde{\pi}^{+,infra}_{j,t}}$$
$$+ \frac{\sum_i I^{+,margin}_{i,j,t}}{\sum_i I^{+}_{i,j,t}} \underbrace{\frac{1}{\sum_i I^{+,margin}_{i,j,t}} \sum_i (p_{i,j,t} - p_{i,j,t-1})^{+,margin}}_{\tilde{\pi}^{+,margin}_{j,t}}. \tag{5}$$

The first term captures the contribution of inframarginal production units that would have raised prices irrespectively of the change in monetary policy. The second term captures the contribution of the marginal production units that adjust their price only because of monetary policy. Empirically, we cannot separate inframarginal from marginal production units. Nevertheless, our empirical estimates reveal why the average size of a price decrease goes down.

Initially, only inframarginal production units adjust, i.e., $\frac{\sum_i I^{+,infra}_{i,j,t}}{\sum_i I^{+}_{i,j,t}} = 1$. In response to monetary easing, inframarginal production units desire to increase their prices by even more and $\tilde{\pi}^{+,infra}_{j,t}$ rises. At the same time and consistent with our empirical findings, the share of marginal production units $\frac{\sum_i I^{+,margin}_{i,j,t}}{\sum_i I^{+}_{i,j,t}}$ becomes non-zero and there are more price increases. Since in standard menu cost models $\tilde{\pi}^{+,infra}_{j,t} > \tilde{\pi}^{+,margin}_{j,t}$, these price increases are smaller in comparison. The net effect on $\tilde{\pi}^{+}_{j,t}$depends on the relative strength of these two forces. Our finding that $\tilde{\pi}^{+}_{j,t}$ falls suggests that the mass of price changes shifts towards the adjustment threshold after the shock and smaller price changes become more important.

In the case of price decreases, we observe the opposite. Initially, both marginal and inframarginal production units adjust. After the shock, marginal production units stop to change prices and, all else equal, price decreases get larger. However, inframarginal production units also choose to lower their prices by less, i.e., $\tilde{\pi}^{infra,-}_{j,t}$ falls. This latter force dominates and $|\tilde{\pi}^{-}_{j,t}|$ decreases as a result. In principle, this effect puts upward pressure on inflation. However, according to our results the overall price level response is economically small which suggests that the contribution of these price decreases is minor.

Caballero and Engel (2007) argue that selection effects are not a necessary condition to generate monetary neutrality. Instead, the key statistic is the additional change in inflation coming from price adjustment in marginal production units. According to our empirical results, since the extensive margin response is economically small, both for price increases and price decreases, the mass of marginal firms is small to start with. Moreover, we just argued that the intensive margin pricing response of marginal production units is weak. Hence, we conclude that menu costs models with large degrees of monetary non-neutrality are the empirically relevant case.

3.5 Robustness

Independent Evidence on the Extensive Margin Response We also use the IFO Business Climate Survey (IFO-BCS) to estimate the effects of monetary policy on the extensive margin pricing decision in independent product-level data. To this end, we estimate Equation (4) and include on the left-hand side a variable that take the value 1 if the price of a product changes, increases, or decreases, respectively, and the value 0 otherwise. On the right-hand side, in addition to industry fixed effects and month fixed effects, we add dummy variables to control for Taylor pricing, i.e., price changes that occur in fixed time intervals (e.g. every six months, see Lein (2010) and Bachmann et al. (2019)). We find that the increase in the probability to change prices after an expansionary monetary policy shock is weaker, while price increases and decreases react marginally stronger compared to our main results estimated across EPIs.[23]

Control Variables The baseline specification in Equation (4) does not include any control variables, except for month and EPI effects. The motivation for such parsimony was the tight and plausible identification of monetary policy shocks. We now demonstrate that our results remain unchanged to the inclusion of other covariates. To do so, we augment Equation (4) and estimate

$$y_{j,t+h} = \alpha_{m,h} + \alpha_{j,h} + \psi_h \, \varepsilon_t^s + \psi_{X,h} X_{i,t-1} + u_{j,t+h} \tag{6}$$

where $X_{i,t-1}$ is a vector of control variables which enters with a lag to ensure predeterminedness at the time of the monetary policy shock.

In the FSO producer price data, no additional information beyond price setting is reported. We therefore merge data on outcomes and expectations from the IFO-BCS, aggregated at the EPI level. Specifically, we add business situation, business expectations, orders, and employment expectations as controls. There are three answer categories for each corresponding question, and we compute separately the fraction of positive and negative responses. Our results are virtually unchanged once we include control variables. Unsurprisingly, the estimates have somewhat more precision. Figure A.3 in the Appendix documents the results.

4 Conclusion

In the menu cost literature, the recent debate revolves around the question of how to calibrate the moments of the price gap distribution. The shape of this distribution determines the relative importance of small versus large price changes and, hence, the real effects of monetary policy changes. That is, it crucially influences the inflation-output trade-off in the economy, i.e. the slope of the Phillips curve. This paper provides direct estimates for the effects of monetary policy on the frequency of price changes and the average size of price changes. These moments provide novel cali-

[23] Figure A.2 in the Appendix plots the results. We also obtain very similar results in the full sample from 1999:M01 to 2016:M12. We also obtain very similar results when we aggregate the product-level data from the IFO Business Climate Survey at the 4-digit EPI level and run the same regressions as on administrative data. The 4-digit GP 2009 product classification used in administrative data has an almost one-to-one mapping into the 4-digit WZ2008 industry classification used in the IFO Business Climate Survey.

bration targets for models of price setting in general and menu cost models in particular. Importantly, they rule out menu cost models which feature strong selection on large price adjustments after expansionary monetary policy. Instead, our findings are broadly consistent with models that find a strong degree of monetary non-neutrality.

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A Additional Tables and Figures

Table A.1 – Summary Statistics in Baseline Sample

	Mean	P10	P50	P90	Std. Dev.	N
MP shock	0.0009966	-0.03048	0	0.02536	0.02970	14,381
CBI shock	-0.002857	-0.03023	-0.00006145	0.02757	0.02534	14,381
Price Changes ($fr_{j,t}$)	0.3269	0.08491	0.2821	0.6364	0.2117	14,381
Price Increases ($fr^{+}_{j,t}$)	0.1762	0.03604	0.1316	0.3846	0.1499	14,381
Price Decreases ($fr^{-}_{j,t}$)	0.1508	0.02597	0.1053	0.3333	0.1423	14,381
Average Price Change ($\tilde{\pi}_{j,t}$)	0.002992	-0.01400	0.002620	0.02041	0.01491	14,381
Average Absolute Price Change ($\tilde{\pi}^{abs}_{j,t}$)	0.02171	0.008409	0.01974	0.03696	0.01216	14,381
Average Price Increases ($\tilde{\pi}^{+}_{j,t}$)	0.02246	0.005673	0.01970	0.04186	0.01539	14,381
Average Absolute Price Decreases ($\lvert\tilde{\pi}^{-}_{j,t}\rvert$)	0.02023	0.004721	0.01721	0.03868	0.01508	14,381
Inflation Sample ($\pi_{j,t}$)	0.0009470	-0.004432	0.0004743	0.007004	0.007248	14,381
Inflation Official	0.0008511	-0.007280	0	0.009709	0.01206	14,218

Notes: This tables lists summary statistics for the main variables in this paper's baseline sample. MP shock and CBI shock are the pure monetary policy shock and the central bank information shock, respectively, by Jarociński and Karadi (forthcoming). Price-setting variables refer to 4-digit Elementary Price Indices (EPIs) based on administrative Federal Statistical Office (FSO) producer price data and are defined as described in the text. Monthly frequency, sample Period: 2005:M02–2016:M12

Table A.2 – Summary Statistics in IFO-BCS Data

	Mean	Std. Dev.	N
Price Changes ($fr_{j,t}$)	0.3158	0.4648	143,241
Price Increases ($fr^{+}_{j,t}$)	0.1792	0.3835	143,241
Price Decreases ($fr^{-}_{j,t}$)	0.1366	0.3434	143,241

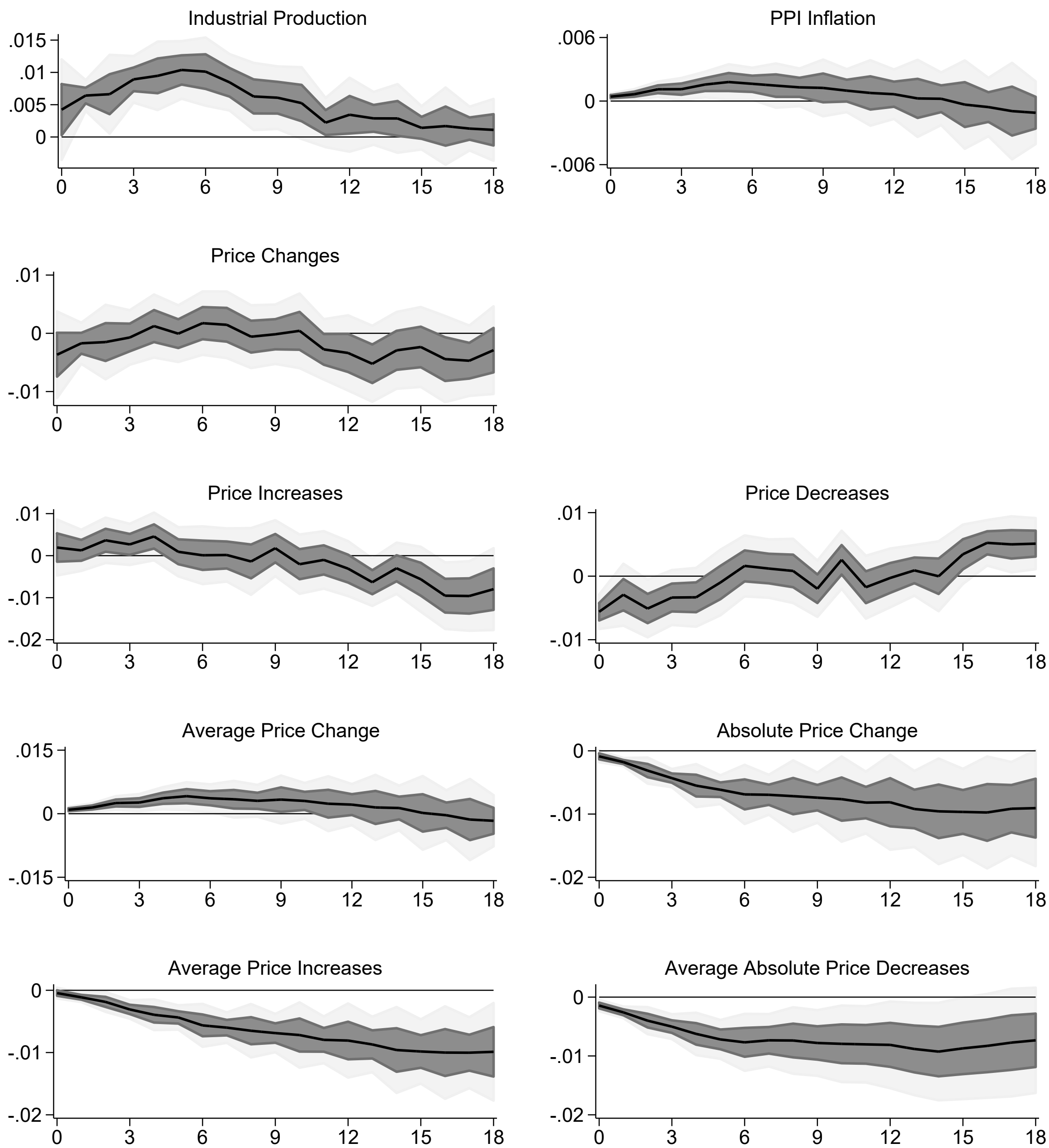
Notes: This tables lists summary statistics on extensive margin price-setting behavior based on the IFO Business Climate Survey and defined as described in the text. Frequency is monthly for all variables. Sample Period: 2005:M02–2016:M12

Table A.3 – Summary Statistics in Aggregated IFO-BCS data

	Mean	P10	P50	P90	std.dev.
Price Changes	0.1847	0	0.1582	0.4000	0.1604
Price Increases	0.1095	0	0.06667	0.2857	0.1392
Price Decreases	0.07524	0	0.02778	0.2000	0.1102
Business Situation +	0.2852	0.04000	0.2683	0.5455	0.1893
Business Situation -	0.1829	0	0.1429	0.4286	0.1766
Business Expectations +	0.1879	0	0.1667	0.3750	0.1396
Business Expectations -	0.1739	0	0.1429	0.3846	0.1518
Orders +	0.1908	0	0.1667	0.4000	0.1485
Orders -	0.2194	0	0.2000	0.4444	0.1703
Employment Expectations +	0.08488	0	0.05882	0.2174	0.1015
Employment Expectations -	0.1326	0	0.1111	0.3077	0.1304

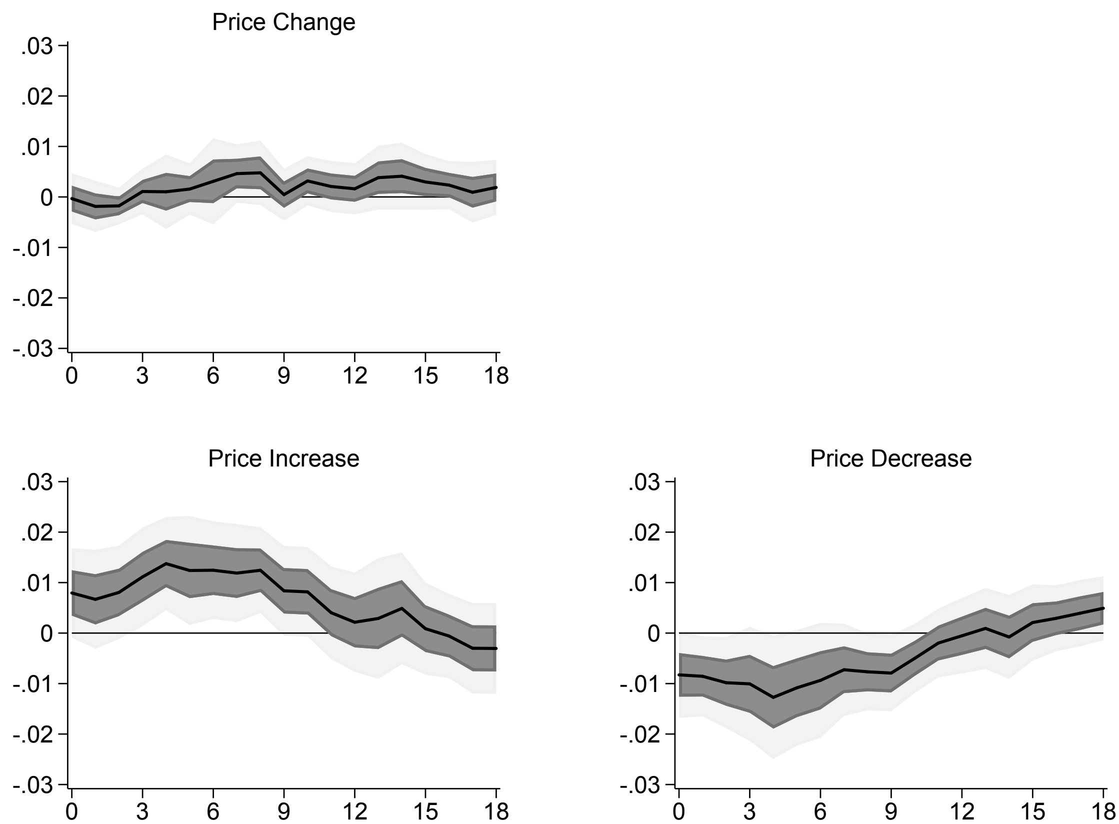
Notes: This table presents the same summary statistics on extensive margin price-setting behavior as Table A.1 but calculated on data from the IFO Business Climate Survey aggregated at the 4-digit EPI level. In addition, the table shows summary statistics at the 4-digit EPI level for the fraction of positive and negative responses to questions on other outcomes and expectations in the IFO Business Climate Survey as described in the text. See the notes to Table A.1 for further information.

Figure A.1 – Responses of Output, Inflation, and Price Setting: Central Bank Information Shocks



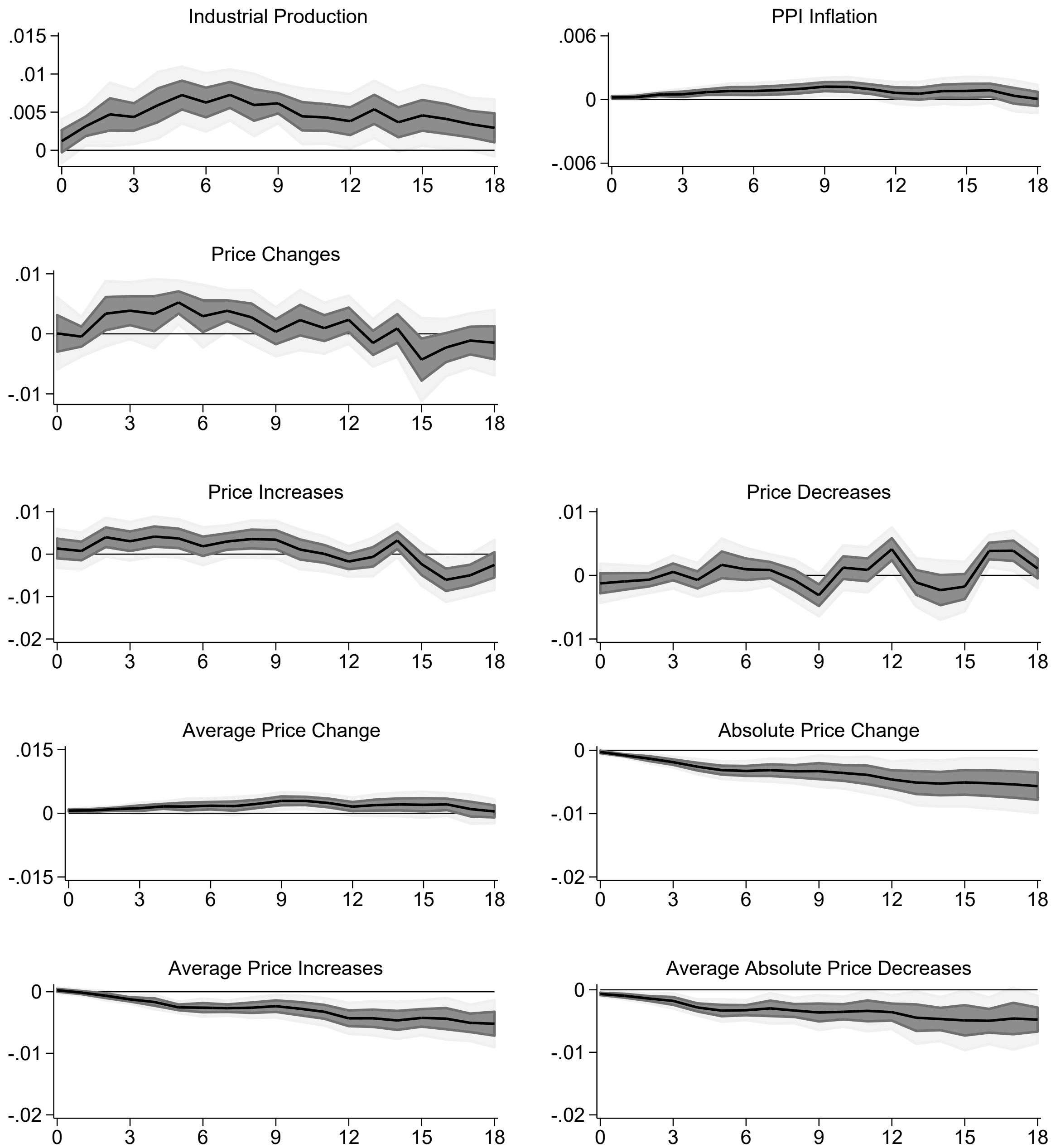
Notes: This figure shows impulse response functions to a three basis points (one standard deviation) expansionary central bank information shock over 18 months obtained from estimating Equation (4) on 4-digit EPI-level German manufacturing data. The top row displays the response of industrial production in natural logarithms and of cumulative producer price inflation. The second an third row show the responses of the frequency of price change, the frequency of price increase, and the frequency of price decrease. The fourth and fifth row contain responses of the average size of a price change, the average absolute size of a price change, the average size of a price increase, and the average absolute size of a price decrease. All price changes in cumulative growth rates. Monthly data from Federal Statistical Office. Central bank information shock from Jarociński and Karadi (forthcoming) with sign normalized so that a positive value corresponds to a cut in rates. Driscoll and Kraay (1998) standard errors. Solid lines are point estimates, light-shaded and dark-shaded gray areas are one and two standard error confidence bands, respectively. Sample period: 2005:M02-2016:M12.

Figure A.2 – Extensive Margin Response in IFO-BCS Data: Monetary Policy Shocks



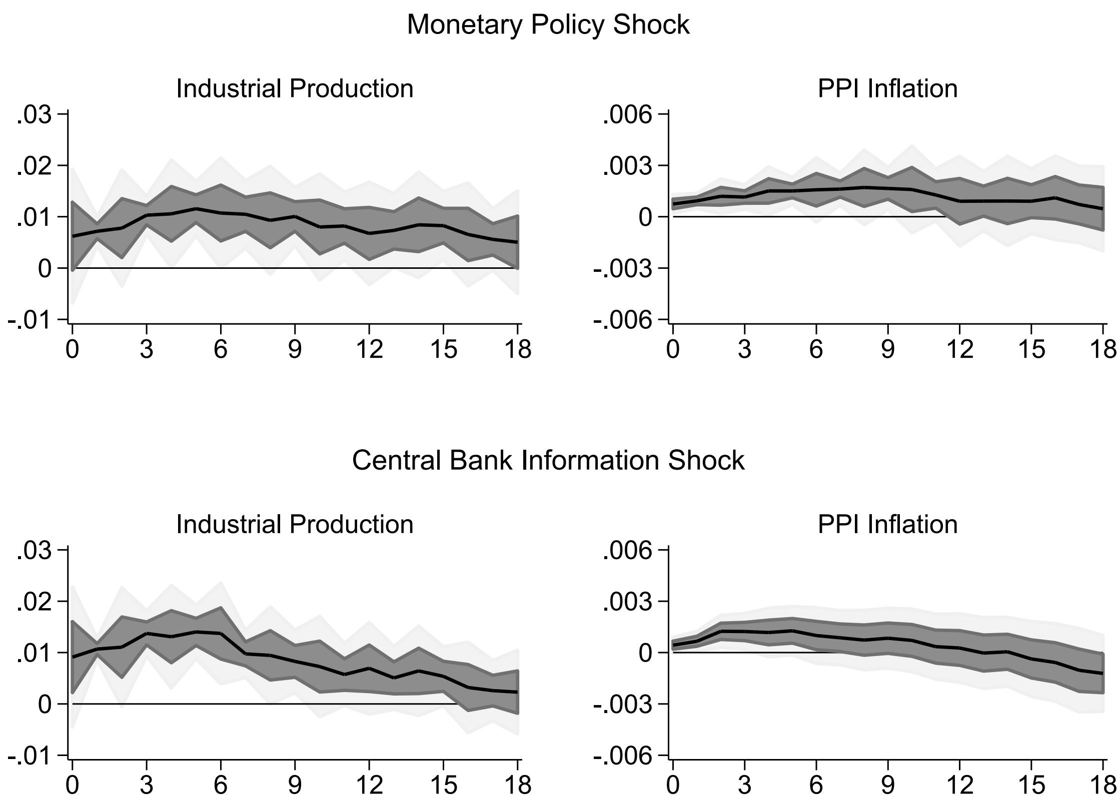
Notes: This figure shows impulse response functions to a three basis points (one standard deviation) expansionary central bank information shock over 18 months obtained from estimating Equation (4) on product-level survey data from the IFO Business Climate Survey. The top row displays the response of the frequency of price change, the bottom row the responses of the frequency of price increases and the frequency of price decreases. Pure monetary policy shock from Jarociński and Karadi (forthcoming) with sign normalized so that a positive value corresponds to a cut in rates. Driscoll and Kraay (1998) standard errors. Solid lines are point estimates, light-shaded and dark-shaded gray areas are one and two standard error confidence bands, respectively. Sample period: 2005:M02-2016:M12.

Figure A.3 – Baseline Specification Including Control Variables: Monetary Policy Shocks



Notes: This figure shows impulse response functions to a three basis points (one standard deviation) expansionary monetary policy shock over 18 months obtained from estimating Equation (6) on 4-digit EPI-level German manufacturing data. The top row displays the response of industrial production in natural logarithms and of cumulative producer price inflation. The second an third row show the responses of the frequency of price change, the frequency of price increases, and the frequency of price decreases. The fourth and fifth row contain responses of the average size of a price change, the average absolute size of a price change, the average size of a price increase, and the average absolute size of a price decrease. All price changes in cumulative growth rates. Monthly data from Federal Statistical Office. Pure monetary policy shock from Jarociński and Karadi (forthcoming) with sign normalized so that a positive value corresponds to a cut in rates. Driscoll and Kraay (1998) standard errors. Solid lines are point estimates, light-shaded and dark-shaded gray areas are one and two standard error confidence bands, respectively. Sample period: 2005:M02-2016:M12.

Figure A.4 – Long Sample: Responses of Output and Inflation at the Aggregate Level



Notes: This figure shows the same impulse response functions as Figure 2 but estimated on the longer sample 1999:M01-2016:M12. See the notes to Figure 2 for further information.