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JEL Classification: E30, E31, E32, E44, E52

Keywords: Price Setting, extensive margin, intensive margin, monetary policy, local projections, Menu cost, credit constraints

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Monetary Policy, Price Setting, and Credit Constraints[†]

Almut Balleer[§]   Peter Zorn[¶]

November 2019

Abstract

We estimate the effects of monetary policy on price-setting behavior in administrative micro data underlying the German producer price index. We find a strong degree of monetary non-neutrality. After expansionary monetary policy, the mass of additional price adjustments is economically small and the average absolute size across all price changes falls. The aggregate price level hardly adjusts, and monetary policy has real effects. These estimates rule out quantitative structural models that generate small and transient effects of monetary policy through selection on large price adjustments. We provide evidence that monetary policy propagates primarily through production units with weak financial positions.

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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. We directly estimate this moment in German administrative micro-level producer price data to provide a fresh perspective on this classic question. We find a strong degree of monetary non-neutrality. After expansionary monetary policy, the mass of additional price adjustments is economically small and the average absolute size across all price changes falls. As a result the aggregate price level hardly adjusts. We confirm the strong degree of monetary non-neutrality in two independent ways. First, we estimate that monetary policy accounts for about 20% of aggregate output fluctuations. Second, our empirical estimates rule out quantitative structural models that generate small and transient effects of monetary policy through selection on large price adjustments.

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. 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 a price change per adjuster increases by about half a percent. This finding primarily reflects a composition change in the extensive margin towards more price increases. The average absolute size of a price change actually decreases over time, reaching about minus one percent after nine months, which dampens inflationary pressures.

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, 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.

Our study of price-setting behavior uses monthly Federal Statistical Office micro data underlying the German producer price index for the period 2005 to 2016. The sample 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 level 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.

In a second step, we provide suggestive evidence that monetary policy primarily propagates through production units with constrained access to credit. The effect of monetary policy on the frequency of price increases is about one percentage point larger when our measure of credit constraints is one-standard deviation above the overall sample mean. There is no discernible difference in the frequency of price decreases, hence constrained observations also adjust their prices more frequently overall after monetary easing. The differential effect on the average absolute size of a price change is about half a percentage point lower. In combination with the negative level effect we estimate, this finding implies that constrained observations adjust their prices by even less following expansionary monetary policy shocks.

We obtain these results by conditioning the estimated level response of pricing behavior on a measure of credit constraints. Our motivation is recent evidence on the importance of financial conditions for price-setting behavior (Gilchrist et al., 2017; Kim, 2017) and for the effects of monetary policy on firm behavior more generally (Ottonello and Winberry, 2018, for example). To the best of our knowledge, this paper is the first to provide empirical evidence on the role of financial constraints in the transmission of monetary policy to price-setting behavior.

Our baseline measure of credit constraints comes from a question in the IFO Business Climate Survey on the general perceptions of credit supply. Huber (2018) shows that identified *firm-level* credit supply shocks are a strong predictor for a manager's response to this question. To control for other factors that affect pricing behavior and financial positions at the same time, we use additional information on outcomes and expectations from the survey. The finding that monetary policy propagates primarily through weak financial positions is consistent with Balleer et al. (2017), who introduce a working capital constraint in an otherwise standard menu cost model. In this model, credit constrained production units bunch close to the thresholds triggering price adjustment, because credit constraints make low prices and high output costly (or even infeasible). As a result, these production units are the first to adjust and drive the price level response following monetary policy shocks. At the same time, price changes of these additional production units are smaller, consistent with our estimated differential effects, and the real effects of monetary policy are strong.

This paper adds to empirical work on price-setting behavior at the micro level. 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 are complimentary in that they report conditional moments following monetary policy shocks. 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. Relative to this complementary research, we study the extensive and intensive margin of price setting. Empirical measurement of kurtosis is a daunting task, and these margins provide a simple alternative to discriminate among quantitative structural models. Moreover, we investigate the role of financial heterogeneity in the transmission of monetary policy.

The paper also relates to the vast empirical literature that investigates the effects of monetary policy on the economy (see Ramey (2016) for a recent survey). 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); Howes (2019) for investment spending, Bahaj et al. (2018) for employment, and Enders et al. (2019) for expectations about output prices and production.

The outline of this paper is as follows. Section 2 describes the data we use in our empirical analysis and provides descriptive statistics. Section 3 presents the baseline specification and estimates for the level effect of monetary policy shocks on price setting. In Section 4 we further condition these responses on measures of credit constraints to investigate the role of financial heterogeneity in the transmission of monetary policy. Section 5 concludes.

2 Data Description

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

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.[1] The identifying assumption is that any price movements within these narrow time windows are due to monetary sur-

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

prises 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.[2]

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.[3]

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):

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

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

[3]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.

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 increase (decrease). 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 a price change ($\tilde{\pi}_{j,t}$) 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 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.[4] 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.[5]

[4] 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.

[5] 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

Financial Constraints Another attractive feature of the IFO-BCS is that it also asks about financial constraints. We can merge this information to the FSO data in order to investigate the role of financial heterogeneity in the transmission of monetary policy to prices.[6] Specifically, the survey questionnaire asks: "How do you evaluate the current willingness of banks to grant credits to businesses?". The survey questionnaire includes this question in March and August since 2003:M06, and in every month since 2008:M11. We flag an observation as credit constrained if the answer to this question is "restrictive", the remaining answer categories being "normal" and "accommodating". The monthly frequency is an advantage over balance-sheet based measures of financial constraints, which are available at the quarterly or at the yearly frequency. A limitation of this question is that it asks about perceptions *in general*. However, Huber (2018) shows that identified *firm-level* credit supply shocks are a strong predictor for the answer to this question. Similarly, Fidrmuc et al. (2018) document that individual credit market experiences of firms determine perceptions of general credit supply conditions. Even if managers act upon their perceptions and set prices *like* a constrained production unit, we are able to estimate the differential effect of monetary policy on price-setting behavior in the presence of financial constraints.

In addition, the survey also asks managers at the quarterly frequency if they experience any firm-specific constraints to production and, if so, which. Since 2002:Q1 the survey questionnaire includes the following reasons, where multiple choices are possible: insufficient orders, missing intermediate inputs, too small technological capacity, financing, and a residual category. We use this question as an alternative to test for heterogeneity in price-setting behavior.

To match the survey responses in the IFO-BCS to to price-setting data from the FSO, we compute for each EPI the fraction of managers that report constraints.

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 factors that simultaneously affect financial constraints as well as 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.

dimension results in larger correlation coefficients is consistent with a measurement error interpretation.

[6] The 4-digit GP 2009 product classification used in the FSO data has an almost one-to-one mapping into the 4-digit WZ2008 industry classification used in the IFO-BCS.

Table 1 shows summary statistics for the baseline sample. The standard deviation of monetary policy shocks and central bank information shocks is small and equals about 3 basis points each.[7] 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.[8] The mean of month-on-month inflation in our sample is roughly 0.1%, which compares nicely to official producer price inflation.[9] On average 23% of observations per month are credit constrained. While some observations do not experience any credit constraints, about 50% of managers at the 90th percentile and about 71% at the 99th percentile, respectively, witness tight credit supply.

Table 2 compares EPIs with credit constraints below and above the median. Tighter credit constraints are associated with a larger frequency of price change, both upward and downward. The average absolute size of a price change is larger with tighter constraints, both for price increases and in particular for price decreases. Because price decreases are larger in size, the average size of a price change ($\tilde{\pi}_{j,t}$) and hence inflation tend to be smaller (see Equation (3)) with credit constraints. Except for inflation, all differences are statistically significant. These differences are consistent with differential price-setting behavior of financially constrained managers on average, and potentially also in response to monetary policy shocks.[10]

Table 3 contains summary statistics for the IFO-BCS in our baseline 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. On average 24% of observations assess their situation as credit constrained every month. The mean share of managers reporting productions constraints is about 45%.[11]

3 Price Adjustment in Response to Monetary Policy

This section presents estimates for the level effect of monetary policy on pricing behavior. The following section investigates the role of financial constraints in determining this level response.

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

[8] 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.

[9] 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.

[10] Table 4 in the Appendix reports the same statistics using production constraints. The patterns are similar, albeit less prominent.

[11] Table 5 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.

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 to mitigate concerns about endogeneity because identification of ε_t^m is tight and plausible. 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.[12] 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 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 ($\tilde{\pi}_{j,t}^{abs}$), 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

[12] 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.

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.

As Figure 2 shows, the results for central bank information shocks are very similar. 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 changes goes down. Third, the responses of inflation and average price changes is less persistent and dies off after about 9 months.

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. 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.[13]

The top two panels in Figure 3 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.[14] 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

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

[14]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.

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.[15]

The results for central bank information shocks are again very similar, as the bottom two panels in Figure 3 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 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).[16]

3.4 Implications for Menu Cost Models

Our 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. Our estimates on the extensive pricing margin and the intensive pricing margin responses conditional on monetary shocks therefore allow to discriminate among these models in favor of the empirically relevant case and thus provide a fresh perspective on this classic debate.

In the presence of a menu cost, managers decide whether to change prices and, if so, by how

[15] In the full sample 1999:M01-2016:M12, the responses are somewhat larger and more precisely estimated. See Figure 9 in the Appendix.

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

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 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:

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

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 $\tilde{\pi}_{j,t}^{+,infra}$ rises. At the same time and consistent with our empirical findings, the share of marginal production units $\frac{\sum_i I_{i,j,t}^{+,margin}}{\sum_i I_{i,j,t}^{+}}$ becomes non-zero and there are more price increases. Since in standard menu cost models $\tilde{\pi}_{j,t}^{+,infra} > \tilde{\pi}_{j,t}^{+,margin}$, 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., $\tilde{\pi}_{j,t}^{infra,-}$ 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 now 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)).

Figure 6 plots results. The bottom-left panel shows the probability to increase prices, which rises by about 1% for ten months before returning to normal. The estimate is statistically significant and modest in economic terms. Relative to the unconditional mean, monetary policy raises the probability to increase prices by about 6%. Similarly, the bottom-right panel shows that the likelihood to decrease prices declines significantly by around 1% over the same horizon, which corresponds to a 7% increase relative to the mean.

Overall, the probability to change prices does not move initially, as the the top-left panel displays of Figure 6 shows. If anything, the probability to change prices rises weakly significantly and for a short time after 6 months. In economic terms, the effects are very small though. In the full sample from 1999:M01 to 2016:M12, we obtain very similar findings (see Figure 10 in the Appendix).

These product-level estimates are commensurate to our main results estimated across EPIs. If anything, the effects are economically marginally stronger. The fact that the results from the IFO Business Climate are very similar to those obtained from administrative data provides another piece of evidence for the high quality of our survey data.[17]

3.6 Robustness: 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.

Figure 4 and 5 shows that our main results are virtually unchanged once we include control variables. Unsurprisingly, the estimates have somewhat more precision. If anything, the effects of monetary policy shocks are a little bit weaker at the extensive margin, which were small to begin with. Price adjustment primarily happens along the intensive margin, as before. In the case of central bank information shocks, only the response of inflation becomes weaker while the remaining responses are the same as without control variables.

4 The Role of Firm-level Constraints

4.1 Credit Constraints

This section studies the role of financial heterogeneity in the transmission of monetary policy to prices. We extend our baseline specification in Equation (6) to this end and condition on the share of firms facing credit constraints in a given industry and month. Specifically, we estimate

$$y_{j,t+h} = \alpha_{m,h} + \alpha_{j,h} + \psi_{\varepsilon,h} \, \varepsilon_t^s + \psi_{c,h} \, credit_{j,t-1}^{-} + \psi_{\varepsilon c,h} \, \varepsilon_t^s \times credit_{j,t-1}^{-} + \psi_{X,h} \, X_{j,t-1} + u_{j,t+h} \tag{7}$$

[17] 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, we obtain very similar results. See Figure 11 in the Appendix. 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.

The dynamic causal effect of expansionary monetary policy now depends on $credit^{-}_{j,t-1}$, which we construct from the IFO-BCS's question on the perceived willingness of banks to grant credits to businesses. Although this variable is not available at monthly frequency over the entire sample, local projections easily accommodate the missing data in the beginning of our sample. We also include the level of $credit^{-}_{j,t-1}$ to allow for different average price-setting behavior of financially constrained firm. Indeed, Table 2 shows that prices change more frequently in the presence of credit constraints. We include the same set of control variables as in Section 3.6 to account for factors that simultaneously influence financial constraints and price-setting behavior. Finally, we also estimate this specification using product-level information from the IFO-BCS, again adding Taylor dummies.

Figures 7 shows the estimated coefficients $\psi_{\varepsilon c,h}$ obtained from the FSO data. In each panel, a positive value indicates greater responsiveness to monetary policy when credit constraints are tighter. We center $credit^{-}_{j,t-1}$ around its mean and divide by its standard deviation. The coefficient $\psi_{\varepsilon c,h}$ therefore represents the differential effect when credit constraints are one-standard deviation above the overall sample mean. The first row shows that the increase in industrial production and inflation is significantly stronger when more firms in an industry are constrained. The semi-elasticity with respect to monetary policy is about 0.05 units larger for output and 0.03 units larger for inflation. Moreover, the size of the interaction coefficient is very close to the overall responses documented in Figure 1, which suggests that the overall response is mainly driven by constrained observations. The effects on price increases and price changes are moderately stronger in the presence of credit constraints. At the intensive margin, the average absolute size of a price change is significantly smaller. Taken together with the negative level effect ($\psi_{\varepsilon,h}$), this finding means that financially constrained industries decrease their prices by more. Again, the level dynamics appear primarily driven by limited credit supply. The results are similar in the IFO-BCS (see Figure 8) as well as when considering the effect of central bank information shocks (see Figure 13).

In addition to the inclusion of fixed effects, Ottonello and Winberry (2018) take out within-observation means of the conditioning variable, $credit^{-}_{j,t-1}$ in our case, prior to estimation. The regression in this case reads:

$$y_{j,t+h} = \alpha_{m,h} + \alpha_{j,h} + \psi_{\varepsilon,h}\,\varepsilon^{s}_{t} + \psi_{c,h}\,credit^{-}_{i,t-1} + \psi_{\varepsilon c,h}\,\varepsilon^{s}_{t} \times \left(credit^{-}_{j,t-1} - E_i\left\{credit^{-}_{j,t}\right\}\right) + \psi_{X,h}\,X_{j,t-1} + u_{j,t+h} \tag{8}$$

where $E_i\left\{credit^{-}_{j,t}\right\}$ denotes the mean of $credit^{-}_{j,t}$ in industry j. This specification gives very similar results as Figure 14 documents.

4.2 Production Constraints

A mechanism through which credit constraints affect the economy is the cost channel. Macroeconomic models typically incorporate this channel by a working capital constraint. This constraint severely restrict production possibilities if credit is not available or very costly. We now investigate whether general production constraints affect the price-setting decisions by firms and, if so, whether in a similar way to credit constraints. To do so, we replace $credit^{-}_{i,t-1}$ in Equation (7) by a measure for product constraints which we construct from the IFO-BCS's question on the production constraints of any kind. Figures 15 and 16 plot the coefficient estimate on the interaction term using the FSO data and the IFO-BCS, respectively. The results are remarkably similar to those conditioning on credit constraints. Hence, credit constraint and production constraints moderate the effect of monetary policy on price-setting behavior, inflation, and output in a similar way.

4.3 Discussion

Our results suggest that small price changes become more important in response to expansionary monetary policy shock if more observations face a binding credit constraint. Hence, the real effects of monetary policy should be larger when credit constraints are tight.

What is the intuition behind this result? If the working capital constraint binds, low product prices are very costly as demand cannot be satisfied at these prices. In terms of a menu cost model, this means that tighter credit constraints decrease the price adjustment thresholds for a given menu cost. This is consistent with the fact that product prices are adjusted more frequently in more constrained industries as documented in table 2. Smaller price adjustment thresholds correspond to a larger mass of marginal products at these thresholds. Following the discussion in section 3.4, a larger mass at the thresholds results in larger in larger fluctuations of the share of marginal production units. This is visible in the larger response of the frequency of price adjustment that we estimate conditional on tight constraints. The larger mass at the thresholds also results in a larger share of small price changes after a monetary policy shock and, hence, weaker selection towards large price changes in the presence of tighter constraints and, hence, larger real effects. Balleer et al. (2017) formulate a menu-cost model with a working capital constraint that is consistent with these findings.

5 Conclusion

Assessing the effects of monetary policy in a menu cost model, the recent debate has centered around the question of how to calibrate the moments of the price gap distribution. The shape of this distribution then crucially influences the relative importance of small or large price changes and, correspondingly, large or small output changes in reaction to monetary policy changes. This means that it crucially influences the inflation-output trade-off in the economy, hence, the slope of the Phillips curve. Our paper provides direct estimates of the response of the fraction of price changes, the size of these price changes and output. We find substantial variation in the response of price increases and decreases in line with the general dynamics in a menu cost model of price setting. The average size of price changes falls which supports selection towards small rather than large price changes in response to a monetary policy shock. We find that output responds strongly relative to inflation.

Our results can be used as key calibration targets for models of price setting in general and menu cost models in particular. Using our results, we can back out the relative importance of marginal and inframarginal firms in these models and we can pin down the central moments of the price gap distribution. Our results therefore provide a fresh perspective in this debate. In fact our results are broadly consistent with menu cost models such as (Midrigan, 2011; Gertler and Leahy, 2008;

Nakamura and Steinsson, 2010; Alvarez and Lippi, 2014) and may even help to discriminate between these. A second set of results suggest that an alternative mechanism may drive the real effects of monetary policy: credit constraints. If credit constraints are tight, the extensive margin fluctuates by more, the size of price changes decreases by more and the real effects of monetary policy are larger. As dynamics are similar for credit and general production constraints, our results may inform models in which credit constraints appear in form or working capital constraints and in which credit constraint and price setting interact.

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Table 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
Credit Constraints	0.2258	0	0.2000	0.4762	0.1701	6,143
Production Constraints - All	0.4051	0.1875	0.4000	0.6250	0.1765	2,788

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. Credit constraints and production constraints variables refer to the share of managers reporting constraints in corresponding questions of the IFO Business Climate Survey (IFO-BCS). Frequency is monthly for all variables except production constraints, which have quarterly frequency. Sample Period: 2005:M02–2016:M12

Table 2 – Price-Setting Behavior and Credit Constraints

	Low Credit Constraints		High Credit Constraints	
	Mean	Std. Dev.	Mean	Std. Dev.
Price Changes ($fr_{j,t}$)	0.2482	0.1894	0.2790	0.1963
Price Increases ($fr^+_{j,t}$)	0.1340	0.1249	0.1484	0.1329
Price Decreases ($fr^-_{j,t}$)	0.1142	0.1197	0.1306	0.1327
Average Price Change ($\tilde{\pi}_{j,t}$)	0.003520	0.01251	0.002233	0.01516
Average Absolute Price Change ($\tilde{\pi}^{abs}_{j,t}$)	0.01991	0.009652	0.02320	0.01237
Average Price Increases ($\tilde{\pi}^+_{j,t}$)	0.02102	0.01333	0.02362	0.01489
Average Absolute Price Decreases ($\lvert\tilde{\pi}^-_{j,t}\rvert$)	0.01817	0.01221	0.02208	0.01594
Inflation Sample ($\pi_{j,t}$)	0.0006844	0.004570	0.0005370	0.006586
Inflation Official	0.0006015	0.006837	0.0002401	0.009318
Credit Constraints	0.1029	0.06809	0.3713	0.1363
Production Constraints - All	0.3795	0.1734	0.4762	0.1857

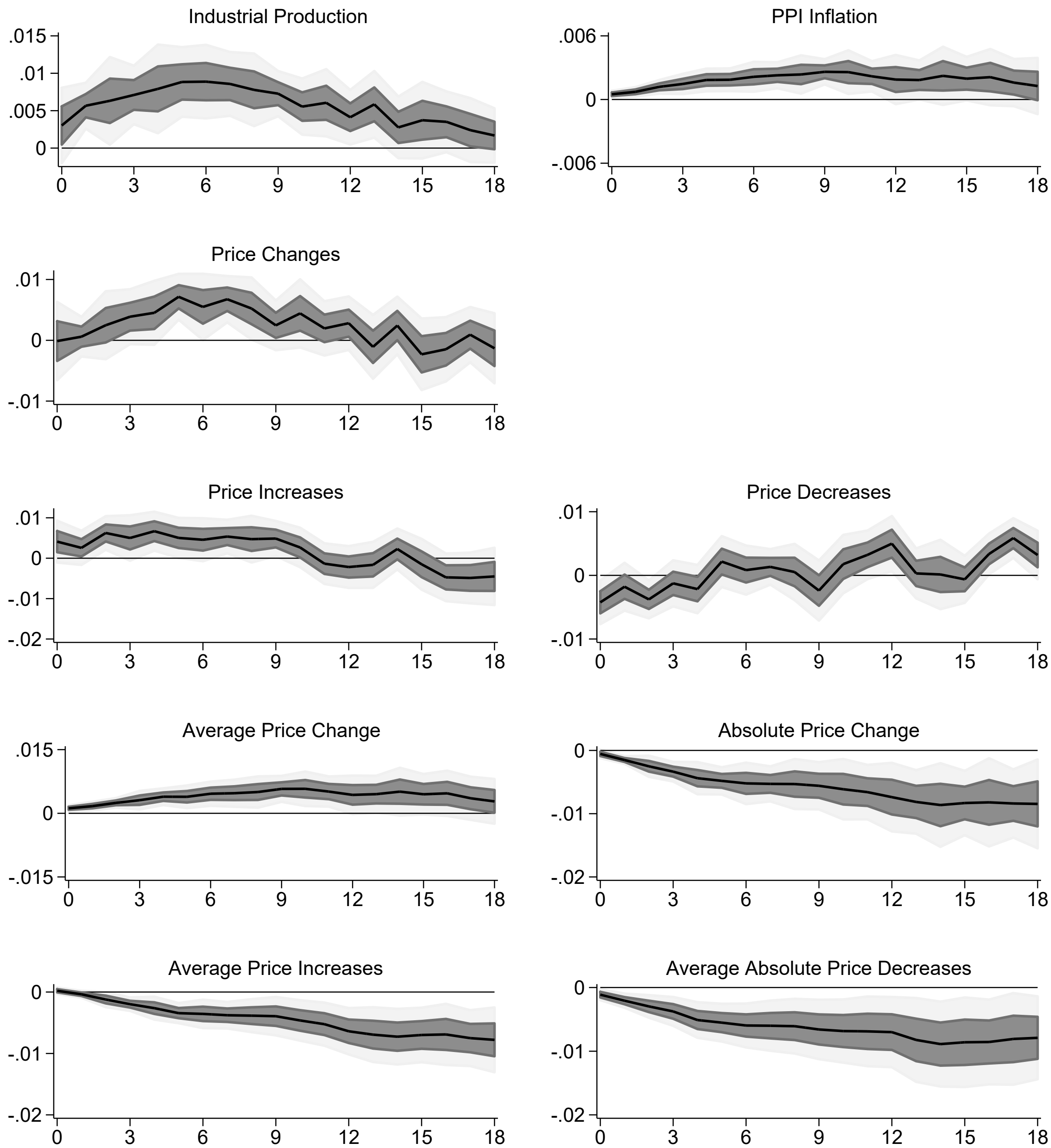
Notes: This tables presents summary statistics for the main price-setting variables in this paper's baseline sample, conditional on credit constraints. Low credit constraints refer to industries where the fraction of credit constrained firms is below the median, and vice versa for high credit constraints. See the notes to Table 1 for further information.

Table 3 – 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
Credit Constraints	0.2395	0.4268	90,061
Production Constraints - All	0.4475	0.4972	46,263

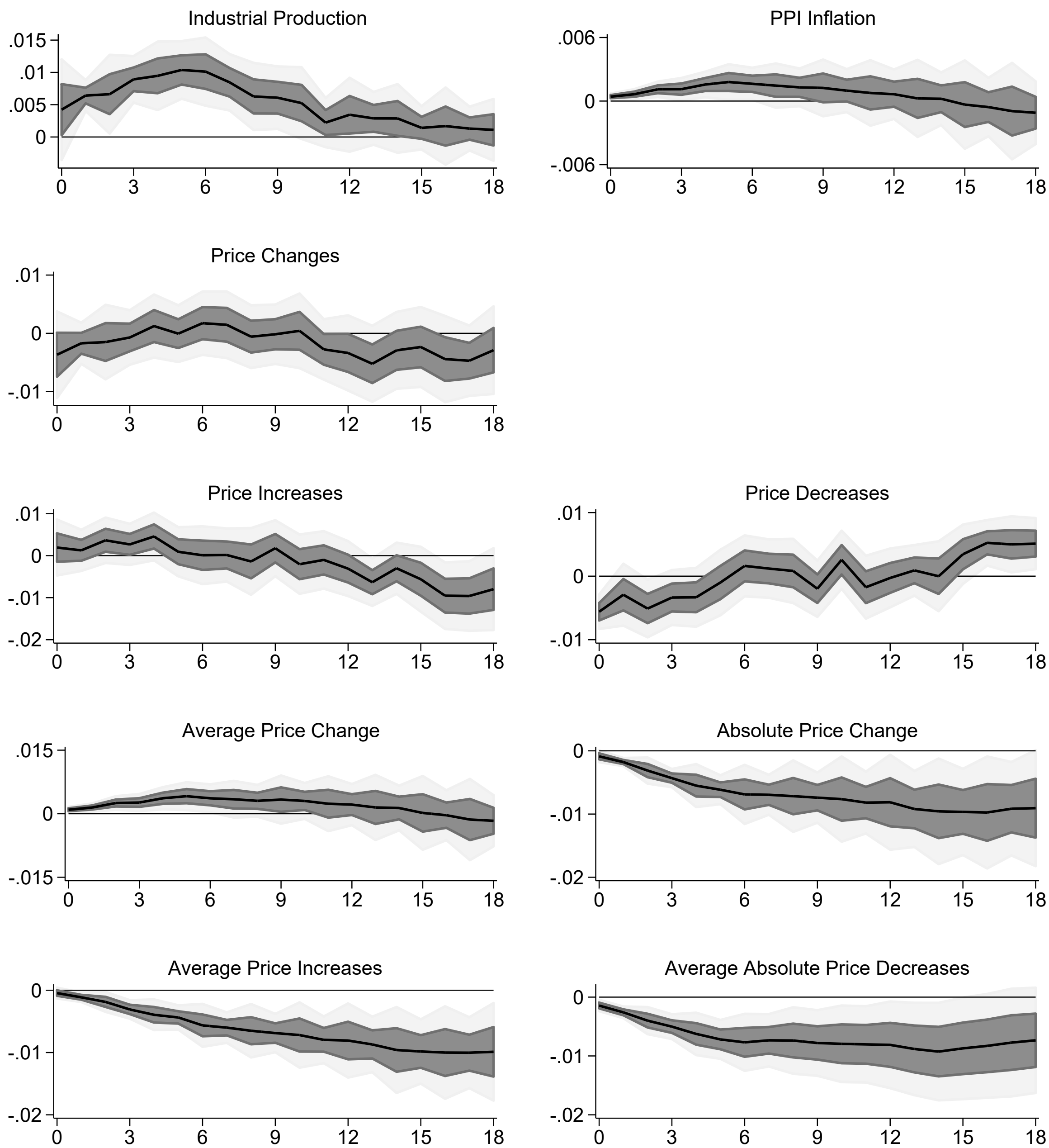
Notes: This tables lists summary statistics on extensive margin price-setting behavior based on the IFO Business Climate Survey and defined as described in the text. Frequency is monthly for all variables. Sample Period: 2005:M02–2016:M12

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



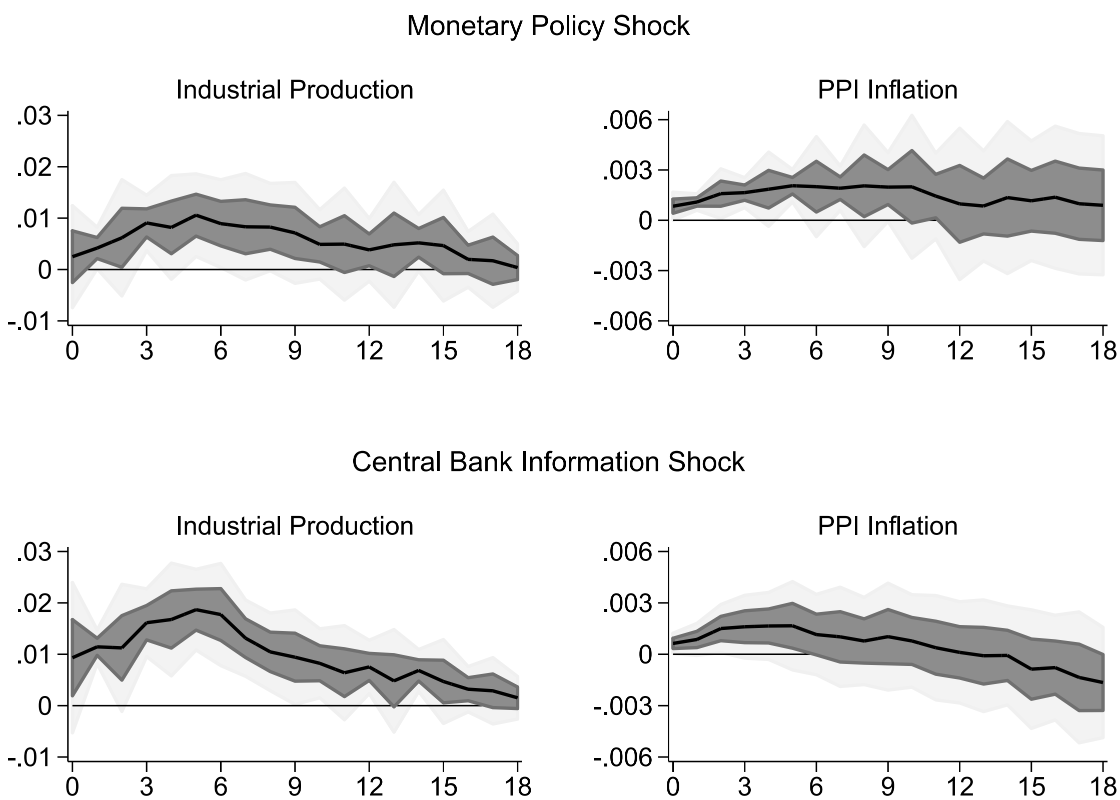
Notes: This figure shows impulse response functions to a three basis points (one standard deviation) expansionary monetary policy shock over 18 months obtained from estimating Equation (4) on 4-digit EPI-level German manufacturing data. The top row displays the response of industrial production in natural 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 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. 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 2 – Responses of Output, Inflation, and Price Setting: Central Bank Information Shocks



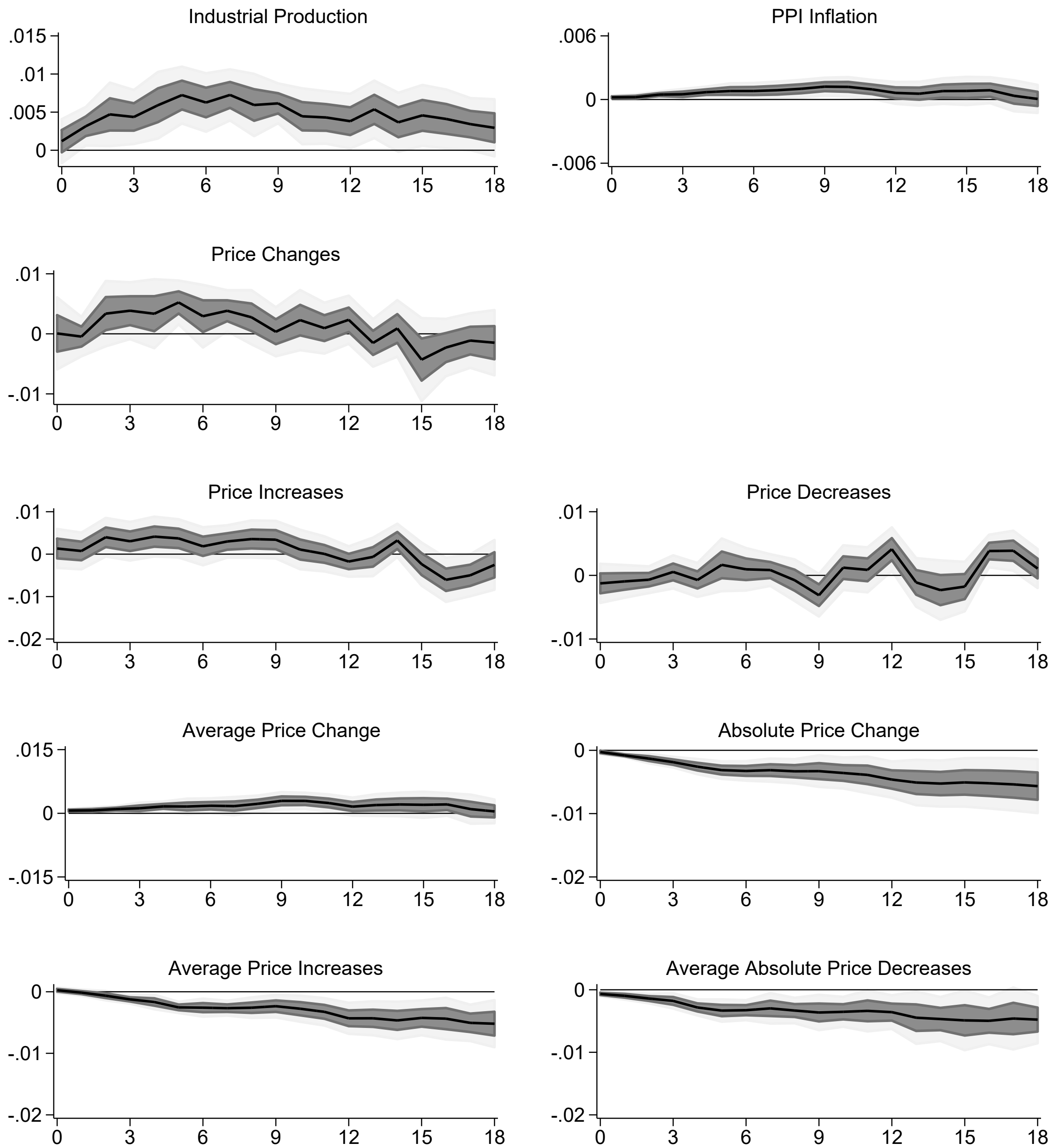
Notes: This figure shows impulse response functions to a three basis points (one standard deviation) expansionary central bank information shock over 18 months obtained from estimating Equation (4) on 4-digit EPI-level German manufacturing data. The top row displays the response of industrial production 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 3 – Responses of Output and Inflation at the Aggregate Level



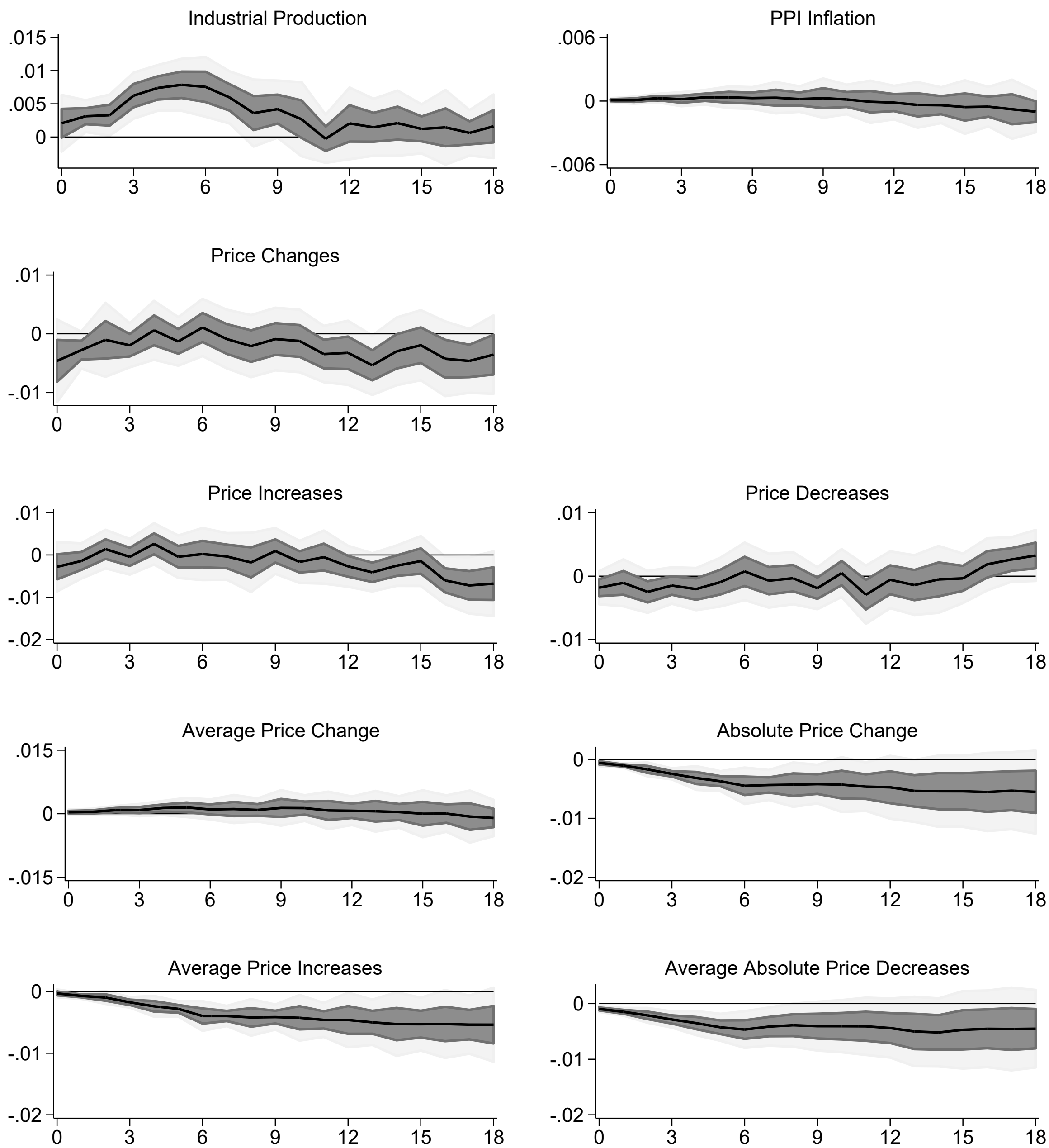
Notes: This figure shows impulse response functions to three basis points (one standard deviation) expansionary monetary policy shocks (top panels) and central bank information shocks (bottom panels) over 18 months obtained from estimating Equation (4) on aggregate German manufacturing data. Left panel 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.

Figure 4 – Baseline Specification Including Control Variables: Monetary Policy Shocks



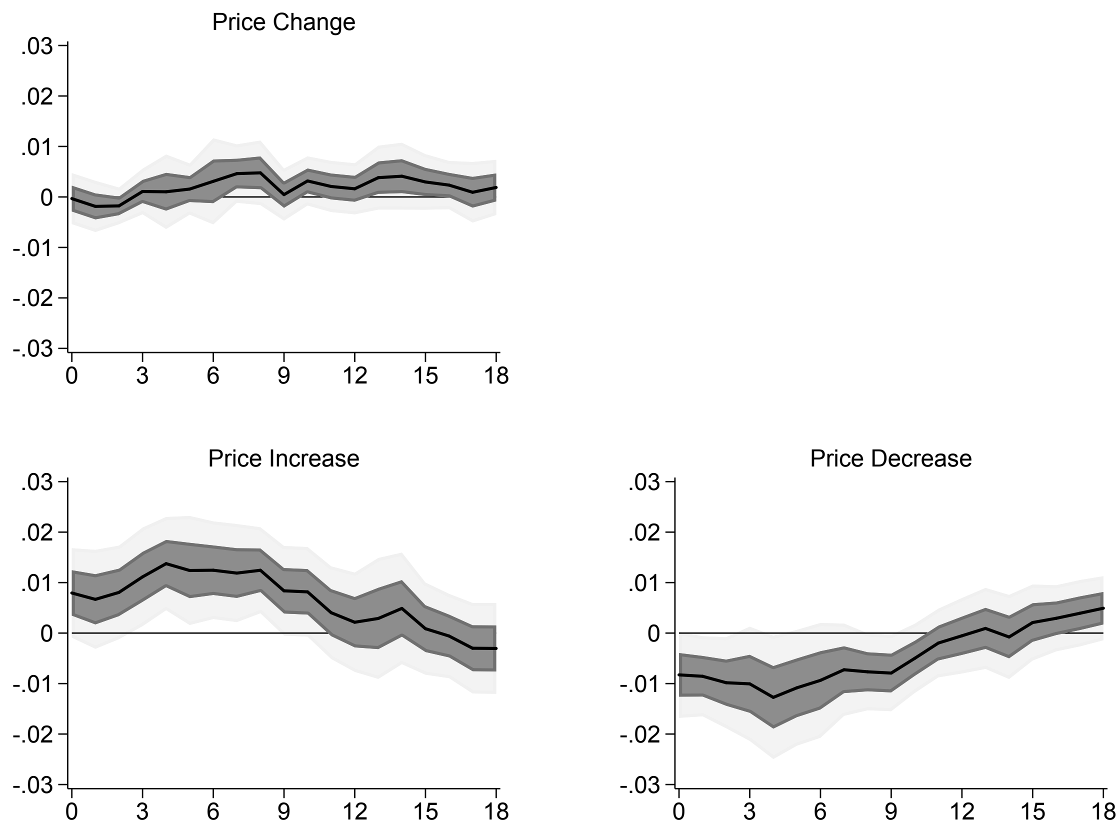
Notes: This figure shows impulse response functions to a three basis points (one standard deviation) expansionary monetary policy shock over 18 months obtained from estimating Equation (6) on 4-digit EPI-level German manufacturing data. The top row displays the response of industrial production in natural 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 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. 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 5 – Baseline Specification Including Control Variables: Central Bank Information Shocks



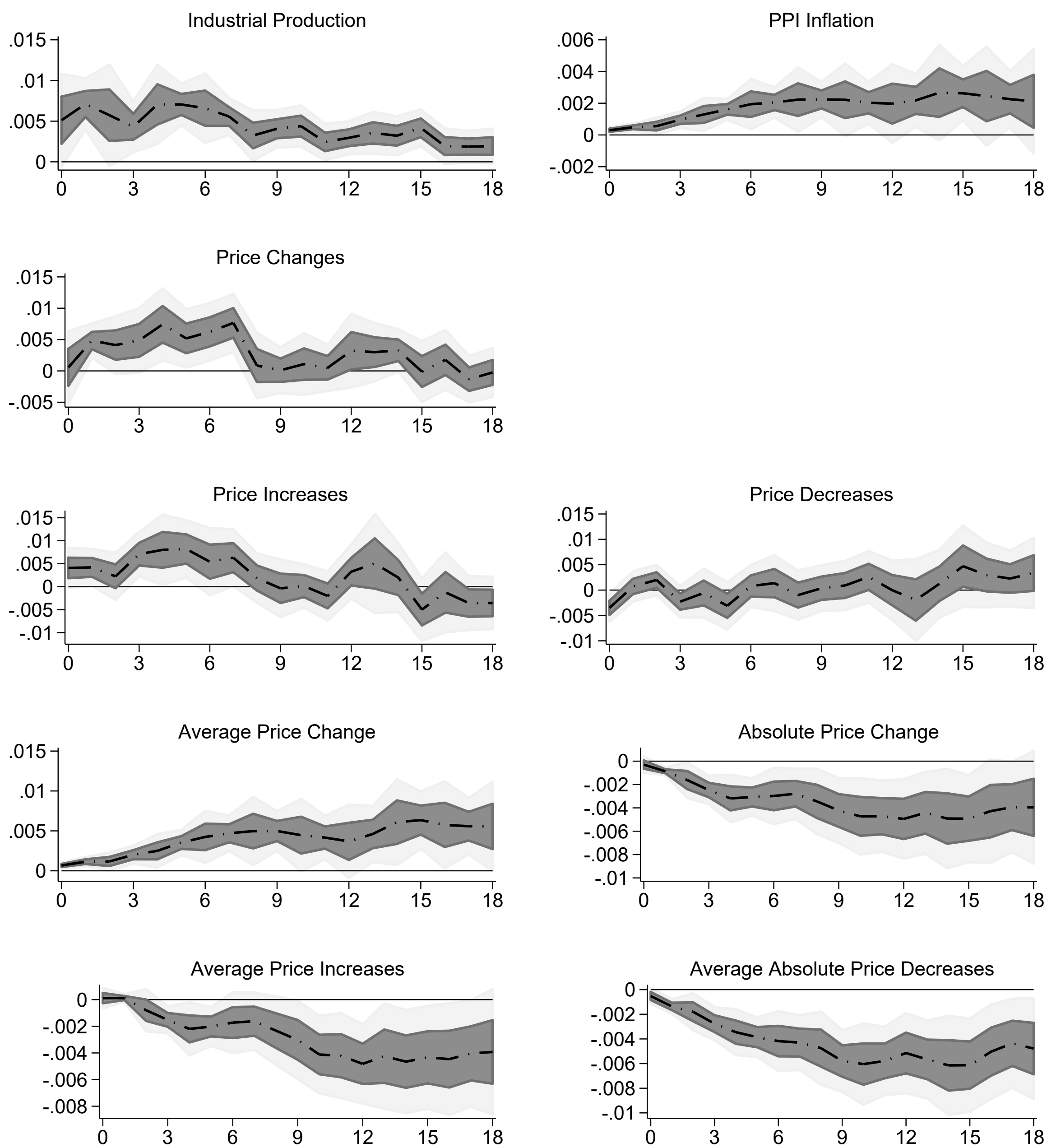
Notes: This figure shows impulse response functions to a three basis points (one standard deviation) expansionary central bank information shock over 18 months obtained from estimating Equation (6) on 4-digit EPI-level German manufacturing data. The top row displays the response of industrial production 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 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 6 – Extensive Margin Response in IFO-BCS Data: Monetary Policy Shocks



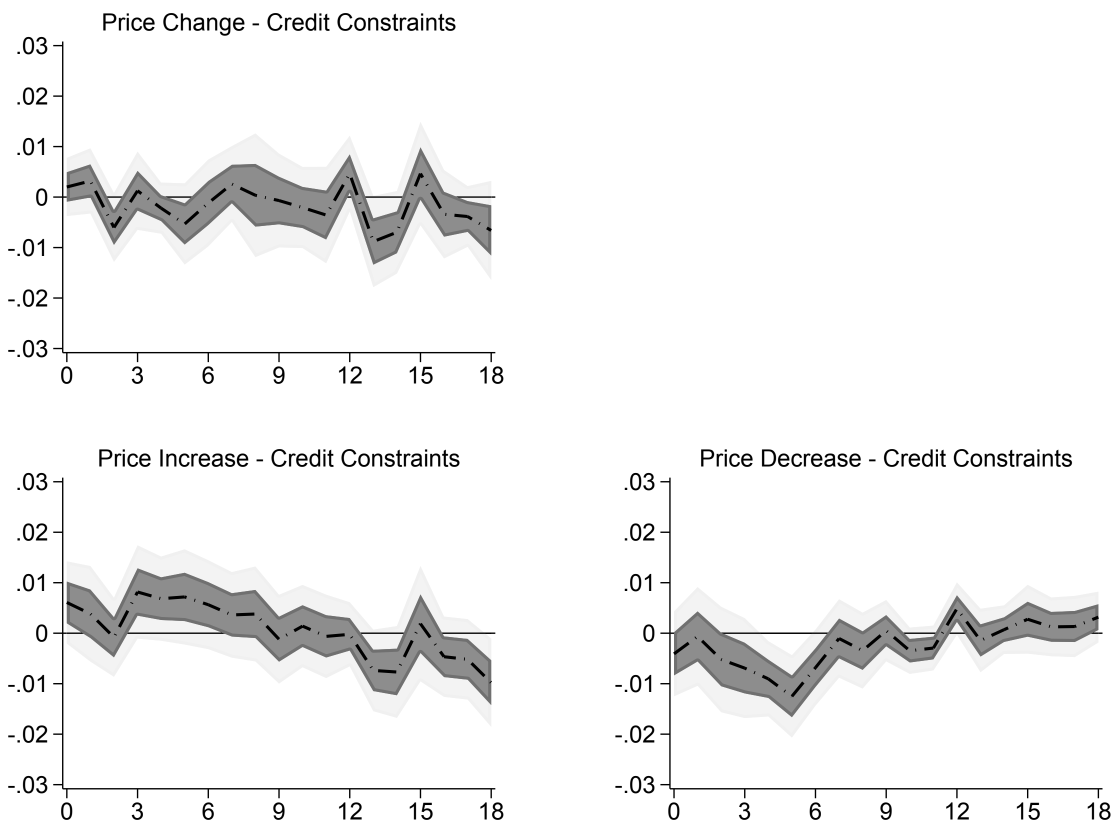
Notes: This figure shows impulse response functions to a three basis points (one standard deviation) expansionary central bank information shock over 18 months obtained from estimating Equation (4) on product-level survey data from the IFO Business Climate Survey. The top row displays the response of the frequency of price change, the bottom row the responses of the frequency of price increase and the frequency of price decrease. 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 7 – Conditioning Responses on Credit Constraints: Monetary Policy Shocks



Notes: This figure shows the interaction coefficient $\psi_{\varepsilon c,h}$ in Equation (7) estimated from 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. Pure monetary policy shocks 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 8 – Conditioning Responses on Credit Constraints in IFO-BCS Data: Monetary Policy Shocks



Notes: This figure shows the interaction coefficient $\psi_{\varepsilon c,h}$ in Equation (7) estimated from 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 increase and the frequency of price decrease. 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.

A Additional Tables and Figures

Table 4 – Price Setting and Production Constraints

	Low Production Constraints		High Production Constraints	
	Mean	std.dev.	Mean	std.dev.
Price Changes ($fr_{j,t}$)	0.2715	0.1954	0.2726	0.1922
Price Increases ($fr^{+}_{j,t}$)	0.1488	0.1311	0.1479	0.1319
Price Decreases ($fr^{-}_{j,t}$)	0.1227	0.1265	0.1248	0.1250
Average Price Change ($\tilde{\pi}_{j,t}$)	0.003206	0.01229	0.002623	0.01395
Average Absolute Price Change ($\tilde{\pi}^{abs}_{j,t}$)	0.01924	0.009651	0.02136	0.01181
Average Price Increases ($\tilde{\pi}^{+}_{j,t}$)	0.02032	0.01316	0.02221	0.01529
Average Absolute Price Decreases ($\lvert\tilde{\pi}^{-}_{j,t}\rvert$)	0.01814	0.01229	0.02036	0.01465
Inflation Sample ($\pi_{j,t}$)	0.0008535	0.005115	0.0006382	0.005567
Inflation Official	0.0005838	0.008617	0.0003791	0.008472
Credit Constraints	0.1813	0.1488	0.2599	0.1752
Production Constraints - All	0.2734	0.1007	0.5492	0.1200

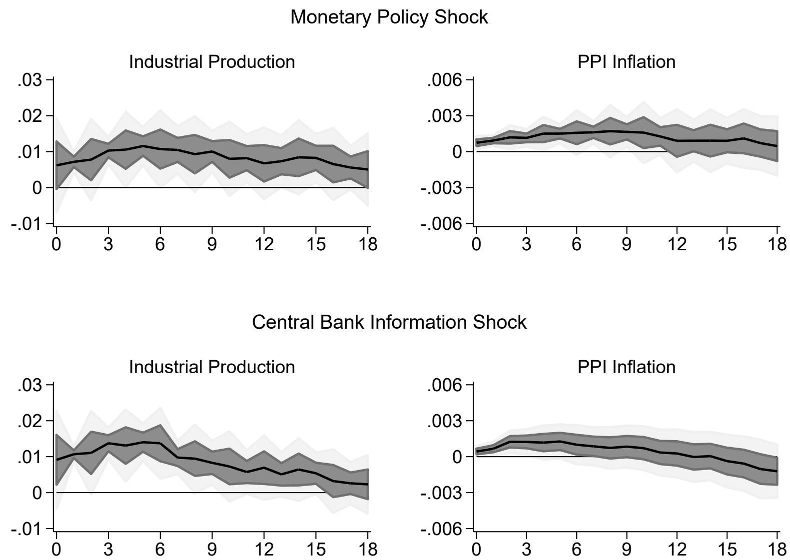
Notes: This table presents the same summary statistics as Table 2 but conditioning production constraints instead of credit constraints. See the notes to Table 2 for further information.

Table 5 – 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
Fraction Credit Const.	0.2287	0	0.2000	0.5000	0.1813
Fraction Prod. Const. (all)	0.3987	0.1667	0.4000	0.6410	0.1905
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

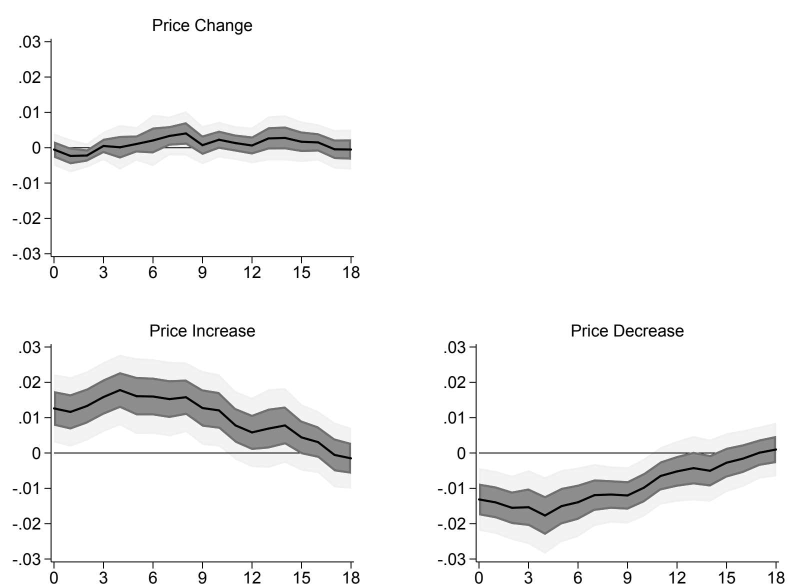
Notes: This table presents the same summary statistics on extensive margin price-setting behavior as Table 1 but calculated on data from the IFO Business Climate Survey aggregated at the 4-digit EPI level. In addition, the table shows summary statistics at the 4-digit EPI level for the fraction of positive 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 1 for further information.

Figure 9 – Long Sample: Responses of Output and Inflation at the Aggregate Level



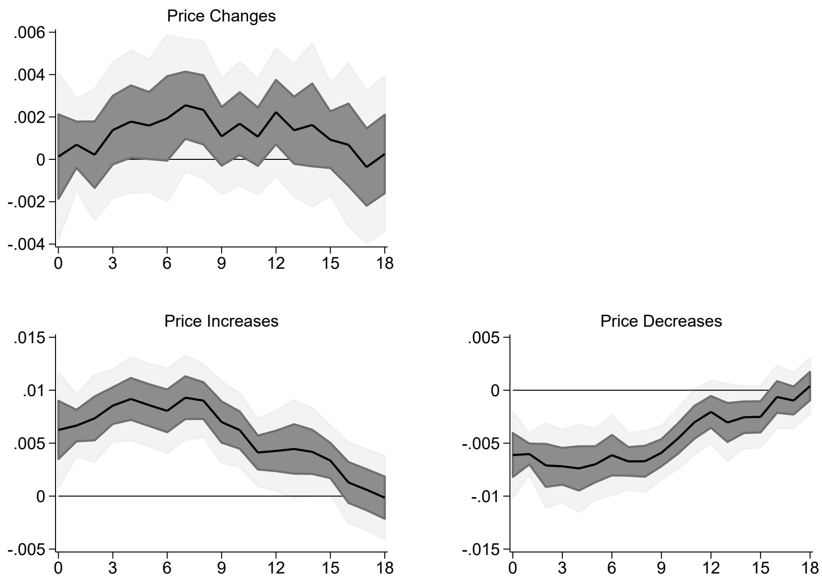
Notes: This figure shows the same impulse response functions as Figure 3 but estimated on the longer sample 1999:M01-2016:M12. See the notes to Figure 3 for further information.

Figure 10 – Long Sample: Extensive Margin Response in IFO-BCS Data: Monetary Policy Shocks



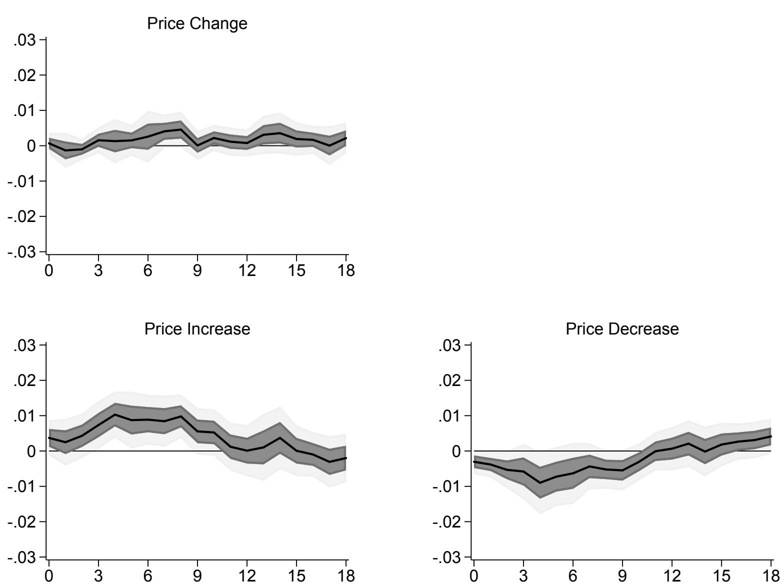
Notes: This figure shows the same impulse response functions as Figure 6 but estimated on the longer sample 1999:M01-2016:M12. See the notes to Figure 6 for further information.

Figure 11 – Extensive Margin Response in Aggregated IFO-BCS Data: Monetary Policy Shocks



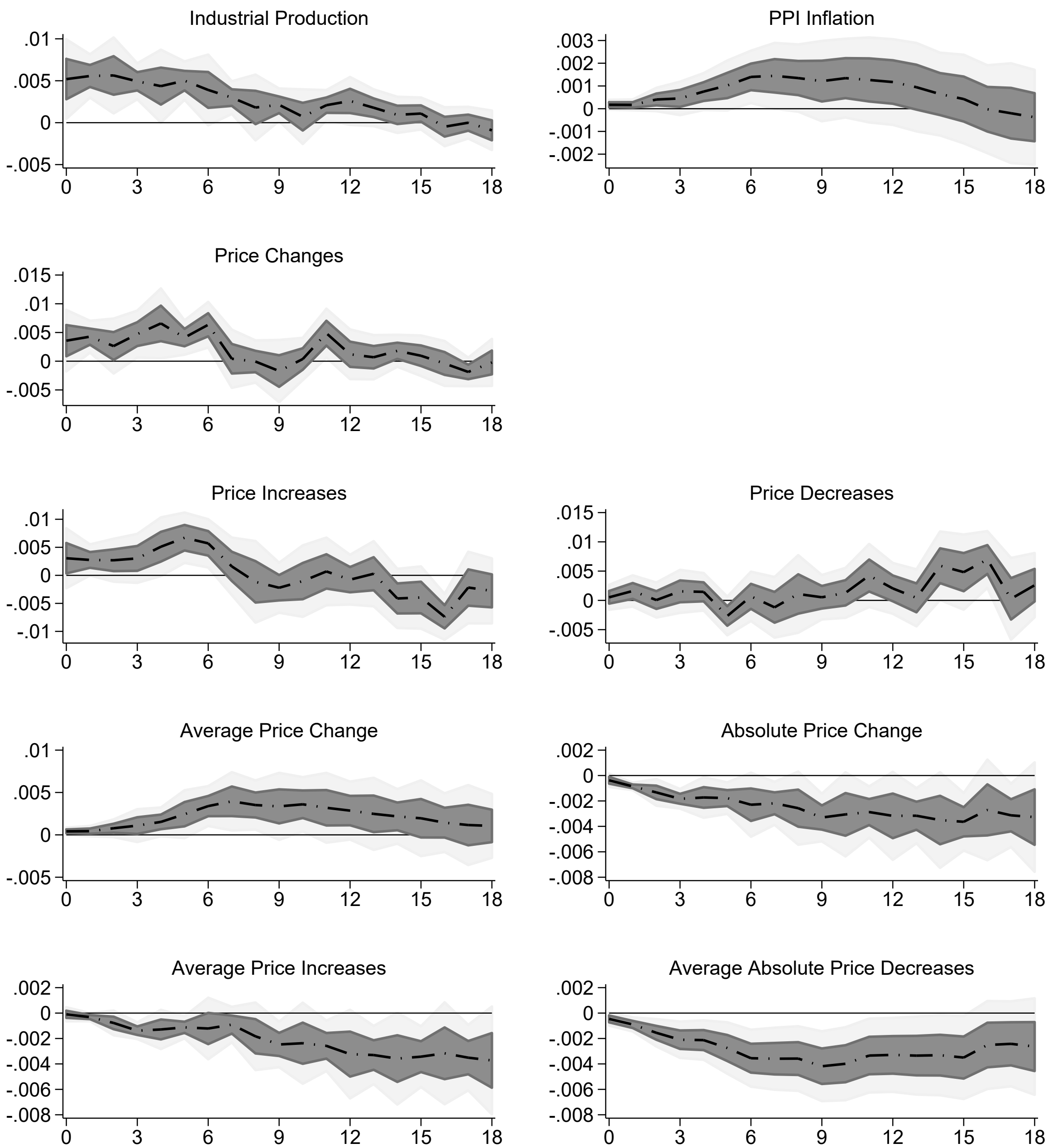
Notes: This figure shows the same impulse response functions as Figure 6 but estimated on data from the IFO Business Climate Survey aggregated at the 4-digit EPI level. See the notes to Figure 6 for further information.

Figure 12 – Extensive Margin Response in IFO-BCS Data Including Control Variables



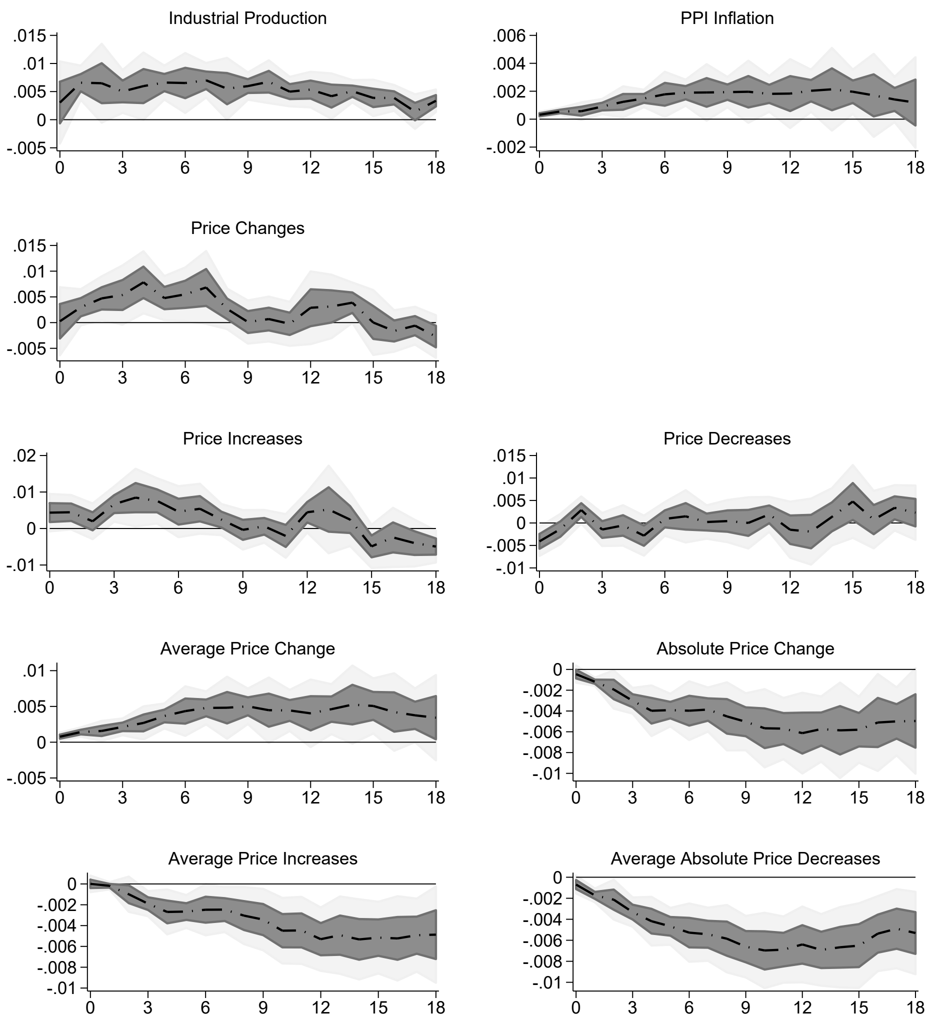
Notes: This figure shows the same impulse response functions as Figure 6 but additionally including control variables as in Equation(6). See the notes to Figure 6 for further information.

Figure 13 – Conditioning Responses on Credit Constraints: Central Bank Information Shocks



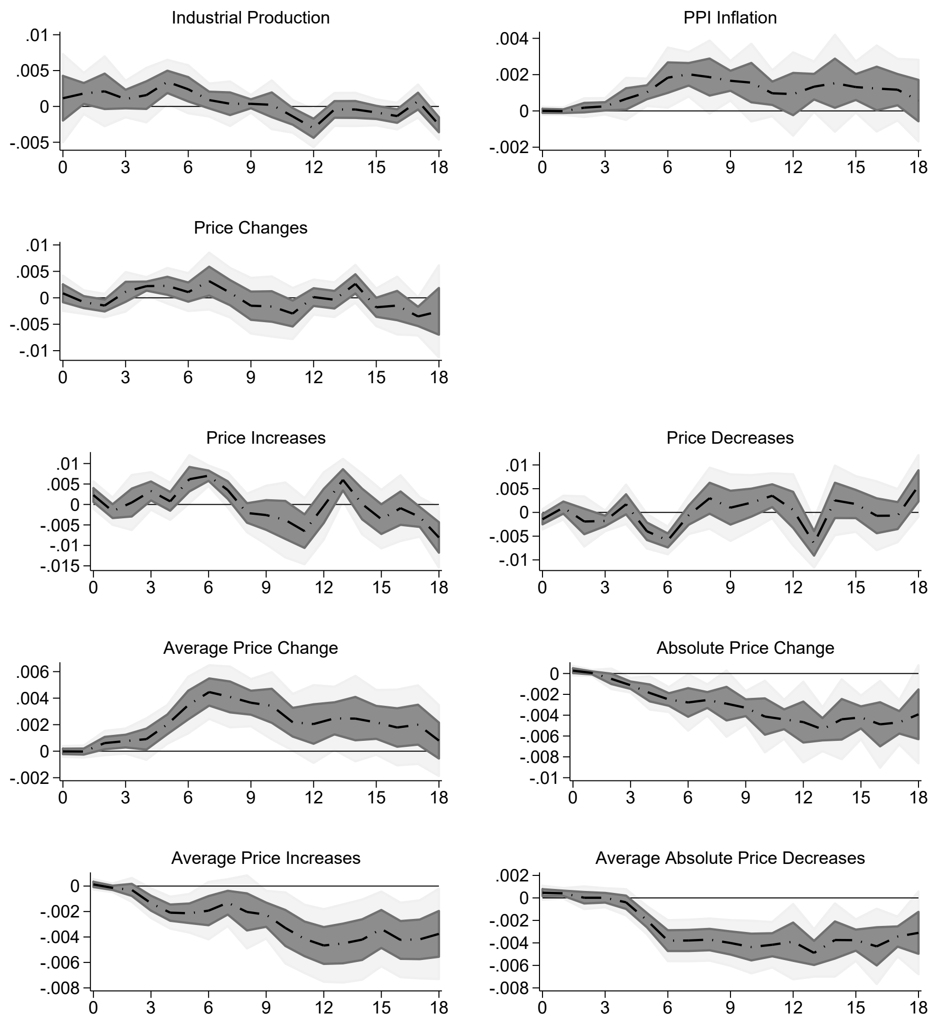
Notes: This figure shows the same coefficient as Figure 7 but estimated using central bank information shocks instead of pure monetary policy shocks.

Figure 14 – Conditional Responses Using Within Variation: Monetary Policy Shocks



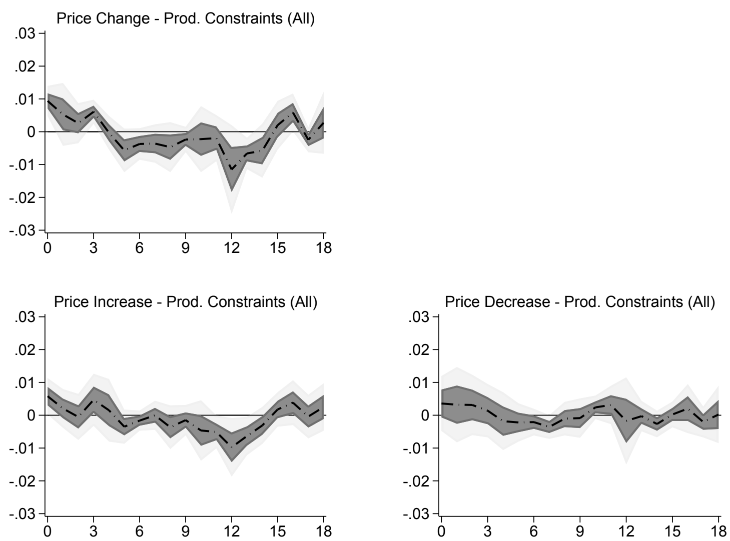
Notes: This figure shows the interaction coefficient $\psi_{\varepsilon c,h}$ in Equation (8) estimated from 4-digit EPI-level German manufacturing data. The top row displays the response of industrial production in natural logarithms and of cumulative producer price inflation. The second an third row 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. Pure monetary policy shocks 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 15 – Conditioning Responses on Production Constraints: Monetary Policy Shocks



Notes: This figure shows the same coefficients as Figure 7 but with the variable $credit^{-}_{i,t-1}$ replaced by the fraction of production constrained firms.

Figure 16 – Conditioning Responses on Production Constraints in IFO-BCS Data: Monetary Policy Shocks



Notes: This figure shows the same coefficients as Figure 8 but with the variable $credit^{-}_{i,t-1}$ replaced by the fraction of production constrained firms.