Monetary policy in the presence of supply constraints: Evidence from German firm-level data*

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Abstract

Using unique firm-level survey data, this paper investigates how supply constraints propagate monetary policy. We find that firms that face upstream pressure in form of material constraints increase prices substantially more often than unconstrained firms after expansionary monetary policy shocks. This suggests that material constraints exert substantial inflationary pressure when monetary policy is loose. This also suggests that nominal rigidities decrease when material constraints are present. Downstream pressure in form of capacity constraints does not play a similarly large role in the propagation of monetary policy. Our results complement the growing literature on the role of production networks in macroeconomics.

Keywords: supply constraints, price setting, local projections, monetary policy
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1 Introduction

The Covid-19 pandemic has shown that supply-chain disruptions can lead to severe constraints in inputs which have often been associated with the concurrent surge in inflation. Consequently, there is a renewed and growing interest in how supply constraints propagate economic shocks in general and monetary policy shocks in particular. In this paper, we provide novel firm-level evidence from Germany that documents the importance of input constraints for the propagation of monetary policy shocks to price setting. We find that firms facing material shortages increase prices significantly more often in response to an expansionary monetary policy shock than firms not facing comparable constraints. Our results therefore suggest that material constraints exert substantial inflationary pressure in times of loose monetary policy. They also lead to decreasing nominal rigidities thus rendering monetary policy less effective.

Our results offer a new view on the role of production networks in the transmission of monetary policy. One common result in the existing literature is that input-output linkages increase monetary non-neutrality via strategic price setting resulting from heterogeneity in price stickiness across sectors (Nakamura and Steinsson, 2010; Pasten, Schoenle and Weber, 2020; Ghassibe, 2021a,b; La'O and Tahbaz-Salehi, 2022; Rubbo, 2023; Afrouzi and Bhattarai, 2023). In this quantitative literature, nominal rigidities are given, while in some cases the production network can be endogenous. Our empirical results are complementary, since we show that in the presence of quantity constraints along the network, nominal rigidities endogenously change in response to monetary policy.[1] Our results also inform theoretical studies that discuss optimal monetary policy in the presence of supply constraints such as Caballero and Simsek (2023) or Fornaro and Wolf (2023) as we provide an estimate of the costs of loose monetary policy in this situation.

Measuring supply constraints is key to our analysis. We use firm-level data from the ifo Business Survey (ifo-BCS), a representative survey of German firms in the manufacturing sector. Our data uniquely combines quarterly measures of supply constraints with monthly information about price and production decisions at the firm-level. Firms are asked directly if their current production is limited due to material shortages. We document that this indicator of material constraints can be associated with supply-chain disruptions at the firm-level and therefore reflects upstream pressure on supply in a production network. Our firm-level information allows us to explore heterogeneity in material constraints. On average, between-industry variation accounts for only 3.2 percent of the total variation in material constraints, and increases up to at most 10 percent in its peaks. Hence, heterogeneity within industries is substantial and an important component to understand the total variation in material constraints. We exploit this heterogeneity when investigating how supply constraints propagate monetary policy shocks.

We estimate firm-level price and production responses to high-frequency identified monetary policy shocks for the euro-area from Jarocinski and Karadi (2020). We run Jordà (2005)-type local projections in a panel framework in which monetary policy shocks interact with material constraints. We show

[1] Pellet and Tahbaz-Salehi (2023) offer a theoretical mechanism that is in line with our results.

that material constraints are important for the propagation of monetary policy. Firms that face material constraints have an about 29 percentage points higher probability to increase prices after an expansionary monetary policy shock than unconstrained firms, while the response of production hardly differs. This difference vanishes after about 12 months. We also find that price effects are larger in industries with lower nominal rigidities. We obtain these results based on a sample that ends in 2019, i.e. these results are not driven by the Covid-19 induced recession.[2] When the share of material-constrained firms is high, as, e.g., between January 2021 and June 2022, a back-of-the-envelope calculation delivers that a one-basis point increase in the safe interest rate can lead to an increase of at least 1 percent in inflation driven by the extensive margin response of constrained firms only. Compared to a concurrent average month-to-month PPI inflation rate of 1.9 percent, the cost of inflation of loose monetary policy in the presence of material constraints is hence substantial, but short-lived.

A growing quantitative literature focuses on the role of capacity constraints for the propagation of aggregate shocks (see, e.g., Fagnart, Licandro and Portier (1999), Alvarez-Lois (2006), or Kuhn and George (2019)). Boehm and Pandalai-Nayar (2022) argue that capacity utilization is a sufficient statistic for the convexity of supply curves at the industry level.[3] Comin, Johnson and Jones (2023) build a model for the U.S. and conclude that capacity constraints together with capacity shocks and loose monetary policy explain the recent inflation dynamics. The ifo-BCS contains information about capacity utilization that forms the basis of the official aggregate capacity utilization measure for Germany and is comparable to the respective series in other countries, e.g. the U.S. We show that material constraints are distinct from capacity constraints as many firms that indicate material shortages exhibit low capacity utilization. We also show that capacity constraints arise in a situation with unexpectedly high demand which cannot be met. Capacity constraints therefore reflect downstream pressure on supply in a production network. To see if this distinction between constraints matters for the propagation of monetary policy, we further condition the response to monetary policy shocks on low and high capacity utilization. While we do not see different responses for firms operating at high or low capacity utilization (both with material shortages and without material shortages), responses are different if firms report material constraints, no matter if they operate at high or low utilization. Our results therefore suggest a small role of capacity utilization for the propagation of monetary policy shocks at the firm level, especially when material constraints are present. Put differently, an increase in demand due to expansionary monetary policy shocks leads to an increase in inflation because of upstream pressure on supply, but not because of downstream pressure of supply. While we do not reject the general view that aggregate capacity utilization can be indicative of inflationary pressure (c.p. Corrado and Mattey (1997); Stock and Watson (1999)) or the convexity of the aggregate supply curve, our results question the primary focus on capacity constraints and ask for a more accurate distinction between different constraints.[4]

[2]We also extend the sample to 2022 to address the Covid-19 pandemic separately.

[3]Boehm and Pandalai-Nayar (2022) is the only study that offers empirical evidence in this respect.

[4]Lein and Koeberl (2009) analyze Swiss survey data to study the non-linearity of the Phillips curve. They also find that capacity utilization is not in all cases a good indicator for measuring supply constraints.

Our paper is more generally related to existing aggregate evidence on the link between supply constraints and monetary policy (e.g., Laumer and Schaffer, 2022; Bai, Fernandez-Villaverde, Li and Zanetti, 2024) as well as to the literature that studies the heterogeneity in the transmission of monetary policy at the firm level. The most prominent aspect here is how financial conditions of firms affect the investment channel of monetary policy (see, among others, Jeenas, 2019; Ottonello and Winberry, 2020; Jungherr, Meier, Reinelt and Schott, 2022; Cloyne, Ferreira, Froemel and Surico, 2023). We rule out that financial conditions may drive (part of) our results. Our study further relates to the literature that investigates the relationship between supply constraints, price setting and inflation during and after the Covid-19 pandemic.[5] Our distinction between different types of supply constraints connects to an older literature trying to understand capacity utilization and its missing link to inflation (see Shapiro (1989); Corrado and Mattey (1997); Pierce and Wisniewski (2018) and also Berndt and Morrison (1981) and Finn (1995)). Last, our paper relates to the literature that documents the importance of the extensive margin of price setting for inflation dynamics (e.g., Nakamura and Steinsson (2008) or Montag and Villar (2022)).

The remainder of the paper is organized as follows. In Section 2 we describe the ifo business survey, our measures of supply constraints and the remaining variables. We present facts across time and industries in Section 3, where we also compare material constraints to measures of capacity utilization and supply-chain disruptions. We then study the propagation of monetary policy shocks to pricing and production decisions in the presence of supply constraints in Section 4. Section 5 concludes.

2 Data

2.1 The ifo Business Climate Survey

Our main data source is the ifo Business Climate Survey, a mostly qualitative monthly firm-level survey for Germany.[6] The survey is part of the EU-harmonized business surveys commissioned by the Directorate General for Economic and Financial Affairs of the European Commission and is mostly recognized for providing the basis of the ifo Business Climate index, a much-followed leading indicator for the German economy.[7] The underlying micro-data is available for research since 1980. For our analysis we focus on the manufacturing sector (IBS-IND, 2022b), the sector with the largest number of firms and the longest available time period. Between 2000 and 5000 firms respond to the survey every month. While participation in the survey is voluntary (firms receive non-monetary compensation), the ifo maintains a representative sample of German businesses by replacing exiting firms with new

[5] Balleer, Link, Menkhoff and Zorn (2024) document the increasing importance of supply-side factors for inflation towards the end of the pandemic in the same dataset as this paper. Cavallo and Kryvtsov (2023) show that shortages of consumer products have a substantial, but transitory effect on inflation.

[6] The unit of observation in the survey is a product. Large companies therefore respond to several questionnaires each month. Most firms (more than 90 percent according to Born, Enders, Müller and Niemann (2022b)) respond to only one questionnaire per month, however. Therefore, we follow related studies and refer to observations as a firm rather than a product (see, e.g., Bachmann, Born, Elstner and Grimme, 2019; Enders, Hünnekes and Müller, 2019, 2022; Born, Enders, Menkhoff, Müller and Niemann, 2022a).

[7] Lehmann (2023) provides a survey on the forecasting power of the ifo business survey.

respondents.[8] The survey questionnaires are mostly filled out by managers, CEOs, or owners of the firms (Sauer and Wohlrabe, 2019; Hennrich, Sauer and Wohlrabe, 2023).

2.2 Supply constraints

A supply constraint is a situation in which the supply curve is steep in the short-run, i.e. it is very difficult to adjust output. In most models prices adjust to lower demand such that demand and supply are equal in equilibrium. Hence, output and prices are alone not able to inform us about the existence of supply constraints or the underlying shifts in demand and supply. We therefore have to rely on other measures. Here, we use two measures of supply constraints in the ifo data: First, a direct measure of production constraints due to lack of material input and, second, capacity utilization, defined as current output relative to output at full capacity. More details on these variables are provided in Appendix A.

2.2.1 Material constraints

As a unique feature, the ifo survey has a direct question on a firm's production constraints. If firms state that their domestic production is currently constrained, they are further asked to provide the underlying reason. The question reads

"*Our domestic production is currently constrained by*

1. *insufficient demand*
2. *lack of raw materials or pre-materials*
3. *insufficient technical capacity*
4. *lack of skilled employees*
5. *difficulties of financing*
6. *other*"

Since the question addresses an evaluation of a firm's production constraints, it is crucial that the respondents are well informed about the firm's production process. This is the case as respondents are managers that rank high in the firm's hierarchy (see above). The question is asked in the first month of a quarter, i.e. in January, April, July, and October. We define a firm as material-constrained if it chooses answer category 2. Material constraints can be interpreted as quantity constraints along the supply-chain and do not just reflect an increase in input prices. Appendix B provides descriptive evidence to support this interpretation. Note that category 4 relates to labor, a separate production factor that could also limit supply. We discuss differences and similarities between these constraints as

[8] Hiersemenzel, Sauer and Wohlrabe (2022) provide recent evidence on the representativeness of the ifo Business Survey with regard to industry representation, regional distribution, and firm size. In general, sample attrition is moderate (Enders *et al.*, 2022).

we proceed. Category 3 on "insufficient technical capacity" relates to constrained capacity. We will use this category to check consistency of the information on capacity utilization described below. Category 5 on "difficulties of financing" relates to financial conditions of the firm. Using this category allows us to distinguish production constraints due to material constraints from those that relate to financial conditions in firms as prominently addressed in the literature.

2.2.2 Capacity utilization

Each quarter firms are also asked a quantitative question about their current capacity utilization.[9]

"*Currently the utilization of our plants (full capacity utilization normal for the company =100%) is up to*"

Answer categories are 30, 40, 50, 60, 70, 75, 80, 85, 90, 95, 100, and more than 100 in which case the firms can type a concrete number. The ifo question on capacity utilization forms the basis for the "official" aggregate measure of capacity utilization in Germany.[10] As the ifo survey is part of the harmonized survey program from the European Commission, the data is directly comparable to measures of capacity utilization for other countries within Europe.[11] It is also comparable to the capacity utilization series for the US which is based on the Census Survey on Plant Capacity Utilization and is provided by the Federal Reserve Board (FRB). In both the US and the German series, (full) production capacity refers to equipment and machinery. Material input is not part of capacity. Appendix C provides more details on the measurement of capacity utilization in the ifo survey and comparability to the corresponding U.S. measure.

2.2.3 Differences between measures of supply constraints

How can we conceptualize the relationship between capacity utilization rates and material constraints? First, we need to recognize that there are two types of production inputs: variable inputs and pre-determined inputs. Pre-determined inputs are fixed within the short run (a period), for example equipment and machinery, and have been planned according to demand expectations. Variable inputs are inputs that are used to operate the machinery, for example material inputs. These two types of inputs are complementary in production in the short run. Second, as described above, full capacity of a firm is defined in terms of fixed factors of production (i.e. pre-determined inputs). Shapiro (1989) refers to this as the "engineering concept" of capacity.[12] Hickman (1957) notes that measures of capacity assume an uninterrupted flow of variable inputs such as labor and material. It is then possible that constraints in variable inputs, e.g. material, may bind (far) below the capacity constraint and material

[9]Due to a harmonization of the ifo survey with the EU-harmonized business surveys, there are changes on the timing of the questions over time. We describe how we deal with this in Appendix A.

[10]Bachmann and Elstner (2015) use the same question and show that aggregate capacity utilization co-moves well with the quarterly growth-rate of the official industrial production index for Germany.

[11]Aggregate series for the Euro-Area countries are, for example, provided by the Bundesbank here.

[12]If full capacity includes all inputs, pre-determined or variable, this relates to the "cost-minimizing definition" of capacity, or "productive capacity". This distinction has already been discussed by Cassels (1937).

constraints co-exist with low capacity utilization.[13] Therefore, low capacity utilization is not only not informative about economic slack, but high capacity utilization may also understate the severity of supply constraints in the economy.

Our firm-level data allow us to corroborate the interpretation, that (i) material constraints do not necessarily reflect capacity constraints and (ii) capacity constraints arise in a situation with unexpectedly high demand which cannot be met. We divide the sample into four different groups of firms: Firms that report material constraints, but do not face excess demand; firms that report material constraints, but do face excess demand; firms that do not report material constraints and do not face excess demand and firms that do not report material constraints, but do face excess demand.[14] We find that firms with material constraints do not exhibit average capacity utilization that is different from the groups of firms without material constraints or excess demand. Firms with excess demand exhibit significantly higher capacity utilization, however. Appendix C shows the details of this result.

Our two different measures of supply constraints relate to different sources of constraints within a production network. Material constraints reflect supply constraints that arise from suppliers, i.e., they reflect upstream pressure from the perspective of the firm. Capacity constraints arise from firms or consumers increasing their demand for the product of the respective firm, i.e., they reflect downstream pressure. We establish below that this distinction is important for the propagation of monetary policy.

The measurement of capacity does not clearly include or exclude variable or pre-determined aspects of labor input. In principle, some parts of labor input might be adjusted flexibly such as hours worked or the hiring of unskilled workers at short notice. Some parts of labor input might be less flexible such as the hiring of skilled workers. However, our data suggest that firms also do not generally include labor input into their measure of capacity, see Appendix C.

Financial difficulties have been addressed as important to propagate monetary policy in firms. As they may arise as a result of material constraints, financial constraints may therefore confound the interpretation of our measures when assessing the effect of monetary policy shocks. Firms that report material constraints also report financial constraints in only ten percent of cases (see Appendix C for details). Below, we will distinguish firms with material constraints that face financial constraints from those that do not face financial constraints in a robustness check.

2.3 Other variables

The ifo asks firms about both their price and production decisions in a qualitative manner. Specifically, with respect to their pricing decisions firms are asked every month if their domestic sales price (excluding taxes) increased, did not change, or decreased compared to the previous month. Regarding production, firms are asked whether they produced at all and, if yes, to assess if their activity of domestic production increased, did not change, or decrease. For both questions we create i) a dummy

[13] Appendix C formulates this distinction in the framework of Boehm and Pandalai-Nayar (2022).

[14] We define a firm as facing excess demand if it answers "relatively high" to the question "*We consider our order backlog (provided that it is customary) to be . . .*".

variable that indicates if a firm changed its price or production activities or not and ii) separate dummy variables for production and price increases and decreases. These questions are used by several studies in the literature.[15] Nakamura and Steinsson (2008) argue that the fraction of price increases is important to understand inflation dynamics. Aggregate series calculated from these questions are known to track the dynamics of the German producer price (PPI) and industrial production (IP) indices well.[16]

We add several control variables at the firm level to our analysis. The ifo survey asks firms to assess both their current business situation and their business outlook. In line with the literature cited above we construct dummy variables that capture if a firm's business situation and outlook improved or worsened, respectively. Moreover, we utilize questions on whether or not firms currently implement overtime hours or short-time work. We measure firm size by the number of employees, on which firms are asked once a year. We define a firm as large when it employs at least 450 people, which is the 75th percentile of the firm employee distribution. Since the ifo data do not contain any information on input costs, we follow related studies (Schenkelberg, 2013; Bachmann *et al.*, 2019; Dixon and Grimme, 2022) and construct an input price measure at the two-digit industry level using input-output tables for the German manufacturing sector provided by the OECD and PPI indices provided by DESTATIS. An exact description of these variables is provided in Appendix A.

2.4 Sample

Our baseline sample covers the years 1990 to 2019. This excludes factors related to German reunification. It also excludes the Covid-19 pandemic. The Covid-19 pandemic has been special in general, but especially with respect to supply constraints. We will show robustness extending our sample to 2022 including Covid and discuss differences in the results whenever appropriate.

We have price and production information at monthly and (some of) the variables measuring supply constraints at the quarterly frequency. Our baseline sample used in the empirical analysis in Section 4 will be monthly in order to explore the largest possible variation in prices and monetary policy shocks. Here, we assume that firms which report supply constraints at the beginning of the quarter are supply-constrained for the entire quarter. We address this assumption in the robustness analysis.

Our data is unique in that it combines representative firm-level information on prices and output with information on firms supply constraints. This combination is not available for US manufacturing firms (see Kehrig and Vincent (2021) and Boehm and Pandalai-Nayar (2022)). It is also unique with respect to measuring supply constraints as it distinguishes material from capacity and other supply constraints at the firm-level. The harmonized surveys from the European Commission contain similar information, but only at the more aggregate level and less acutely measured.

[15] Most recent examples are Bachmann *et al.* (2019) who study the role of uncertainty on firm's pricing decisions, Dixon and Grimme (2022) who provide evidence of time- vs. state-dependent pricing, Enders *et al.* (2022) who study the role of expectations for production and pricing decisions, and Born *et al.* (2022a) who study firm's reactions to news.

[16] Bachmann *et al.* (2019) and Balleer and Zorn (2019) compare the frequency of price changes in the ifo survey and data underlying the official PPI series for Germany and find that frequencies are identical. Balleer *et al.* (2024) show that aggregate series calculated from the price question tracks the dynamics of official PPI well.

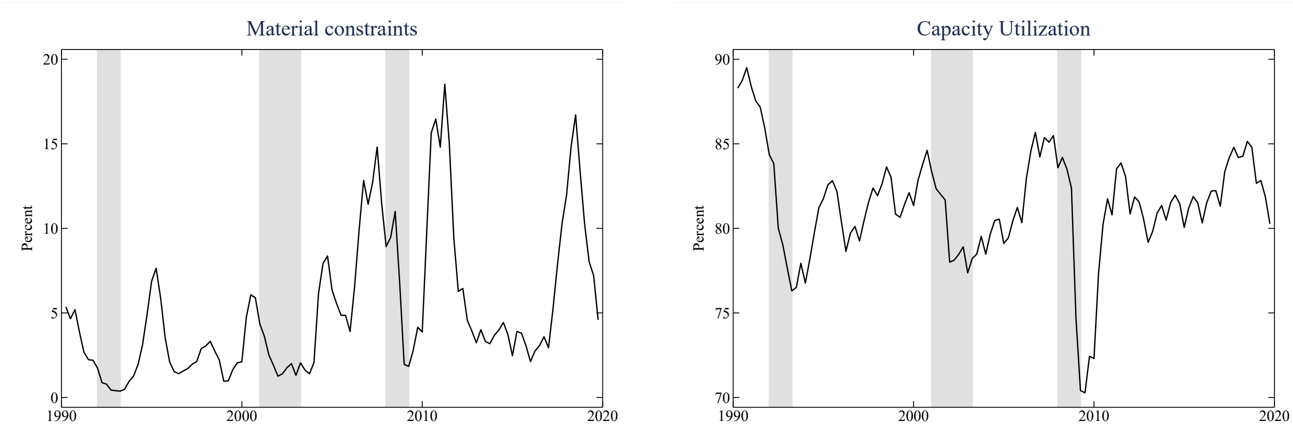

FIGURE 1: Material constraints and capacity utilization over the business-cycle

Notes: Sample period: 1990 to 2019. The left panel shows for each quarter the fraction of firms reporting material constraints. The right panel shows for each quarter the average capacity utilization rate over all firms. Grey shaded areas correspond to recessionary periods 1992Q1-1993Q2, 2001Q1-2003Q2, and 2008Q1-2009Q2 as indicated by the German Council of Economic Experts (see Breuer *et al.*, 2022).

3 Facts about supply constraints

In this section we report stylized facts about our two measures of supply constraints. Since our direct measure of material constraints is new, we focus on documenting statistics both in the aggregate and across firms and industries for this measure. We also look at the persistence of material constraints at the firm-level. These new facts help to build and calibrate models that incorporate material constraints. Heterogeneity in supply constraints across firms will also be used in addressing the propagation of monetary policy shocks in Section 4.

3.1 Business-cycle fluctuations

Our sample from 1990 to 2019 allows us to track cyclical dynamics of the German economy which include three recessions dated by the Council of Economic Experts (Breuer *et al.*, 2022). Figure 1 shows aggregate time-series of our supply constraints measures together with these recession dates. Both measures exhibit substantial cyclical variation. The left panel depicts the fraction of forms reporting material constraints which decreases during recessions and increases out of recessions. Material constraints build up over time, exhibiting a moderate upward trend. The right panel shows average capacity utilization across firms which decreases sharply during recessions, increases out of recessions and continues to increase gradually during normal times. Capacity utilization returns to its long-term average value of about 82 percent in normal times. While the cyclical patterns of both series are comparable, the relation to the business cycle appears to be more pronounced in the case of capacity utilization. We calculate the correlation between the two series and the ifo Business Climate index for the manufacturing sector. The correlation between capacity utilization and the ifo index is 0.67, the correlation between the fraction of firms reporting material constraints and the index is 0.66. However, the correlation between material constraints and capacity utilization is only 0.4 which indicates that the two indicators of supply constraints capture different aspects of the overall cyclical variation.[17]

At the onset of the Covid-crisis, capacity utilization decreased sharply and returned to its normal level quickly, i.e., capacity utilization was not exceptionally high during this period. By contrast, the fraction of firms reporting material constraints exploded during this time period. At the end of the sample, more than 60 percent of the firms reported material constraints. See Figure D.3 in the Appendix for a graph. Hence, while material constraints co-move with inflation during the Covid recession, capacity utilization did not. This resembles the opposite co-movement of capacity utilization and inflation together with the existence of severe supply constraints in the 1970's that is documented in Berndt and Morrison (1981) and Finn (1995).

3.2 Heterogeneity

The aggregate series mask substantial heterogeneity in supply constraints. Figure 2 plots the fraction of firms reporting material constraints and the average capacity utilization across firms at the two-digit industry level (24 industries following the German WZ08 classification). The left column shows the mean (blue solid line), the median (blue dashed line), and the inter-quartile range (blue shaded area) across industries over time. The right column documents the individual series for each of the 24 industries (in grey) and highlights the two industries with the highest (in red) and lowest (in blue) volatility. Here, we focus on industries for which we observe at least twenty firms on average in order to ensure that the high and low standard deviations are not just a result of the low sample size.

The first row exhibits material constraints. During the first 15 years of our sample period, the lower quartile of this measure is usually zero, both during booms and during recessions. By contrast, the upper quartile fluctuates over this time period in line with the average and the median. Starting in 2005, material constraints become more common across industries. Before the Great Recession and at the beginning of the boom following the Great Recession most industries report material constraints and continue to do so until the end of the sample. Moreover, every spike in the mean is accompanied by a rise in the inter-quartile range which indicates that material constraints become more industry-specific. To investigate this result further, we follow Balleer *et al.* (2024) and decompose the variation in material constraints into within-industry and between-industry variation according to

$$\text{var}\left(m_{ij}\right) \equiv \bar{m}(1-\bar{m}) = \underbrace{\sum_j \frac{N_j}{N}\overline{m_j}\left(1-\overline{m_j}\right)}_{\text{within}} + \underbrace{\sum_j \frac{N_j}{N}\left(\overline{m_j}-\bar{m}\right)^2}_{\text{between}}, \quad (1)$$

where m_{ij} is a dummy-variable indicating if firm i in industry j is material-constrained or not, N_j denotes the number of firms in sector j, N is the total number of firms, $\overline{m_j}$ is the industry mean of m_{ij}, and $\overline{m}$ its unconditional mean. We suppress the time subscript here for convenience. Figure D.4 in the Appendix plots the share of variance explained by between-industry variation over the sample period. The share of the between-variation fluctuates and therefore explains part of the fluctuations of

[17]See Figure D.1 and Figure D.2 for the corresponding graphs.

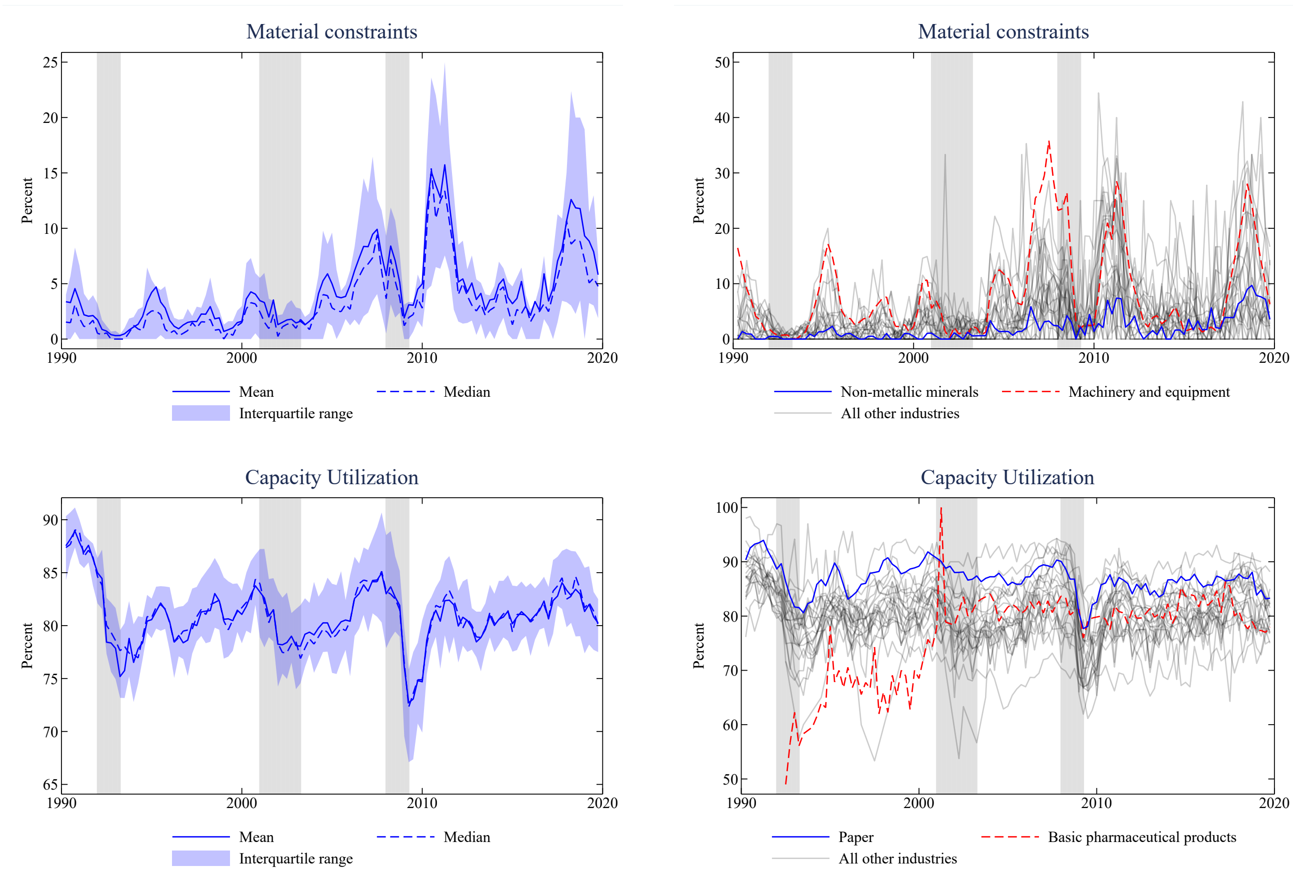

FIGURE 2: Heterogeneity in material constraints and capacity utilization across industries

Notes: Sample period: 1990 to 2019. The left column shows the quarterly mean (solid line), median (dashed line), and inter-quartile range of the fraction of firms reporting material constraints and average capacity utilization across two-digit industries. The right column shows the individual time-series for each industry (grey lines). Industries with the lowest (in blue) and highest (in red) volatility are highlighted. For the highlighting we focus on industries for which we observe at least twenty firms on average. Grey shaded areas correspond to recessionary periods 1992Q1-1993Q2, 2001Q1-2003Q2, and 2008Q1-2009Q2 as indicated by the German Council of Economic Experts (see Breuer *et al.*, 2022).

Table 1: Summary statistics: Spells in material constraints

	N	Mean	Std. Dev.	P10	P25	P50	P75	P90
Material	54377	5.596	9.412	1	1	2	6	14

Notes: Sample period: 1990 to 2019. Spells are calculated at quarterly frequency and are defined as follows: If a firm reports material constraints in quarter t but not in quarter $t-1$ a new spell starts. If the firm reports again material constraints in the next quarter the spell prolongs, otherwise the spell ends.

the aggregate material constraints that we document above. On average, between-industry variation accounts for only 3.2 percent of the total variation in material constraints, however, and increases to less than 10 percent in its peaks. Hence, heterogeneity within industries is substantial and an important component to understand the total variation in material constraints.

The industries for which firms most often do not report any material constraints during this time period (again focusing on firms with at least twenty firms) are "Beverages", and "Wearing apparel". Industries that face the highest fraction of firms reporting material constraints on average are "Wood and product of wood", "Electrical equipment", and "Machinery and equipment". Industries differ in the volatility of material constraints. Some industries face a modest level of material constraints that is not much affected by the overall business cycle, while other industries are much more volatile with respect to their material constraints. "Non-metallic minerals" exhibit the highest standard deviation in material constraints across industries (blue solid line in the right graph), "Machinery and equipment" show the lowest standard deviation (red dashed line in the right graph). In addition, not all industries experience times of high material scarcity simultaneously. This can be seen particularly well in the period from 2010 onward as the different spikes in they grey lines all correspond to different industries.

The second row of Figure 2 shows average capacity utilization in two-digit industries. Throughout the sample capacity utilization fluctuates in all industries around roughly 80 percent. The inter-quartile range, i.e., the dispersion across industries, is stable over time and fluctuates around six percentage points. This reflects well the volatility in most industries. Exceptions are, for example, "Basic pharmaceutical products" which shows large volatility during the earlier periods of our sample. The industry with the lowest standard deviation in capacity utilization is "Paper". Figure 2 does not suggest that heterogeneity in material constraints and capacity utilization is very similar across industries.

3.3 Persistence of material constraints

The panel dimension of our data allows to investigate spells of material constraints in firms over time. We define a spell as follows: If a firm reports material constraints in quarter t but not in quarter $t-1$ a new spell starts. If the firm reports again material constraints in the next quarter the spell prolongs, otherwise the spell ends. Summary statistics for these spells are reported in Table 1. In total we can look at 54377 material spells. The average length of a material shortage period is about 5.6 quarters, i.e. about one and a half years. However, the distribution is highly skewed. Both the 10^{th} and the

Table 2: Markov transition matrix for spells in material constraints

	Material$_t$		
Material$_{t-1}$	0	1	Total
0	97.44	2.56	100.00
1	50.67	49.33	100.00
Total	95.17	4.83	100.00

Notes: Sample period: 1990 to 2019. States of being material constrained (= 1) and states of not being material constrained (= 0) are measured at quarterly frequency according to equations (2).

25$^{\text{th}}$ percentiles are just one quarter, even the median is just two quarters. Moving from the median to the 75$^{\text{th}}$ percentile, the length of a material shortages spell increases to six quarters. The longest 10 percent of the spells even last for at least three and a half years.

Markov transition matrices offer a different way to look at the persistence of constraints.[18] Specifically, we estimate the probability that firm i reports (no) material constraints in period t conditional on reporting (no) material constraints in period $t-1$. More formally, define $k \in \{0,1\}$ and $j \in \{0,1\}$ the two states a firm can report in period t and $t-1$, respectively, where 0 indicates no material constraint and 1 indicates a material constraint. We then estimate the probabilities as

$$p_{jk} = Pr\left(material_t = k \mid material_{t-1} = j\right) \quad \text{with} \quad \sum_{j=0}^{1} p_{jk} = 1, \quad \forall k \in \{0,1\}, j \in \{0,1\}. \tag{2}$$

Table 2 shows the results. The state of not reporting material constraints is highly persistent. A firm that reports no material constraints in period $t-1$ reports no material constraint in period t with about 97 percent probability. With a probability of about three percent firms report material constraints in the period following a period without material constraints. The persistence is lower, however, once a firm enters the state of having material constraints. It is roughly as likely that a firm will stay in the state of constrained material as that a firm will switch to no material constraints in the next period.

On average, firms rarely enter a period in which they report material constraints at all. Moreover, once they enter a period with material constraints in about 50 percent of the cases these periods do not last longer than half a year on average. Even though some spells of material constraints are long lasting, our results generally suggest that material constraints at the firm level are not very persistent. We can also consider persistence at the industry-level. In Table D.1 in Appendix D we report AR(1) coefficients for the two-digit industry-level time-series of firms reporting material constraints. Again we see a lot of cross-industry heterogeneity as coefficients range from 0.02 to 0.9 with an average coefficient of about 0.62.

Caballero and Simsek (2023) argue that it can be optimal not to raise rates or even decrease rates and risk inflation when production is constrained temporarily, since this ensures sufficiently high demand

[18] See Lein (2010) for a related approach in the context of firms pricing decisions and Kehrig and Vincent (2021) in the context of a firm's labor share.

when supply recovers. Material constraints as our preferred measure of supply constraints are indeed transitory. Our estimates below measure the costs of the policy recommendation for expansionary monetary policy in this situation.

4 Supply constraints and the propagation of monetary policy

4.1 Estimation strategy

To study firms pricing and production decisions in response to a monetary policy shock, we estimate impulse-response functions using panel local projections (LP) following Jordà (2005). The method has recently been applied to estimate firm-level responses to monetary policy shocks conditional on firms' financial positions in order to investigate the investment-channel of monetary policy (Jeenas, 2019; Ottonello and Winberry, 2020; Jungherr *et al.*, 2022; Cloyne *et al.*, 2023). To the best of our knowledge, we are the first to document firm-level price and production responses to a monetary policy shock conditional on production limitations more generally and specifically related to the lack of material input.

We estimate the heterogeneous effects of monetary policy conditional on supply constraints in two sets of local projections: First, we condition on material constraints only, and, second, we compare firms with both capacity and material constraints to firms facing only one of these constraints. Our first set of local projections then estimates

$$\begin{aligned} y_{ij,t+h} = \alpha_h + \beta_{1,h}\, x_{ij,t-1} \times shock_t + \beta_{2,h}\, (1 - x_{ij,t-1}) \times shock_t \\ + \varphi_h\, x_{ij,t-1} + \gamma_h\, Z_{ij,t-1} + \delta_{j,h} + \delta_{t,h} + \varepsilon_{ij,t+h}, \end{aligned} \tag{3}$$

for $h = 0, \ldots, 12$. Here, the dependent variable $y_{ij,t+h}$ indicates whether a firm i in industry j at time $t + h$ changed, increased or decreased its price or level of production or not. Our setup follows Ottonello and Winberry (2020) in that $shock_t$ is a separately, in high-frequency identified monetary policy shock in t. Here, we use the Euro Area series provided by Jarocinski and Karadi (2020).[19] Using sign-restrictions, Jarocinski and Karadi (2020) decompose the identified shocks further into two components: pure monetary policy shocks and central bank information shocks. For our analysis we restrict ourselves to the pure monetary policy measure. The shock series is available from January 1999 to October 2022. As stated above, our baseline sample ends in 2019 and we will extend the sample including the Covid-period in a robustness check. The daily shocks are aggregated to monthly frequency by summing up shocks occurring within the same month. To ease the exposition we multiply the shocks with (-1) so that positive shocks correspond to expansionary monetary policy.

The variable $x_{ij,t-1}$ indicates whether or not firm i in industry j reported material constraints in period $t - 1$. Thus, the series of $\beta_{1,h}$ and $\beta_{2,h}$ directly estimate the different impulse response functions of

[19] The identification assumption is based on high frequency financial markets data around ECB policy announcements (specifically, 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). The identifying assumption is that any price movements within these narrow time windows are due to monetary surprises revealed at the press event.

material-constrained ($\beta_{1,h}$) and unconstrained ($\beta_{2,h}$) firms to a monetary policy shock. This is comparable to the specification by Cloyne *et al.* (2023) who condition the effect of a monetary policy shock on different groups of firms. Recall from Section 3 that not all firms experience material constraints at the same time, but that there is substantial variation in material constraints across and within industries. Therefore, we can estimate responses for both constrained and unconstrained firms at different states of the business cycle. $Z_{ij,t}$ is a vector of control variables that are either at the firm level i or the industry level j. These variables include a firm's assessment of its current state of business, expectations about its future state of business, and, most importantly, a variable capturing the change in input-prices at the industry level. We include industry fixed effects $\delta_{j,h}$ to control for the sectoral heterogeneity which we documented in Section 3 as well as other unobserved time-invariant characteristics of different industries, such as the market structure or the degree of price stickiness. Furthermore, to control for seasonality in pricing and production decisions, we include seasonal fixed effects $\delta_{t,h}$. Following Cloyne *et al.* (2023), we do not include any additional time fixed effects or industry-by-time fixed effects and interpret our results as including general-equilibrium effects. $\varepsilon_{ij,t+h}$ is the error-term. We estimate the series of linear probability models stated in equation (3) by ordinary least squares.[20] Standard errors are clustered at the firm-level.

Our second set of local projections extends equation (3) in the following way:

$$\begin{aligned} y_{ij,t+h} = \alpha_h &+ \beta_{1,h}\, x^{c,+}_{ij,t-1} \times shock_t + \beta_{2,h}\, x^{c,-}_{ij,t-1} \times shock_t \\ &+ \beta_{3,h}\, x^{uc,+}_{ij,t-1} \times shock_t + \beta_{4,h}\, x^{uc,-}_{ij,t-1} \times shock_t \\ &+ \varphi_{1,h}\, x^{c,+}_{ij,t-1} + \varphi_{2,h}\, x^{uc,+}_{ij,t-1} + \gamma_h Z_{ij,t-1} + \delta_{j,h} + \delta_{t,h} + \varepsilon_{ij,t+h} \end{aligned} \tag{4}$$

All variables are defined as in equation (3). In this specification, however, we decompose the effect of the monetary policy shock into four groups according to whether or not firms face material constraints and whether firms operate at high or low capacity utilization. Here we define a firm as operating at high utilization rates if its current utilization rate is above its firm-specific sample mean. Conversely, we define a firm to operate at low utilization rates if its current utilization rate is below its firm-specific mean. The different groups are then described in (4) by $x^{c,+}_{ij,t-1}$ which equals 1 if firm i in industry j reports material constraints (c) and operates at a high utilization rate ($+$) in period $t-1$, and zero otherwise; $x^{c,-}_{ij,t-1}$ which equals 1 if a firm reports material constraints and operates at low utilization rates ($-$) in $t-1$, and zero otherwise; and $x^{uc,+}_{ij,t-1}$ and $x^{uc,-}_{ij}$ which indicate whether or not a firm reports no material constraints (uc) and operates at high ($+$) or low ($-$) utilization rates.

Note that we do not impose linearity in these interactions. More importantly, the grouping strategy allows us to look at the marginal effect of one constraint conditional on the presence of a second constraint. For example, comparing the series of $\beta_{1,h}$ and $\beta_{3,h}$ allows us to study the effect of material constraints conditional on high capacity utilization. In doing so, we can test whether upstream or downstream pressure is more important to understand the propagation of monetary policy shocks.

[20] Grimm, Jordà, Schularick and Taylor (2023) study linear probability models in a local projection framework to study the impact of loose monetary policy on the likelihood of a financial crises.

Suppose $\beta_{1,h}$ is greater than $\beta_{3,h}$, then the presence of material constraints has an additional effect on firm decisions in response to a monetary policy shock over and above the effect of high capacity utilization. If the coefficients are not different from each other, then material constraints do not affect firm decisions when already operating at high utilization. This way, we can also address the sufficient statistic argument by Boehm and Pandalai-Nayar (2022) who state that capacity utilization is a sufficient statistic to detect the curvature of the supply curve. If the utilization rate was a sufficient statistic, we should observe different pricing behavior for firms operating at high and low utilization rates for both material-constrained and unconstrained firms. We should not observe, however, differences in pricing behavior between material-constrained and unconstrained firms conditioning on operating at high utilization, since this suggests that there is additional price pressure not induced by high utilization.

In equations (3) and (4), the index t refers to the monthly frequency of the price and production decisions as well as the monetary policy shocks. Material constraints are reported only in January, April, July, and October. As stated above, we interpolate material constraints to the monthly frequency in our baseline sample assuming that material constraints reported at the beginning of the quarter hold for the entire quarter. Doing so, we can utilize the full variation in the dependent variable and the monetary policy shock. We report robustness checks to this choice below.

4.2 Results

4.2.1 Unconditional responses

Before showing firm-level results conditional on constraints, we investigate unconditional local projections for our data and sample, both for German aggregate measures and at the firm-level. The German aggregate producer price index and industrial production (both in logarithms) respond in a reasonably and statistically significant way to the high-frequency Euro Area monetary policy shock: Both industrial production and producer prices increase in response to an expansionary shock (see Figure E.1). A similar result emerges if we estimate the unconditional response in our firm-level data. Here, we show the average response of the fraction of price increases and decreases and the corresponding average response for production to the expansionary policy shock (see Figure E.2). As expected, the fraction of price and production increases increases in response to the shock, while the fraction of price and production decreases decreases.

4.2.2 Responses conditional on material constraints

Table 3 presents the results of estimating equation (3) for $h = 0$ for our different indicators of firms' pricing decisions. We show a firms' probability to change, increase or decrease their current price in response to a monetary policy shock when facing material constraints (MP, material) or not (MP, no material). We estimate a version of equation (3) with seasonal and fixed effects only, and then add covariates to capture a firms' business situation and outlook as well as the change in input-prices at the industry level. In response to an expansionary monetary policy shock, material-constrained firms

Table 3: Firms' pricing decisions in response to monetary policy

	Price change			Price Increase			Price Decrease		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
MP, material	0.289***	0.318***	0.296***	0.368***	0.325***	0.288***	-0.0794**	-0.00657	0.00856
	(0.0722)	(0.0718)	(0.0717)	(0.0657)	(0.0656)	(0.0654)	(0.0385)	(0.0381)	(0.0381)
MP, no material	-0.0258*	0.0220	-0.0102	0.0882***	0.0465***	-0.00781	-0.114***	-0.0245**	-0.00238
	(0.0146)	(0.0145)	(0.0144)	(0.0116)	(0.0114)	(0.0111)	(0.0110)	(0.0107)	(0.0105)
Constant	0.170***	0.129***	0.126***	0.0908***	0.0758***	0.0712***	0.0791***	0.0527***	0.0546***
	(0.00221)	(0.00249)	(0.00249)	(0.00134)	(0.00159)	(0.00155)	(0.00175)	(0.00192)	(0.00196)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	588597	586399	586399	588597	586399	586399	588597	586399	586399

Notes: Sample period: 1999 to 2019. Estimation results for α_0 (Constant), $\beta_{1,0}$ (MP, material), and $\beta_{2,0}$ (MP, no material) based on Equation (3). The dependent variable is a dummy indicating price changes (columns 1 to 3), price increases (columns 4 to 6), or price decreases (columns 7 to 9). Controls Business include a firm's assessment of its current and future business situation. Control Input is a measure of firm's input costs at the industry-level. Standard errors in parentheses are clustered at the firm-level. Stars indicate significance at the 10 percent (*), 5 percent (**), and 1 percent (***) level, respectively.

are more likely to change their price (see columns 1-3). By contrast, firms that are not constrained by material shortages are less likely to change their price in response to a monetary policy shock. The effect is statistically significant for constrained firms, but only marginally so for unconstrained firms. In columns 4 to 6 we study firm's price increases. Both constrained and unconstrained firms have significantly higher probabilities to increase their prices in response to the shock, but the effect vanishes for unconstrained firms when including input-prices. Also, the probability to increase prices is between four and six times larger for constrained firms. In the full specification firms that are material-constrained have an about 29 percentage points higher probability to increase prices in response to an expansionary monetary policy shock. This is remarkable, given that the unconditional probability to increase prices in our sample is 9.5 percent. In the full specification, both types of firms are not significantly more likely to decrease prices when monetary policy shocks occur (see column 9).

Table 4 presents the same set of specifications for firms production decisions. Focusing on our estimation results including all control variables, column 3 of Table 4 shows that constrained firms have a positive probability to change their production in response to a monetary policy shock. The effect is insignificant for unconstrained firms. Columns 6 and 9 reveal that this difference is driven by the decision to increase production more often, not to decrease production. Unconstrained firms both increase production more often and decrease production less often in response to monetary policy shocks. Even though firms are production constrained, it may be reasonable that firms adjust production more often when also adjusting prices. Since experiencing a positive shift in demand, firms would then increase production if possible. Again, our results do not speak to the degree of production increases, i.e., the intensive margin. We expect the production increases for constrained firms to be smaller than those for unconstrained firms.

We provide robustness checks for the price and production decisions in Tables E.1 and E.2. First, we still find significant effects if we employ Driscoll and Kraay (1998) or two-way clustered standard-

Table 4: Firms' production decisions in response to monetary policy

	Prod. change			Prod. Increase			Prod. Decrease		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
MP, material	0.150*	0.191**	0.197**	0.452***	0.303***	0.287***	-0.302***	-0.112*	-0.0902
	(0.0866)	(0.0836)	(0.0836)	(0.0726)	(0.0692)	(0.0692)	(0.0650)	(0.0593)	(0.0593)
MP, no material	-0.118***	-0.00858	0.000182	0.329***	0.199***	0.176***	-0.447***	-0.207***	-0.175***
	(0.0188)	(0.0179)	(0.0179)	(0.0138)	(0.0132)	(0.0132)	(0.0160)	(0.0145)	(0.0144)
Constant	0.327***	0.186***	0.187***	0.142***	0.0800***	0.0780***	0.184***	0.106***	0.109***
	(0.00266)	(0.00270)	(0.00271)	(0.00176)	(0.00157)	(0.00156)	(0.00198)	(0.00167)	(0.00169)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	589796	587513	587513	589796	587513	587513	589796	587513	587513

Notes: Sample period: 1999 to 2019. Estimation results for α_0 (Constant), $\beta_{1,0}$ (MP, material), and $\beta_{2,0}$ (MP, no material) based on Equation (3). The dependent variable is a dummy indicating production changes (columns 1 to 3), production increases (columns 4 to 6), or production decreases (columns 7 to 9). Controls Business include a firm's assessment of its current and future business situation. Control Input is a measure of firm's input costs at the industry-level. Standard errors in parentheses are clustered at the firm-level. Stars indicate significance at the 10 percent (*), 5 percent (**), and 1 percent (***) level, respectively.

errors. Second, we show that our results are robust to including firm fixed-effects instead of industry fixed-effects. In our baseline we assume firms to be supply-constrained for the quarter at the beginning of which they report these constraints. As a third robustness check, we consider price and production decisions together with the monetary policy shocks in the months where constraints are measured only, i.e., in February, May, August, and November. In this way, we focus on price and production decisions that immediately follow reported material constraints. We include seasonal fixed effects to rule out that our effects are just a result of price and production decisions occurring in particular months. Due to the substantially smaller sample, our results lose power, but still replicate the baseline results. Fourth, we also check if our results are robust if we assume instead that firms are constrained at the month of measurement and one month before and after. Again results are robust. Fifth, we restrict firms to be material constrained if they report material constraints but no financial constraints at the same time. Our results are robust to this restricted measure of material constraints. Sixth, we check if our results differ between small and large firms by splitting our sample accordingly. While we lose power for the sample of large firms, these estimations still replicate our results from our baseline analysis. Lastly, we exclude small industries without substantial heterogeneity in material constraints (see also Section 3.2) and show that our results are not driven by these.

Figure 3 plots impulse response functions of price and production increases from the specification including all control variables and fixed effects. The left panel shows the price response, the right panel shows the production response. Red lines represent responses for material-constrained firms, $\beta_{1,h}$, blue lines represent responses of unconstrained firms, $\beta_{2,h}$. The shaded areas depict one- and two-standard-deviation confidence bands. Figure 3 documents that the difference in pricing behavior is persistent as constrained firms have a higher probability to increase prices for the first twelve months after the shock hits. The estimated probability to increase prices is rather constant for constrained firms over this horizon, while the probability to increase prices increases gradually in response to an expansionary monetary policy shock for unconstrained firms. The results for price changes and price decreases are shown in Figures E.3 and E.4, respectively. The probability to decrease prices does not significantly react to the shock on impact for constrained firms, while it directly falls for unconstrained firms. After about 4 months, the dynamics of price decreases are roughly equal for both groups of firms. The right panel of Figure 3 documents that constrained firms have a higher probability to increase production on impact, but throughout the impulse horizon there are hardly any differences in the responses of constrained and unconstrained firms. This also holds true for production decreases as documented in the Appendix.

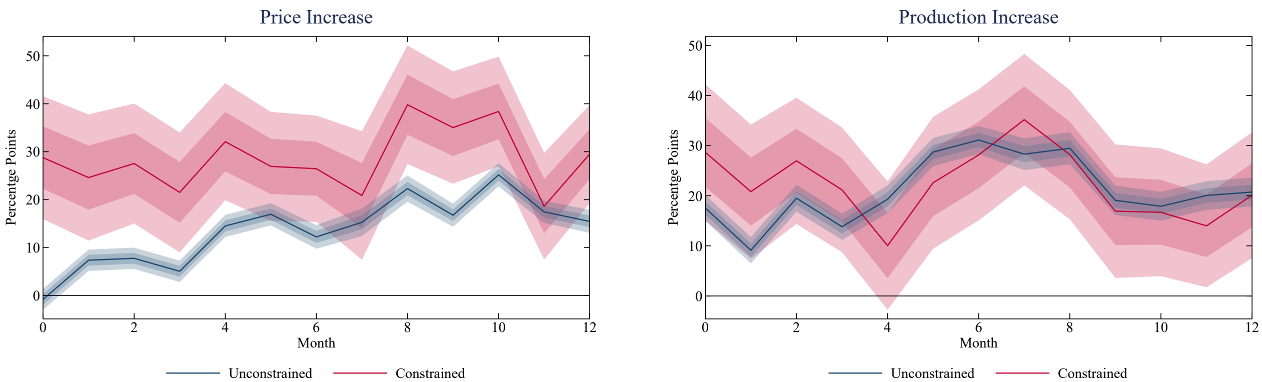

Figure 3: Price and production increases conditional on material constraints

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for material-constrained (red) and not material-constrained (blue) firms based on estimating Equation (3). Dependent variable is a dummy indicating price increases (left panel) and production increases (right panel). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

We provide some additional results with respect to the dynamic responses. First, we plot responses for a longer horizon. In Figure E.5 in the Appendix we document that our estimated results are relatively short-lived. In fact, after the first year after the shock hits there is no difference between the price responses of constrained and unconstrained firms. Second, we follow Andrade, Coibion, Gautier and Gorodnichenko (2022) and estimate a cumulative impulse response function by taking into account price increases and decreases in one-step. For this purpose, we recode the dependent variable in equation (3) so that $\mathbb{I}(y_{ij,t+k}) \in \{-1, 0, 1\}$ indicates whether a firm decreases (-1), does not change (0), or increases (1) its price or production, respectively. The dependent variable then is the cumulative sum of this recoded variable, namely $\sum_{k=0}^{h} \mathbb{I}(y_{ij,t+k})$. There is no direct quantitative interpretation of the left-hand side variable due to the qualitative nature of the price and production decisions. However, a positive value of the dependent variable indicates that there are more price or production increases on net. Figure E.6 shows that constrained firms have higher prices on net over the entire (longer) impulse horizon, while we see no difference in net production. Third, following Cloyne *et al.* (2023), we restrict the sample to firms that we observe for at least two years. Figure E.7 shows that this does not change our estimated impulse response functions. Fourth, we study planned price and production increases, see Figure E.8. Here the differences between constrained and unconstrained firms are less pronounced.

Fifth, Figure E.9 plots the IRFs when extending our sample up until March 2022.[21] Again, constrained firms have a higher probability than unconstrained firms to increase prices over the impulse horizon. The difference is larger than in our baseline sample. The dynamics also change. Now the probability to increase prices rises gradually for both types of firms. As a result of the Covid-outbreak, the breakdown in global supply-chains led to a record high of reported material constraints in 2020 and throughout 2021. At the same time the European Central Bank (ECB) has not tightened its stance up until mid-2022. Our empirical results generally imply that a combination of material constraints and loose monetary policy can lead to a higher fraction of firms increasing their prices, which in turn leads to a high inflation rate. Arguably this is what happened in the euro area during the early 2020's and, therefore, these results are more prominent in the longer sample.

Sixth, we compare firms that are constrained with respect to their labor input or not instead of material-constrained firms. Figure E.10 shows that labor constraints do not lead to significant differences in the pricing reactions between constrained and unconstrained firms. One interpretation of this finding is that labor constraints reflect capacity constraints and labor should not be viewed as a variable input according to the engineering concept of capacity as discussed above.

Taken together, our estimation results reveal that material constraints are important to understand heterogeneous responses of firms to monetary policy, especially with respect to prices. Our results also suggest that material constraints exert substantial inflationary pressures in times of loose monetary policy. These effects are short-term as the constrained and unconstrained responses converge after about 12 months.

4.2.3 Upstream versus downstream pressure

Figures 4 and 5 show the responses of price and production increases to expansionary monetary policy shocks for the four different groups of firms defined in equation (4). To facilitate the exposition, we compare the response for firms with and without material constraints at different levels of capacity utilization, i.e., $\beta_{2,h}$ and $\beta_{4,h}$, in Figure 4 and compare the response for firms with high and low capacity utilization at different states of material constraints, $\beta_{1,h}$ and $\beta_{3,h}$, in Figure 5. Figures E.11 to E.14 in the Appendix show the corresponding results for price changes and price decreases.

Figure 4 shows that firms that face material constraints have a higher and constant probability to increase prices in response to a monetary policy shock while the probability for unconstrained firms increases only gradually, in line with our baseline finding. Again, we do not observe substantial differences in production decisions across firm groups. These results hold irrespective of the level of capacity utilization. Constrained firms are more likely to increase prices with both high and low utilization rates. Figure 5 conveys a similar insight. Here, we do not see different firm responses with respect to price or production increases when firms have high or low capacity utilization, neither when material-constrained or not. The only substantial difference emerges in the response of production

[21]This sample includes the Covid-crisis, but ends before the German gas-crisis induced by the Russian invasion to Ukraine.

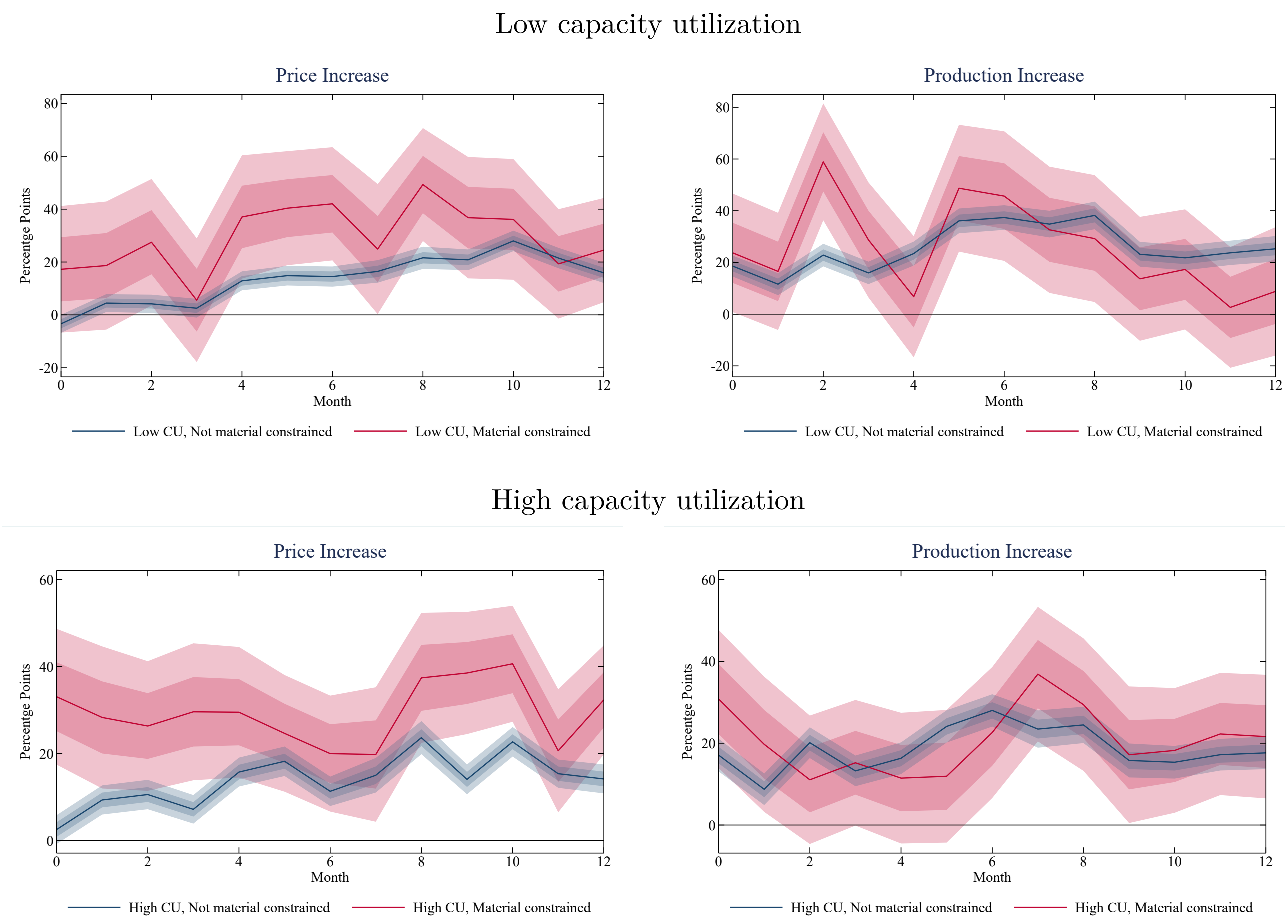

FIGURE 4: Price and production increases conditional on material constraints for high and low capacity utilization

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for material-constrained (red) and not material-constrained (blue) firms within the groups of firms operating at low (top row) and high (bottom row) capacity utilization. Estimation is based on Equation (4). Dependent variable is a dummy indicating price increases (left column) and production increases (right column). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

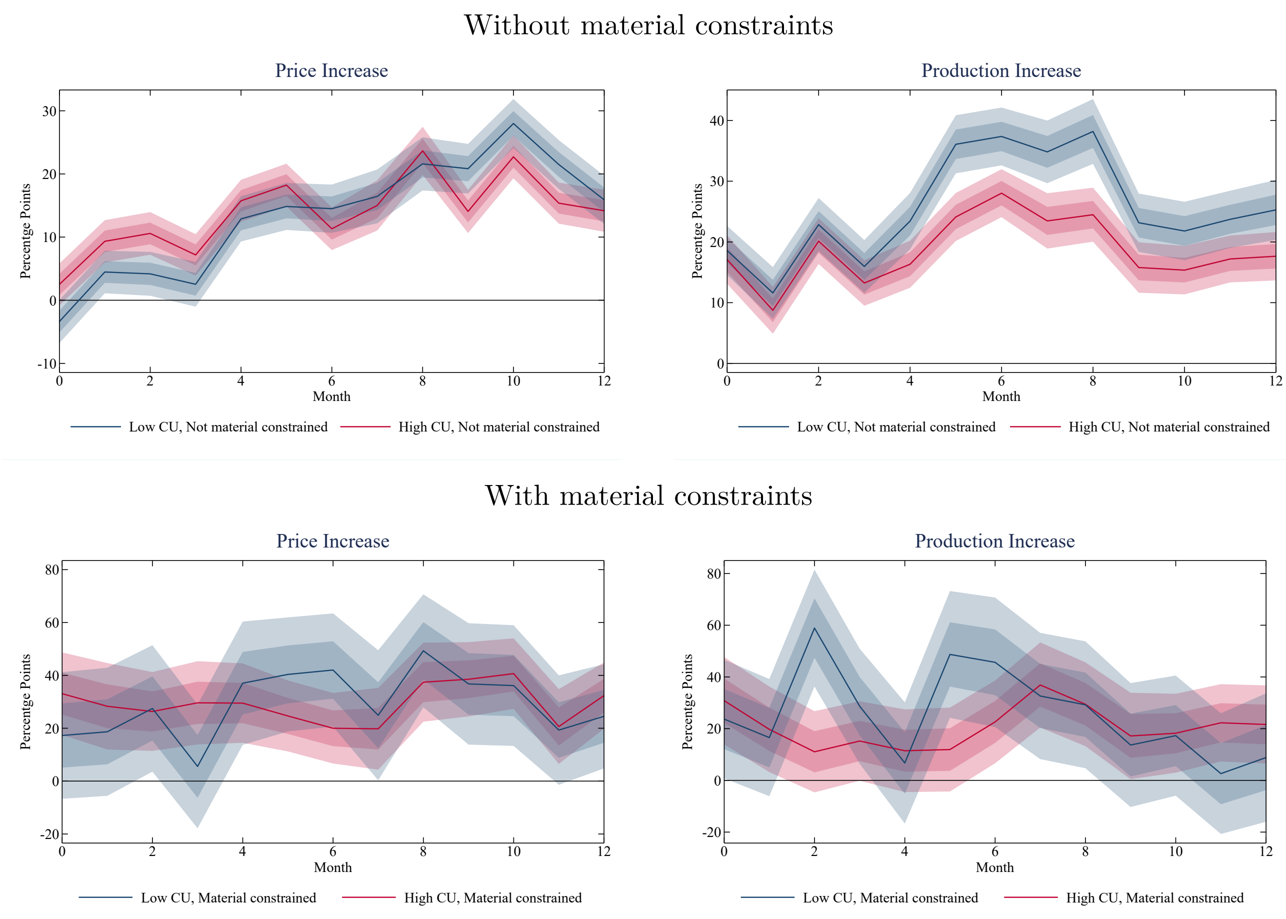

FIGURE 5: Price and production increases conditional on capacity utilization with and without material constraint

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for firms operating at high (red) and not low (blue) capacity utilization within the groups of material constrained firms (bottom row) and not material constrained firms (top row). Estimation is based on Equation (4). Dependent variable is a dummy indicating price increases (left column) and production increases (right column). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

increases after about four month: Low capacity utilization firms increase their production more than high capacity utilization firms when not material-constrained.

Our results underpin the importance of upstream rather than downstream pressure for the propagation of monetary policy. They show that, conditional on monetary policy shocks, capacity utilization is not a sufficient statistic to detect the curvature of the supply curve (as Boehm and Pandalai-Nayar (2022) argue). Our results also imply that monetary policy makers should be cautious in interpreting low utilization rates as idle resources: We show that expansionary monetary policy shocks can lead to higher price reactions of firms even if utilization rates are low.

4.2.4 Heterogeneity in the conditional responses

Having established that material constraints are the crucial supply constraints to understand the propagation of monetary policy, we further investigate the role of heterogeneity across industries behind our result by estimating equation (3) separately for each industry. Here, we restrict ourselves to industries with at least twenty firms on average over our sample period.[22] The resulting IRFs are shown in Figure E.15 in the Appendix. The industry-specific responses show that the number of price increases rises after an expansionary monetary policy shock and remains high in the subsequent months in most industries. In some industries, close to all constrained firms adjust their prices in response to the monetary policy shock ("Food", "Rubber and plastic" and "Non-metallic minerals"). Only in two industries, price increases drop initially and increase only subsequently ("Wearing apparel" and "Electrical equipment"). As is visible across responses, constrained firms increase prices substantially more often than unconstrained firms throughout, even though, due to the lack of statistical power, the difference is mostly insignificant. Statistical differences can be observed in the medium run in "Wearing apparel" or "Chemicals", for example. In only one industry, a substantial reaction to the monetary shock is not virtually different between constrained and unconstrained firms ("Paper").

La'O and Tahbaz-Salehi (2022) emphasize the importance of different industry characteristics when it comes to conduct optimal monetary policy in a model with production networks. Specifically, they argue that monetary policy should focus on sectors with stickier prices, that are more upstream, and that rely on less sticky upstream suppliers. We provide corresponding empirical results. Figure 6 provides scatter-plots of the impact response of constrained firms for each industry on the vertical axis and industry-characteristics on the horizontal axis. To this end, we use the average year-on-year producer-price inflation rate for each industry over our sample period which we calculate from data available at DESTATIS. We further use the ifo data to calculate the average fraction of price-changes over our sample period. The top-row of Figure 6 shows a positive relationship between the impact responses of constrained firms and both average PPI-inflation (left panel) and average frequency of price changes (right panel) in the corresponding industry.[23] Constrained firms in sectors with more

[22]This restriction leaves us with twenty industries, dropping the industries "Tobacco", "Coke", "Transport equipment", and "Repair".

[23]The average negative inflation rate is observed for the sector "Manufacture of computer, electronic and optical products".

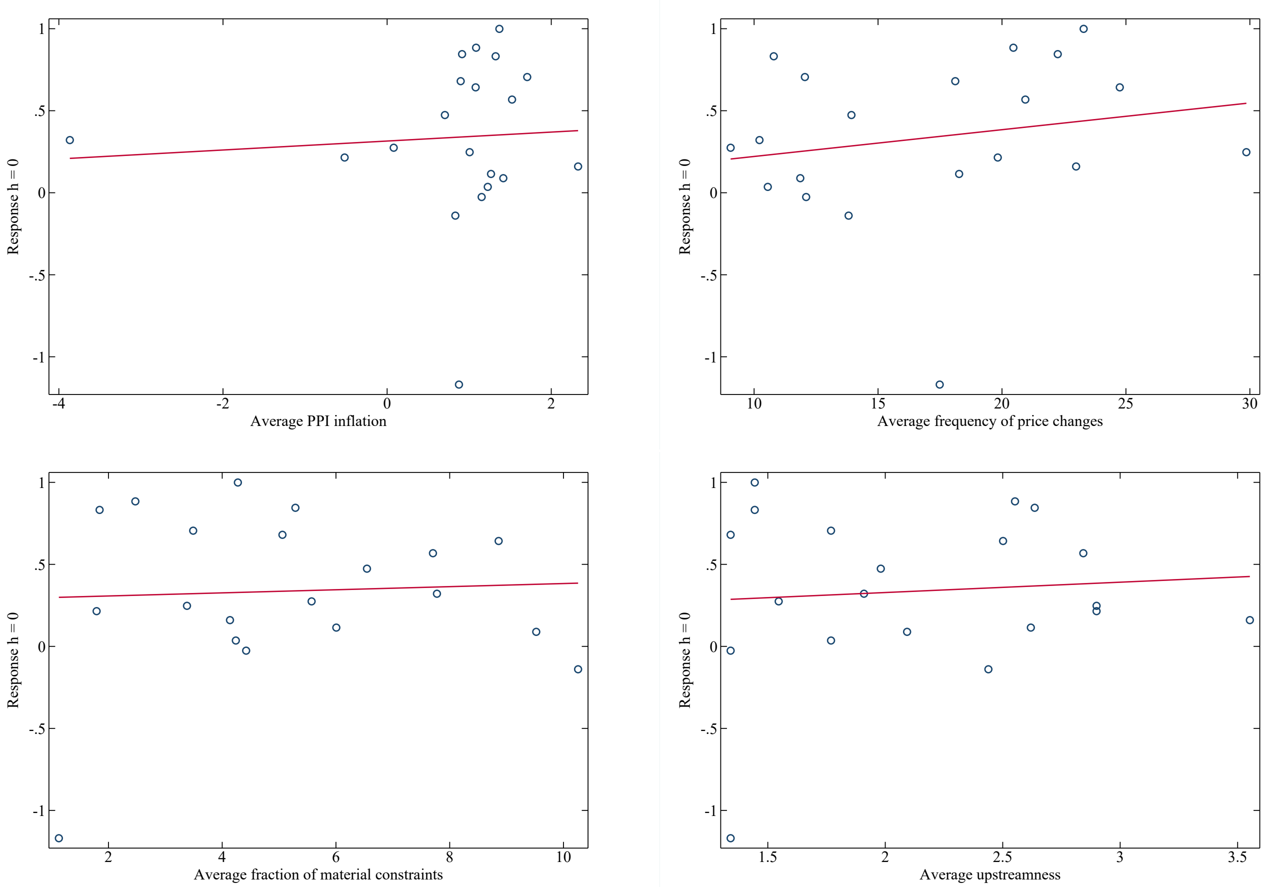

FIGURE 6: Impact responses and industry characteristics

Notes: Sample period 1999 to 2019. Vertical axes plot contemporaneous responses of material-constrained firms to a one-standard deviation monetary policy shock based on estimating Equation (3) separately for each two-digit industry for which we observe at least twenty firms on average over our sample period. Dependent variable is a dummy indicating price increases. The horizontal axes plot averages of industry characteristics for each two-digit industry over the sample period. These averages are calculated using the following data. "Average PPI Inflation": month-to-month PPI inflation rate provided by DESTATIS; "Average frequency of price changes": monthly share of firms stating that they changed their price in the ifo data; "Average fraction of material constraints": quarterly share of firms that report material constraints in the ifo data; "Average upstreamness": yearly measure of upstreamness based on OECD input-output tables following Antràs *et al.* (2012). Details for the ifo data can be found in Section 2, details for the other data are provided in Appendix A.

flexible prices therefore react stronger to a monetary policy shock than firms in sectors with stickier prices.

The bottom row of Figure 6 further shows a mild positive correspondence between the impact response to an expansionary monetary policy shock and the average share of material-constrained firms in an industry from the ifo data. Hence, price adjustments are more frequent in industries with more material constraints. We also use input-output tables provided by the OECD to construct a measure of average upstreamness of an industry following Antràs *et al.* (2012). The measure reflects the distance to final consumption or investment, i.e. the smallest possible value of one means that all output of that industry is sold to final consumption.[24] The least upstream industries in our sample are "Textiles, leathers, and footwear" followed by "Food". The most upstream industry is "Basic metals". The scatter plot shows no strong relationship between the impact response and upstreamness. If at all, the link is positive, i.e., the further away from the final customer, the larger is the response of constrained firms to a monetary policy shock in a particular industry.

5 Conclusion

We present new evidence on supply constraints at the firm-level from German survey data. We distinguish between two types of supply constraints: Capacity constraints and an unavailability of material inputs. We provide evidence that low utilization rates are not necessarily a sign of idle resources that leave room for demand stimulus. In fact, low utilization rates can reflect restricted availability of materials and, hence, severe supply constraints. We show that firms facing upstream pressure in form of material constraints increase prices substantially more often in response to an expansionary monetary policy shock and significantly more so than firms not facing comparable constraints. The price response of material-constrained firms is also stronger than that of firms facing downstream pressure in form of capacity constraints. In general, the idea that macroeconomic policy can stimulate output without inducing inflation in periods of slack is intriguing and goes back to at least Keynes (1936). We do not reject this view, but we ask for caution when measuring slack in the economy. At the firm-level capacity utilization is not indicative of material constraints. If monetary policy makers generally interpret low capacity utilization rates as idle resources, this may lead to wrong policy conclusions.

In a back-of-the-envelope calculation, we can assess the importance of our results for aggregate inflation. As shown in Jarocinski and Karadi (2020), a one-standard-deviation expansionary monetary policy shock corresponds to a one basis point increase in the German one-year government bond yield as a proxy for the safe interest rate. For this shock, we compare the response of constrained and unconstrained firms at $h = 1$ from Figure 3. This is the first horizon for which we estimate a significant positive probability for unconstrained firms to raise prices. The probability to decrease prices is insignificant for both types of firms. The estimated probability to increase prices is 24.61 percent for constrained firms and 7.38 percent for unconstrained firms. Weighing the respective responses with their respective average share in our baseline sample (5.15 percent of material-constrained firms) yields

[24]We describe the measure in detail in Appendix A.

an overall increase in the number of price increases by 8.24 percent. We do not observe the intensive margin of price changes. However, according to the Meta survey by Freuding and Seitz (2022) firms report price changes if they increase or decrease their prices by at least five percent. If firms changed their prices by five percent up- and downwards, this implies a change in inflation of 0.412 percent in response to a monetary policy shock. This is admittedly small due to the small number of material-constrained firms in our sample. By the beginning of 2021, the share of material-constrained firms rose to up to 65 percent. The same calculation implies that the number of price increases now rises to 18.58 percent and inflation now responds by about 1 percent to an expansionary monetary policy shock. This change in inflation keeps the number of price adjustments of constrained and unconstrained firms constant and uses a lower bound of the intensive margin. It can therefore be considered as a lower bound of the contribution of material-constrained firms to inflation. Comparing this figure to an average month-to-month PPI inflation rate of 1.9 percent between January 2021 and June 2022, the contribution of material-constrained firms to this inflation is substantial.

Our results offer a new view on the propagation of monetary policy in production networks. Complementary to the existing literature that highlights the role of nominal rigidities for the propagation of monetary policy to output, our results show that output restrictions might change nominal rigidities in these networks altogether. This means that monetary policy is less effects in the presence of supply constraints. Our empirical setting does not allow us to answer the question of how monetary policy should act optimally in the presence of supply constraints. But we can interpret our results in light of recent contributions that argue that optimal monetary policy response to an adverse supply shock should be less contractionary than previously thought or should even be expansionary (e.g. Caballero and Simsek (2023) or Fornaro and Wolf (2023)). These contributions trade off the costs of loose monetary policy, i.e., the cost of "running the economy hot" against scarring effects of contractionary monetary policy. Not to raise rates may be beneficial when production is constrained only temporarily. Our results provide both an estimate of the persistence of supply constraints and an estimate of the inflationary pressure in times of loose monetary policy.

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Appendix

A Data

In this section we describe the data for our analysis. We start with our main variables from the ifo survey and describe other data in separate subsections. Summary statistics for all variables are presented in Table A.1.

A.1 Main variables

Production limitations Every quarter the ifo asks a question on production constraints that reads

"*Our production is currently constrained*

1. *yes*
2. *no*"

If firms answer "yes" to this question they are further asked for the reason why their production is constrained. This follow-up question reads

"*If yes, by which of the following factors?*

1. *insufficient demand*
2. *lack of raw materials or pre-materials*
3. *insufficient technical capacity*
4. *lack of skilled employees*
5. *difficulties of financing*
6. *other*"

For brevity we have merged these two questions in the main-text. The question is consistently asked in the same month of the quarter (January, April, July, October) since 1980, the option "difficulties of financing" was introduced in 2002. The wording of the option "lack of skilled employees" has changed over time. From 1980 to 1995 the questions contained an option on "lack of manpower", which changed to "lack of qualified manpower" from 1996 to 2001. From 1991 to 1995 there was the additional option to state a "lack of skilled employees", which was then added to the survey permanently from 2002 onward. We combine these options to get a consistent measure on the shortage of skilled labor over time. Specifically, from 1991 to 1995 we use the option "lack of skilled employees", from 1996 to 2001 we use the option "lack of qualified manpower", and from 2002 onward we again use the option "lack of skilled employees". In doing so, we assume that, from a firm's perspective, the phrases "qualified manpower" and "skilled employees" refer to the same group of workers. The ifo follows the same procedure when publishing their survey results within the "Joint harmonised EU programme of business and consumer surveys" commissioned by the Directorate General for Economic and Financial Affairs of the European Commission.

Capacity Utilization In the ifo survey firms are asked to indicate their current level of capacity utilization in a box with the given options 30, 40, 50, 60, 70, 75, 80, 85, 90, 95, 100, and more than 100 in which case firms can type a concrete number. We round these concrete numbers in steps of five. We always round up since, for example, firms that type a value of 101 have explicitly chosen to indicate a utilization rate above 100. Moreover, we winsorize these numbers at 200. A few firms use the option to type a concrete number to indicate utilization rates outside the bins or below 30. We keep these numbers unchanged.

The timing of the question changed within our sample. The question is asked at quarterly frequency. Until 2001 the question was asked at the end of the last month in the quarter, i.e. in March, June, September, and December. From 2002 onward, the question has been asked at the beginning of the first month of the quarter, i.e. in January, April, July, and October. To have the same timing over time we treat the question before 2002 as being asked at the beginning of the next quarter. To be precise, the March value is treated as the value for the second quarter of the year, the June value as the value for the third quarter of the year, and so on. In this way the utilization rates can also be directly mapped to the question on production limitations, which is always asked in January, April, July, and October. More details about the interpretation of capacity utilization can be found in Appendix C.

Excess demand Every month, firms are also asked about the state of their order books which can be related to demand for their products. The question reads

"*We consider our order backlog (provided that it is customary) to be*"

for which the answer categories are "relatively high", "sufficient", and "too small". We define a firm as facing excess demand if it answers "relatively high" to this question. That is for each firm we create a dummy variable, which equals one if a firm answers "relatively high" and zero if the firm answers "sufficient" or "relatively small". In contrast to the questions on capacity utilization and production limitations the question is asked monthly. To ease comparison with these questions we focus on the responses in January, April, July, and October, i.e. we keep the same timing as for the production questions. Note that the above mentioned question on production constraints also contains an answer related to "insufficient demand" (category 1). Since we cannot relate this information to other situations of demand (in particular, we cannot assume that excess demand is the opposite of insufficient demand) the question about orders provides more useful information in this respect. Figure A.1 compares the cyclical dynamics of the fraction of firms reporting excess demand and the log of an index of new orders in the manufacturing sector as published by the German Federal Statistical Office (DESTATIS). The correlation between the two series is very high with a value of about 0.87.

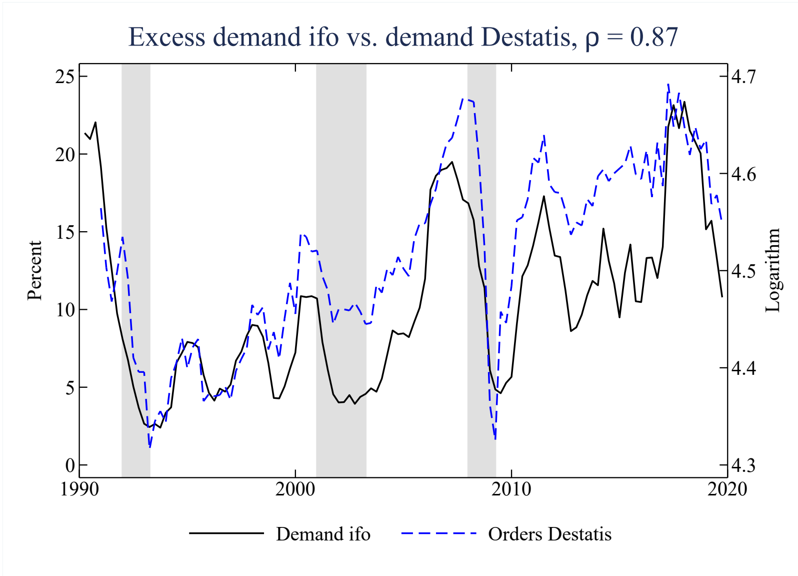

Figure A.1: Demand (orders) ifo vs. Orders Destatis

Notes: Sample period 1990 to 2019. ρ is the correlation coefficient between the two series. Demand ifo (black solid line, left axis) is defined as the fraction of firms reporting that their current order backlog is relatively high. Orders Destatis (blue dashed line, right axis) is the logarithm of a demand index for the manufacturing sector provided by the Federal Statistical Office of Germany. Details are provided in Appendix A. Grey shaded areas correspond to recessionary periods 1992Q1-1993Q2, 2001Q1-2003Q2, and 2008Q1-2009Q2 as indicated by the German Council of Economic Experts (see Breuer *et al.*, 2022).

Price and Production Since 1980 the ifo questionnaire contains a monthly question on a firm's pricing decision. The question reads

"*Compared to previous month our domestic sales prices (net-prices) for XY were*

1. *Increased*
2. *Not changed*
3. *Decreased*"

We create different dummy-variables for price increases (answer category 1), price decreases (answer category 3), and price changes (answer category 1 or answer category 3).

A comparable question is asked with respect to a firm's production. The corresponding question reads

"*Compared to previous month the activity of our domestic production of XY was*

1. *More*
2. *Not changed*
3. *Less*
4. *No production*"

Again, we create different dummy-variables for production increases (answer category 1), production decreases (answer category 3), and production changes (answer category 1 or answer category 3).

The Meta-survey by Freuding and Seitz (2022) contained a question on the threshold after which firms report an increase or decrease in prices and production. Specifically the question reads "How large would an average price or production change have to be for you to report increased or decreased prices or production?". Answers are summarized in Table A.2.

A.2 Additional variables: ifo survey

For some additional results and to construct control variables we make use of additional questions from the ifo survey.

Business situation and business outlook As control variables we include a firm's assessments of its current business situation and its future business outlook over the next 6 months. Both questions have three different response categories. The current business situation and the business outlook can be assessed as being good, satisfactory, or unsatisfactory. To account for possible asymmetric effects we follow the literature using the ifo data, e.g. Bachmann *et al.* (2019), and include separate dummies for the answer categories good and unsatisfactory. These questions have been asked consistently since 1980 at a monthly frequency.

Short-time work and Overtime As control variables we include variables on both short-time work and overtime. With respect to short-time work, firms are simply asked to answer "yes" or "no" to the statement "We currently have short-time work". With respect to overtime, firms are asked two questions. First they, again, simply asked to answer "yes" or "no" to the statement "We currently work with overtime". If they answer "yes" to this questions, they can indicate whether their current implementation of overtime is "more than customary". We include dummy variables for all three questions. The questions are asked quarterly. From 1980 to 2001 they were asked in January, April, July, and October. Since 2002 they have been asked in March, June, September, and December. Here, as described above for the data on capacity utilization, we write these responses in the next month to get a consistent timing. These questions are answered by far fewer firms, so that our sample size decreases when we include these variables.

Planned price and production For some robustness analysis we utilize the ifo questions on planned price and production changes. The questions are comparable to the questions on actual price and production changes described above. Specifically, the question for planned price changes reads "Expectations for the next 3 months: Our net domestic sales prices for XY will ..." with answer options "Increase", "Not Change", and "Decrease". For production the question reads "Expectations for the next 3 months: Our domestic production activity with respect to product XY will probably ..." with the same answer categories. We proceed as in the case for actual price and production changes and create different dummy-variables for price and production increases, decreases, and changes.

Assessment of capacity For some further analysis on the difference between material and capacity constraints we make use of a question that asks firms about their assessment of their current capacity. Every quarter firms are asked "Taking into account our current order backlog and the new orders we expect for the next 12 months, we expect our technical capacities to be ... ". Answer options are "More than sufficient", "Sufficient", or "Not Sufficient".

Firm size For some robustness analysis we define firms as large and small. To this end we use the question "In the whole company (domestic companies only) we occupy . . . persons." where firms type in a concrete number. The question is asked each year in November. We define a firm as large if it employs at least 450 employees, which is the 75th percentile of the firm employee distribution.

A.3 Additional variables: other sources

For further analysis we make use of several other data sources that we describe here.

Business climate manufacturing Every month the ifo publishes the ifo Business Climate Index, a much-followed leading indicator for the German economy, Lehmann (2023) for a recent survey on the forecasting power of the ifo business survey. The index is available for the aggregate economy, and separately for the manufacturing sector, services, retail, and the construction sector. We use the index for the manufacturing sector. The data can be downloaded here.

Industrial production index The index for industrial production is provided by the German federal statistical office (DESTATIS). We use the seasonal- and calendar-adjusted monthly series, which can be downloaded here.

Producer price index Producer price indices are also provided by DESTATIS. We use both the monthly aggregate data for the manufacturing sector and monthly data at the two-digit product level according to the GP2009 classification which can directly be mapped to the WZ08 industry-classification. The data can be downloaded here and here.

Input-Prices As mentioned in the main text we construct a measure for input-prices at the two-digit industry level following related studies that utilize the ifo data to study firm's pricing decisions, see Schenkelberg (2013), Bachmann *et al.* (2019) and Dixon and Grimme (2022). To calculate this measure we use input-output-tables for Germany provided by the OECD, available here, and producer price indices (PPI) provided by DESTATIS as described above. We calculate the average input linkages over the years 1995 to 2018 and focus on the manufacturing sector. For each industry in our sample we then multiply these average input linkages with the PPIs of the input industries. In this way we get a time-series for input-prices for each industry in our sample. Note that the OECD combines some industries for the input-output tables. Therefore, the industries 10, 11, and 12 have the same input-prices, as well as the industries 13, 14, and 15, the industries 17 and 18, and the industries 31, 32, and 33.

New orders We use a volume index of incoming new orders provided by DESTATIS which can be downloaded here. The monthly index is seasonal and calendar adjusted. The underlying data for this index come from plants with more than 50 employees in specific two-digit industries of the manufacturing sector (13, 14, 17, 20, 21, 24 to 30).

GSCPI We compare our direct measure of material constraints to the Global Supply Chain Pressure Index (GSCPI) provided by the Federal Reserve Bank of New York (Benigno, di Giovanni, Groen and Noble, 2022). The index is the principal component out of 27 individual series for the euro area, China, Japan, South Korea, Taiwan, the UK, and the US, that are supposed to measure different forms of supply restrictions. These series include the backlog of orders, delivery time, purchased stocks, global shipping rates, and price indices for airfreight costs. The series is available here. We use the first month of a given quarter to compare the series to our quarterly material constraint series. Moreover, we calculate a three-month backward moving average of the index to reduce the noise.

Upstreamness We build a measure of an industry's upstreamness following Antràs *et al.* (2012). We calculate this measure for each two-digit industry in our sample using the input-output tables for Germany provided by the OECD. Again due to the combination of several industries in the OECD data, the industries 10, 11, and 12 have the same upstreamness, as well as the industries 13, 14, and 15, the industries 17 and 18, and the industries 31, 32, and 33.

Monetary policy shock We use a series of identified Euro area monetary policy shocks due to Jarocinski and Karadi (2020). 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. 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, Jarocinski and Karadi (2020) 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. Jarocinski and Karadi (2020) separate these components based on co-movement restrictions in a sign-identified 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 focus on pure monetary policy shocks in our analysis. The updated shock series can be downloaded here.

Table A.1: Summary statistics baseline sample

	Mean	Std. Dev.	N
Price Variables			
Price Change	0.17	0.38	1054829
Price Increase	0.090	0.29	1054829
Price Decrease	0.084	0.28	1054829
Exp. Price Change	0.22	0.42	1102179
Exp. Price Increase	0.15	0.35	1102179
Exp. Price Decrease	0.074	0.26	1102179
Production Variables			
Production Change	0.34	0.47	1056329
Production Increase	0.15	0.35	1056329
Production Decrease	0.19	0.39	1056329
Exp. Production Change	0.30	0.46	1104177
Exp. Production Increase	0.15	0.36	1104177
Exp. Production Decrease	0.15	0.35	1104177
Production Constraints			
Capacity Utilization	81.3	16.4	308751
Material constraint	0.042	0.20	376777
Labor constraint	0.061	0.24	360649
Financial constraint	0.046	0.21	192682
Excess Demand	0.11	0.32	1098284
Control Variables			
Short Time Work	0.15	0.36	196026
Working Overtime	0.44	0.50	241840
Business Expectations +	0.18	0.38	1100176
Business Expectations -	0.19	0.39	1100176
Business Situation +	0.23	0.42	1102739
Business Situation -	0.24	0.43	1102739
Employment	1828.2	14006.2	1074073
Aggregate Variables			
GSCPI Moving Average	-0.29	0.42	88
Log Domestic Orders	4.51	0.094	116
ifo Business Climate Index, Manuf.	4.80	16.2	116
Log Industrial Production Index	451.3	10.7	252
Log Producer Price Index	453.6	9.89	252
Monetary Policy Shock	-0.0036	0.031	252
Industry Variables			
Input Costs	31.1	9.41	7200
Upstreamness	2.09	0.61	480

Notes: Sample period: 1990 to 2019 for most variables. The industrial production series, the producer price index, and the monetary policy shock are used from 1999 onward. Summary statistics for all variables used in our empirical analysis.

Table A.2: Answers Meta-survey on price and production changes

	Observations	Mean	10^{th} Pctl.	25^{th} Pctl.	50^{th} Pctl.	75^{th} Pctl.	90^{th} Pctl.
Prices	1107	5	1	2	3	5	10
Production	1097	7.5	2	5	5	10	15

Notes: Sample period: 2019. Summary statistics of answers to the question on the threshold after which firms report an increase or decrease in prices and production. Answers are in percent. Table is taken from the Meta-report by Freuding and Seitz (2022).

B Material constraints and supply-chain disruptions

Material constraints are related to supply chain disruptions. Figure B.1 plots the fraction of firms that report material constraints together with the Global Supply Chain Pressure Index (GSCPI) provided by the Federal Reserve Bank of New York, an index introduced in light of the Covid-19 pandemic to capture global supply chain problems in a comprehensive manner (Benigno *et al.*, 2022). For the overlapping period from 1998 to 2019 the two series show comparable cyclical dynamics, reflected in a correlation of 0.68.

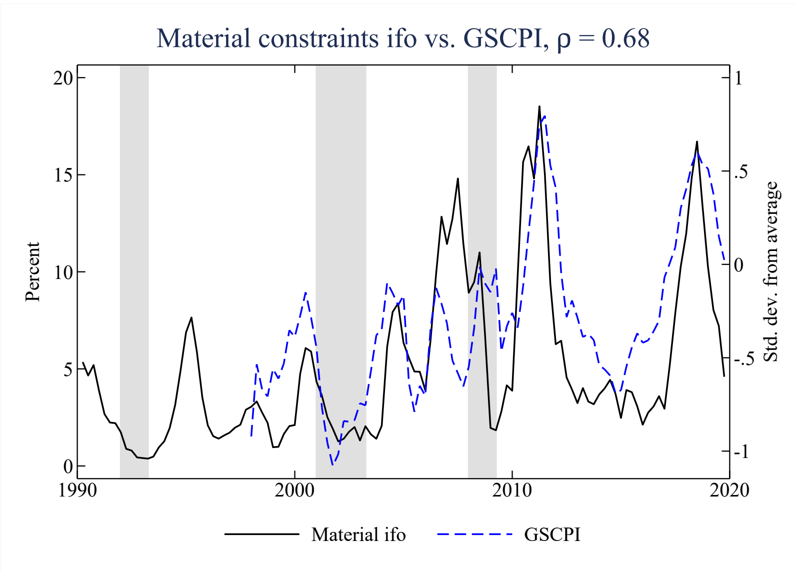

Figure B.1: Material constraints vs. GSCPI

Notes: Sample period 1990 to 2019. ρ is the correlation coefficient between the two series. Material ifo (black solid line, left axis) is the fraction of firms reporting material constraints. GSCPI (blue dashed line, right axis) is the Global Supply Chain Pressure Index provided by Benigno *et al.* (2022). Grey shaded areas correspond to recessionary periods 1992Q1-1993Q2, 2001Q1-2003Q2, and 2008Q1-2009Q2 as indicated by the German Council of Economic Experts (see Breuer *et al.*, 2022).

The highest peak in the series for material constraints during our sample coincides with the Tohoku earthquake in Japan in March 2011. The Japan crisis influenced global supply-chains, see, e.g., Boehm, Flaaen and Pandalai-Nayar (2019). In May 2011, the ifo asked firms "Are you currently directly or indirectly affected via other pre-suppliers by supply shortage resulting from the Japan crisis and/or will you be affected during the next 3 months?". We calculate the fraction of firms answering "yes" to this question in each two-digit industry and relate it to the fraction of firms reporting material constraints in April and July. A higher fraction of firms stating that they are affected by the Tohoku earthquake is associated with a higher fraction of firms reporting material constraints, see Figure B.2 for a scatter plot.

We further regress the series for each industry on the GSCPI (see Table B.1). Industries that exhibit the highest estimated coefficients are "Machinery and equipment", "Electrical Equipment", "Computer and electronic", and "Chemicals" which all heavily rely on intermediate products from abroad. For

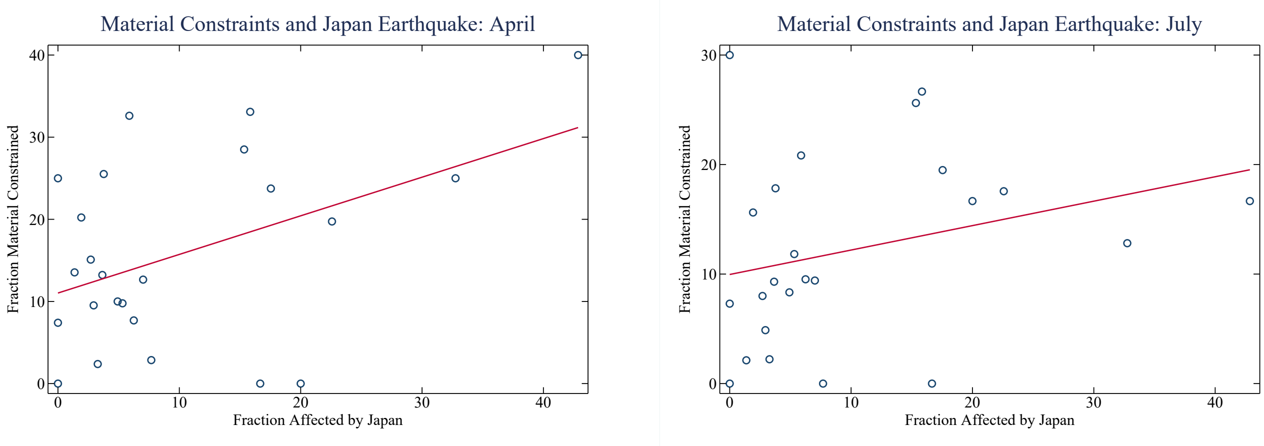

FIGURE B.2: Material constraints and Japan earthquake

Notes: Sample period: April, May, and July 2011. The x-axes plot the fraction of firms within two-digit industries that answered "yes" to a special question in May 2011 that reads "Are you currently directly or indirectly affected via other pre-suppliers by supply shortage resulting from the Japan crisis and/or will you be affected during the next 3 months?". Details are provided in Appendix A. The y-axes plot the fraction of firms reporting material constraints within two-digit industries in April 2011 (left panel) and July 2011 (right panel).

"Food", "Wearing apparel", and "Leather" we observe the lowest and even insignificant coefficients, in turn.

We also regress the fraction of firms reporting material constraints within two-digit industries on average capacity utilization and average share of material constraints of their input industries. To calculate the latter we use average input-output linkages over the years 1995 to 2018 for two-digit industries within the German manufacturing sector based on data provided by the OECD. Table B.2 shows the results. For all specifications we consider, material constraints in an industry are related positively to material constraints in input-industries. Higher capacity utilization in input industries is, if anything, negatively related to material constraints. These results hold true even if we control for input-prices. We draw two conclusions from this exercise. First, we view this as additional evidence that material constraints (mostly) relate to supply-chain disruptions. Second, and more importantly, material constraints measure quantity constraints and not just an increase in input-prices.

Table B.1: Industry-level material constraints and supply-chain pressure

	Estimated coeff. β_1
Industry 10: Food	1.016
Industry 11: Beverages	2.312^{**}
Industry 12: Tobacco	6.032^{*}
Industry 13: Textiles	5.098
Industry 14: Wearing apparel	1.075
Industry 15: Leather	0.756
Industry 16: Wood	5.778^{***}
Industry 17: Paper	4.781^{***}
Industry 18: Printing	1.936^{**}
Industry 19: Coke	4.748
Industry 20: Chemicals	11.79^{***}
Industry 21: Pharmaceutics	4.604^{**}
Industry 22: Rubber and plastic	8.382^{***}
Industry 23: Non-metallic minerals	4.372^{***}
Industry 24: Basic metals	3.572^{***}
Industry 25: Fabricated metal products	5.257^{***}
Industry 26: Computer and electronic	10.51^{***}
Industry 27: Electrical equipment	13.53^{***}
Industry 28: Machinery and equipment	11.10^{***}
Industry 29: Motor vehicles	8.355^{***}
Industry 30: Other transport	5.686
Industry 31: Furniture	2.082^{*}
Industry 32: Other	3.573^{***}
Industry 33: Repair	19.44^{***}

Notes: Separate industry-level regressions of $Y_t = \beta_0 + \beta_1 X_t + u_t$, where Y_t denotes industry-level material constraints and X_t denotes the Global Supply Chain Pressure Index (GSCPI) provided by Benigno *et al.* (2022). Standard errors are Newey-West with one lag. Due to gaps in the time series for industries 12, 21, and 33 we just control for heteroskedasticity in these cases. Stars indicate significance at the 10 percent (*), 5 percent (**), and 1 percent (***) level, respectively.

Table B.2: Linking material constraints to input industries

	Material Constraint, Share				
	(1)	(2)	(3)	(4)	(5)
Material Input	2.967***	2.895***	2.915***	2.963***	3.014***
	(0.228)	(0.238)	(0.235)	(0.246)	(0.258)
CU Input	-0.115***	-0.0992	-0.517***	-0.566**	
	(0.0267)	(0.107)	(0.183)	(0.216)	
CU Own			0.144***	0.137**	
			(0.0510)	(0.0532)	
Input Costs				-0.0852	-0.0928
				(0.0855)	(0.0774)
CU+ Input					-0.267***
					(0.0901)
CU+ Own					0.0674***
					(0.0181)
Seasonal FE	No	Yes	Yes	Yes	Yes
Industry FE	No	Yes	Yes	Yes	Yes
Observations	2792	2792	2792	2336	2336

Notes: Industry-level regressions at two-digit industry-level. Input refers to supplier industries, own refers to the same industry. CU+ refers to industries reporting capacity utilization above their long-run mean. Input industries are computed from input-output-tables for Germany provided by the OECD. Average input-output linkages are calculated over the years 1995 to 2018. Measures of material constraints and capacity utilization for input industries then reflect weighted averages for which the weights are given by the average input-output linkages. Input costs are described in Appendix A.3. Standard errors in parentheses are clustered at the industry-level. Stars indicate significance at the 10 percent (*), 5 percent (**), and 1 percent (***) level, respectively.

C Details on capacity utilization

C.1 ifo Meta survey

The ifo ran a Meta-Survey in January 2019 (Freuding and Seitz, 2022), which contained some questions specifically related to the question of capacity utilization described above which we can use to check internal consistency.[25] We make use of the question

"*The utilization of our facilities (in the event of a normal economic situation without congestion or under-utilization) is on annual average up to ...*"

which firms had to answer by entering a concrete number to check if firms assess their capacity utilization consistently. Specifically, for the firms that answered this question, we calculate their average capacity utilization based on their answers to the quarterly capacity utilization measure and subtract it from their stated average in the Meta-Survey. Figure C.1 compares the results. The left histogram shows the distribution of the difference between the self-reported mean and the calculated mean. The distribution is centered around zero, i.e. most firms can assess their average capacity utilization adequately. The right panel compares the histograms of the self-reported average (in blue) and the calculated average (in red). While the distributions have some overlap, for the self-reported average more probability mass lies on larger values. In general, firms appear to have a consistent view on their reported capacity utilization rates, which lends additional credibility to the survey data.

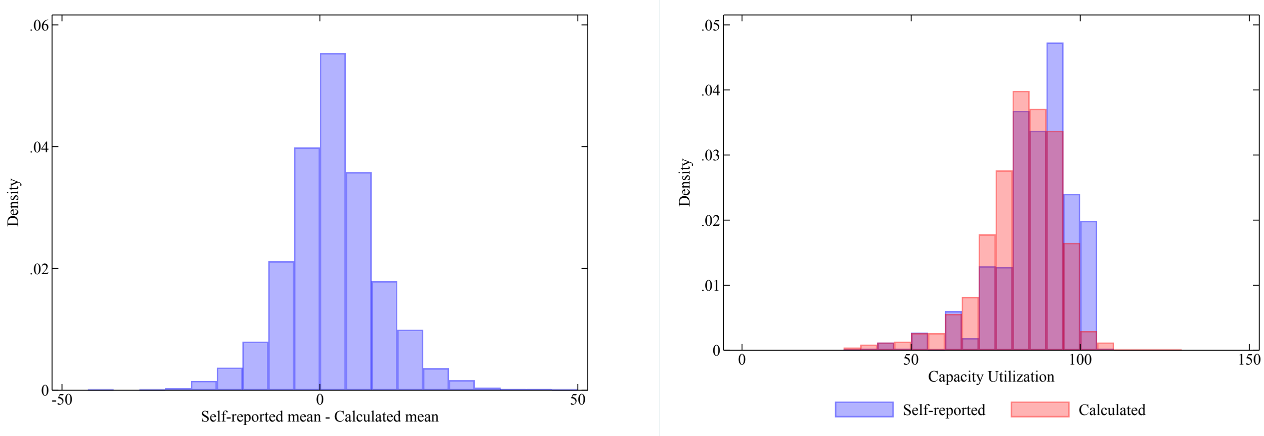

FIGURE C.1: Calculated mean vs self-reported mean in capacity utilization

Notes: Sample period: 1990 to 2019. Left panel plots the histogram of the difference between a firm's average capacity utilization as stated in the Meta-survey by Freuding and Seitz (2022)(labeled as "self-reported mean") and the average capacity utilization calculated based on the regular quarterly survey question (labeled as "calculated mean"). Right panel plots the histograms of the two means separately.

One open question is what firms have in mind when answering the question on capacity utilization. Against this background, the Meta-Survey included the following question:

[25]The results of the Meta-Survey are published in an ifo-internal report which is not publicly available (Freuding and Seitz, 2022). We thank Timo Wollmershäuser and Julia Freuding for providing access to this report.

"Which factors do you have in mind when answering the question on capacity utilization (0 = not relevant, 6 = highly relevant)?

1. *Frequency of maintenance*
2. *Increase or decrease number of workers*
3. *Increase or decrease working time accounts*
4. *Investment in new machinery*
5. *Leasing of machinery*
6. *Operating time of machinery*
7. *Overtime or Short-time work*
8. *Temporary Employment*"

TABLE C.1: Answers Meta-survey on Capacity Utilization

Factor	Observations	Mean	S.D.
Operating time of machinery	1079	5.1	1.5
Overtime or Short-time work	1067	4.4	1.8
Increase or decrease working time accounts	1061	3.9	2.0
Increase or decrease number of workers	1051	3.4	1.9
Temporary Employment	1058	2.7	2.2
Investment in new machinery	1036	2.3	1.8
Frequency of maintenance	1039	2.2	1.8
Leasing of machinery	1023	1.1	1.5

Notes: Sample period: 2019. Summary statistics of answers to the question on which factors firms have in mind when answering the question on capacity utilization. For each factor firms had to state a number between 0 (= not relevant) and 6 (=highly relevant). Table is taken from the Meta-report by Freuding and Seitz (2022).

Answers to this question are summarized in Table C.1. The most important factors mentioned by firms are the operating-time of their machines and devices followed by the implementation of overtime hours and short-time work. Therefore, firms follow the engineering concept when answering this question. These answers imply also a view consistent with the definition of the US measure, which we describe in the next section.[26]

C.2 Comparison with U.S. data

The ifo series and the U.S. measure have been treated as comparable series, e.g., by Franz and Gordon (1993). Here we describe the difference between the measure of capacity utilization in the ifo data and

[26]This view is also consistent over time. In the Meta-Survey about 83 percent of firms state that the ifo questionnaire is "always filled out by the same person", about 15 percent state that it is "mostly filled out by the same person", indicating that the implicit definition is stable over time.

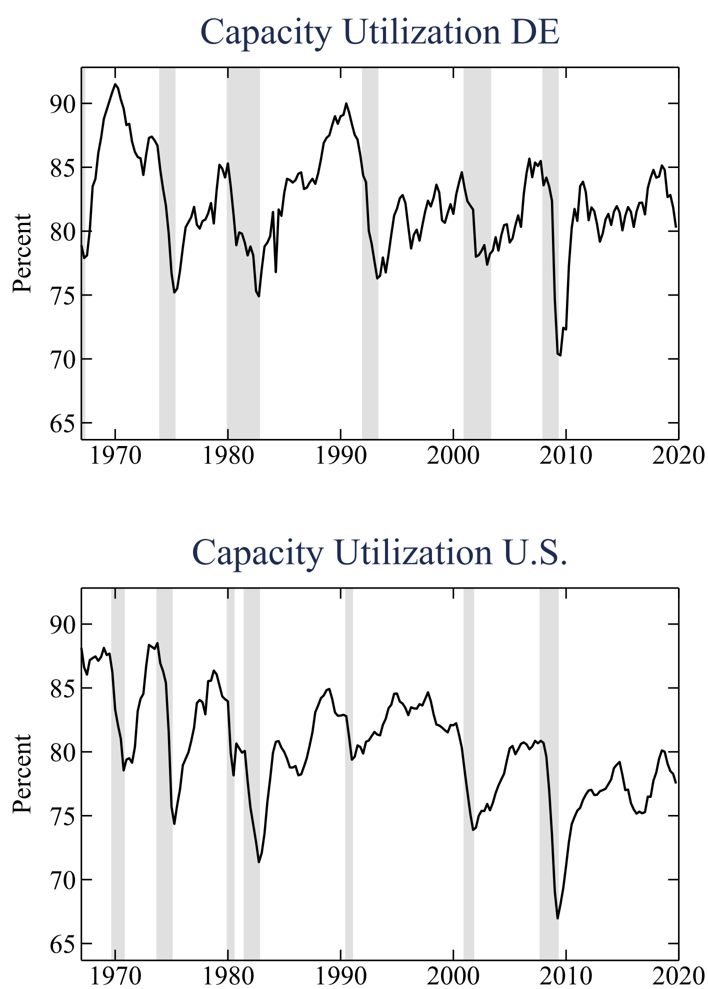

Figure C.2: Capacity utilization in ifo vs. U.S. data

Notes: Sample period: 1967 to 2019. Top panel plots the average capacity utilization across firms in the ifo survey. Data before 1990 is based on a historical series provided by the ifo at https://www.ifo.de/en/ifo-time-series. This series is based on data for West-Germany only. Grey shaded areas correspond to recessionary periods 1967Q1-1967Q2, 1974Q1-1975Q2, 1980Q1-1982Q4, 1992Q1-1993Q2, 2001Q1-2003Q2, and 2008Q1-2009Q2 as indicated by the German Council of Economic Experts (see Breuer *et al.*, 2022). Bottom panel plots the aggregate capacity utilization series for the U.S. provided by the FRB, FRED Code: TCU. We obtain the quarterly series by calculating the quarterly averages of the underlying monthly series. Grey shaded areas correspond to recessionary periods 1969Q4-1970Q4, 1973Q4-1975Q1, 1980Q1-1980Q3, 1981Q3-1982Q4, 1990Q3-1991Q1, 2001Q1-2001Q4, and 2007Q4-2009Q2 as indicated by the National Bureau of Economic Research (NBER).

its U.S. counterpart in detail. The most frequently used source for U.S. capacity utilization rates is the Federal Reserve Board (FRB).[27] As with the ifo data, the principal data source used by the FRB to construct its capacity utilization index is a firm survey, namely the Census Survey of Plant Capacity. Until 2007 the survey was run annually and is now replaced by the Quarterly Survey of Plant Capacity,

[27] See Morin and Stevens (2004) as well as `https://www.federalreserve.gov/releases/g17/About.htm` for a description of the FRB's method.

which is run at quarterly frequency.

The Census survey i) asks about capacity and the current production level separately and ii) provides respondents with an exact definition on what they should incorporate into their measurement of maximal capacity. Specifically, the Census asks firms to provide "the maximum level of production that this establishment could reasonably expect to attain under normal and realistic operating conditions fully utilizing the machinery and equipment in place". Therefore, the concept of capacity conforms to that of a full-input point on a production function (Gilbert, Morin and Raddock, 2000), or, put differently, firms in the U.S. are clearly guided to follow the engineering concept when answering the question on full capacity. The utilization rate is then calculated by the Census as the current production level divided by capacity. Material input is clearly defined not to be part of capacity in the US measure.

Table C.2: Summary statistics: Aggregate Capacity Utilization U.S. and DE

	Mean	Std. Dev.	*N*
Capacity Utilization DE	82.2	3.80	212
Capacity Utilization US	80.2	4.16	212

Notes: Sample period: 1967 to 2019. The series for Germany is the average capacity utilization across firms in the ifo survey. Data before 1990 is based on a historical series provided by the ifo at https://www.ifo.de/en/ifo-time-series. This series is based on data for West-Germany only. The series for the U.S. is the aggregate capacity utilization series provided by the FRB, FRED Code: TCU. We obtain the quarterly series by calculating the quarterly averages of the underlying monthly series.

The monthly utilization series published by the FRB is based on interpolations between the year-end estimates. As a result, within year movements in utilization are dominated by changes in industrial production, not the change in capacity (Corrado and Mattey, 1997), while the true business cycle variation of utilization is unobserved. By contrast, the ifo survey takes place at quarterly frequency, which allows to track business cycle movements properly. However, the FRB combines the survey data with several other data sources to make it consistent with alternative determinants of capacity change. This correction step is missing for the ifo data. Moreover, the Census data have the advantage that respondents are given a specific definition for capacity. However, as described above, the ifo data can be interpreted in a similar way to the U.S. data.

Overall, the concepts behind the ifo and the FRB data are broadly comparable and the resulting aggregate series share common short- and long-run characteristics. In Figure C.2 we plot the aggregate capacity utilization rate for Germany from ifo data (top panel) and the capacity utilization rate for the U.S. from the FRB data (bottom panel). For the ifo data we combine an aggregate series based on our micro data with a historical capacity utilization series published by the ifo institute.[28] For the U.S. we plot quarterly data by calculating the quarterly averages of the underlying monthly series (FRED Code: TCU). Both series decline sharply during recessions and increase slowly during booms.

[28] The time-series can be downloaded here. Note that the historic series ends in 1990 and is based on Western Germany only.

Moreover, the negative trend in capacity utilization visible in the U.S. data, which is discussed by Pierce and Wisniewski (2018), is visible in Germany, too. In addition the U.S. series appears to be somehow smoother, reflecting both the cleaning and the interpolation implemented by the FRB. Mean and standard deviation are comparable across the two series, too, see Table C.2.

C.3 Relationship between material constraints and capacity utilization

Table C.3: Capacity utilization for different groups of firms

	N	Mean	Std. Dev.	P25	P50	P75
No excess demand, no material constraint	259018	79.78	16.15	70	80	90
Excess demand, no material constraint	30650	92.74	12.98	90	95	100
Material constraint, no excess demand	9925	81.82	15.49	75	85	90
Excess demand and material constraint	4685	94.34	12.45	90	95	100
Total	304278	81.38	16.34	75	85	95

Notes: Sample period: 1990 to 2019. Capacity utilization is a firm's stated utilization rate (in percent) in a given quarter. Excess demand counts firms stating their current order book levels to be relatively high. Material constraints counts firms stating that their current production is limited by a lack of raw or pre-materials.

Section 2 discusses that material constraints may not be reflected in high capacity utilization rates, since material should be considered as a variable input that is not contained in the production capacity of firms. This is consistent with the measurement of capacity as outlined above. Material constraints therefore do not necessarily reflect capacity constraints. Capacity constraints, in turn, arise in a situation with unexpectedly high demand which cannot be met, since production inputs which define capacity are pre-determined. To address this in more detail, we define four groups of firms. Firms that report material constraints, but do not face excess demand; firms that report material constraints, but do face excess demand; firms that do not report material constraints and do not face excess demand and firms that do not report material constraints, but do face excess demand. If material constraints are indeed not part of a firm's full capacity, we expect high capacity utilization for firms facing excess demand, but not for firms facing (only) material constraints.

Table C.3 shows capacity utilization for these four groups (Figure C.3 shows the corresponding histograms). Average utilization rates for firms facing material constraints, but no excess demand are about 82 percent. Capacity utilization is higher for firms with no material constraints, but excess demand (about 93 percent), and even higher (about 94 percent) for firms facing material constraints and excess demand. This compares to an overall average capacity utilization of about 81 percent and of about 80 percent for firms that experience neither material constraints nor excess demand. Moreover, the standard deviation and percentiles indicate that for firms facing excess demand, the distribution of capacity utilization is tighter and more left-skewed than for other firms, in particular than for those that report material constraints. This is also visible in Figure C.4 which compares the histogram of capacity utilization of all firms to the histogram of firms that report material constraints, but not

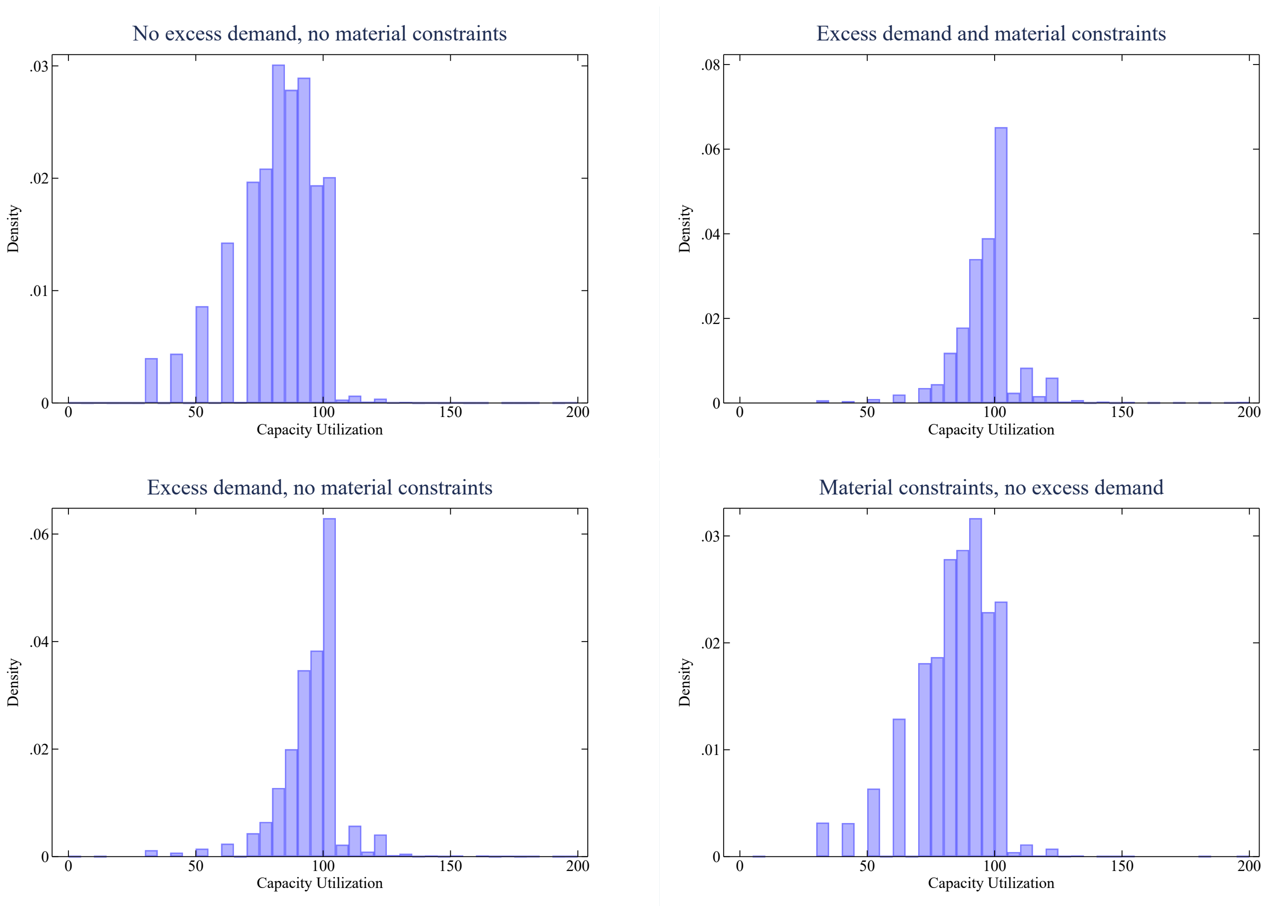

Figure C.3: Capacity utilization with and without material constraints and excess demand

Notes: Sample period: 1990 to 2019. Capacity utilization is a firm's stated utilization rate (in percent) in a given quarter. Excess demand counts firms stating their current order book levels to be relatively high. Material constraints counts firms stating that their current production is limited by a lack of raw or pre-materials.

excess demand (left panel) and to firms that report excess demand, but no material constraints (right panel). While there is no difference between the distributions in the former case, the distribution is shifted to the right in the latter case.

To address the relationship between material constraints and capacity utilization more formally, we regress capacity utilization on indicator variables of the different groups of firms. Table C.4 presents the results. Column one replicates the comparison from Table C.3 and shows that the differences in capacity utilization across firm groups are statistically significant. To control for heterogeneity between industries, aggregate developments as well as seasonal patterns, we include time-fixed effects as well as industry-fixed effects at the two-digit-level. We further add the firms' current and expected business situation and indicators for the use of short-time work or overtime work which firms can use to deal with their supply constraints and which should directly change their capacity utilization.[29] With the full set of controls and fixed effects, firms with material constraints do not exhibit average capacity

[29]See Appendix A for a detailed description of these additional variables.

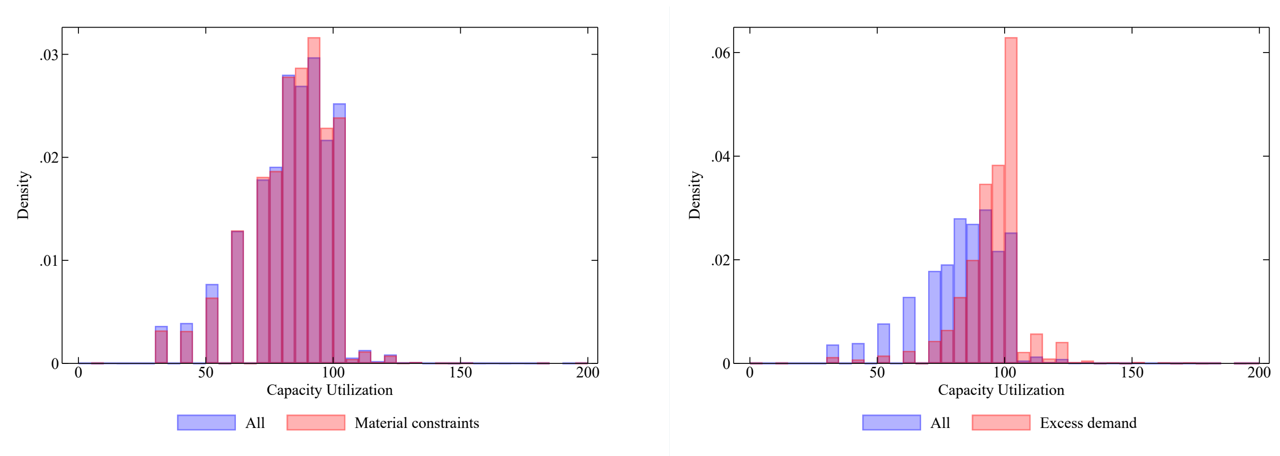

FIGURE C.4: Capacity utilization with material constraints and excess demand

Notes: Sample period: 1990 to 2019. Capacity utilization is a firm's stated utilization rate (in percent) in a given quarter. Excess demand counts firms stating their current order book levels to be relatively high. Material constraints counts firms stating that their current production is limited by a lack of raw or pre-materials. "Material constraints" refers to firms stating material constraints but no excess demand. "Excess demand" refers to firms stating excess demand but no material constraints.

utilization that is different from the groups of firms without material constraints or excess demand. Firms with excess demand continue to show significantly higher capacity utilization, however. Figure C.5 as well as Tables C.5 and C.6 show results including the years 2020 to 2022. Including the Covid crisis does not alter our conclusions. The distinction between excess demand and material constraints also matters at the aggregate level. The aggregate fraction of firms reporting material constraints but no excess demand only mildly correlates with average capacity utilization, with a coefficient of 0.28, see Figure C.6. If we do not sort out firms reporting excess demand, the correlation coefficient increases to 0.4.

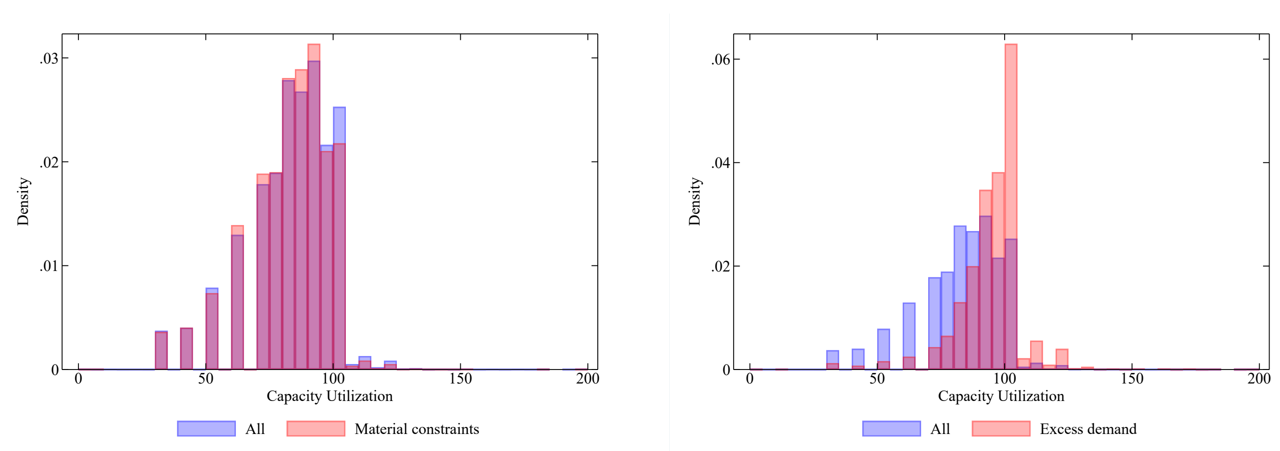

FIGURE C.5: Capacity utilization with material constraints and excess demand: 1990-2022

Notes: Sample period: 1990 to 2022. Capacity utilization is a firm's stated utilization rate (in percent) in a given quarter. "Material constraints" refers to firms stating material constraints but no excess demand. "Excess demand" refers to firms stating excess demand but no material constraints.

Table C.4: Capacity utilization vs. material constraints and excess demand

	Capacity Utilization			
	(1)	(2)	(3)	(4)
Excess demand, no material constraint	12.95***	11.52***	5.613***	3.551***
	(0.235)	(0.229)	(0.194)	(0.261)
Material constraint, no excess demand	2.039***	1.630***	1.050***	0.521
	(0.358)	(0.343)	(0.304)	(0.398)
Excess demand and material constraint	14.55***	12.76***	7.160***	3.924***
	(0.329)	(0.328)	(0.300)	(0.502)
Constant	79.78***	79.97***	82.48***	82.49***
	(0.154)	(0.147)	(0.150)	(0.189)
Time FE	No	Yes	Yes	Yes
Industry FE	No	Yes	Yes	Yes
Controls Business	No	No	Yes	Yes
Controls React	No	No	No	Yes
Observations	304278	304278	304278	141382

Notes: Sample period: 1990 to 2019. Dependent variable is capacity utilization. Capacity utilization is a firms stated utilization rate (in percent) in a given quarter. Excess demand are firms stating their current order book levels to be higher relatively high. Material constraints refer to firms stating that their current production is limited by a lack of raw or pre-materials. Standard errors in parentheses are clustered at the firm level. Stars indicate significance at the 10 percent (*), 5 percent (**), and 1 percent (***) level, respectively.

Our results support the notion that material can indeed be interpreted as a variable input not included in capacity. To back this interpretation, we use answer category 3 from the question on production constraints which indicates constraints in "technical capacities". This relates to machinery and, hence, pre-determined inputs and capacity. Figure C.7 shows capacity utilization for firms with technical constraints which shows a distribution similar to firms with excess demand, but different to firms with

Table C.5: Capacity utilization for different groups of firms: 1990-2022

	N	Mean	Std. Dev.	P25	P50	P75
No excess demand, no material constraint	269537	79.60	16.24	70	80	90
Excess demand, no material constraint	32564	92.63	13.00	90	95	100
Material constraint, no excess demand	14413	80.81	15.90	75	85	90
Excess demand and material constraint	7070	93.54	12.19	90	95	100
Total	323584	81.27	16.43	75	85	95

Notes: Sample period: 1990 to 2022. Capacity utilization is a firm's stated utilization rate (in percent) in a given quarter. Excess demand counts firms stating their current order book levels to be relatively high. Material constraints counts firms stating that their current production is limited by a lack of raw or pre-materials.

Table C.6: Regression analysis capacity utilization: 1990-2022

	Capacity Utilization			
	(1)	(2)	(3)	(4)
Excess demand, no material constraint	13.03***	11.72***	5.647***	3.559***
	(0.228)	(0.223)	(0.188)	(0.261)
Material constraint, no excess demand	1.212***	1.421***	0.937***	0.519
	(0.293)	(0.299)	(0.263)	(0.395)
Excess demand and material constraint	13.94***	12.90***	7.189***	4.045***
	(0.277)	(0.295)	(0.264)	(0.495)
Constant	79.60***	79.75***	82.33***	82.50***
	(0.152)	(0.145)	(0.147)	(0.189)
Time FE	No	Yes	Yes	Yes
Industry FE	No	Yes	Yes	Yes
Controls Business	No	No	Yes	Yes
Controls React	No	No	No	Yes
Observations	323584	323584	323584	141555

Notes: Sample period: 1990 to 2022. Dependent variable is capacity utilization. Capacity utilization is a firms stated utilization rate (in percent) in a given quarter. Excess demand are firms stating their current order book levels to be higher relatively high. Material constraints refer to firms stating that their current production is limited by a lack of raw or pre-materials. Standard errors in parentheses are clustered at the firm level. Stars indicate significance at the 10 percent (*), 5 percent (**), and 1 percent (***) level, respectively.

material constraints.[30] The ifo also asks firms to answer to "Taking into account our current order backlog and the new orders we expect for the next 12 months, we expect our technical capacities to be ...", with "More than sufficient", "Sufficient", or "Not sufficient. Figure C.8 shows that firms facing excess demand have a higher probability to report "not sufficient" capacity levels than "more than sufficient" capacity levels. Material-constrained firms, in turn, have a higher probability to report "more than sufficient" capacity levels.

As discussed above, it is not unambiguous whether or not labor input belongs to a firm's capacity. In Figure C.9, we show a histogram of capacity utilization rates similar to Figure C.4, but instead of material constraints, we look at firms reporting "lack of skilled employees". The same picture emerges. The distribution of utilization rates for firms that report lack of skilled employees but no excess demand and that of all firms are hardly distinguishable from each other. For firms that report excess demand but no lack of skilled employees, however, the entire distribution shifts to the right. Hence, our data suggest that firms do not generally include labor input into their measure of capacity.

Finally, Table C.7 counts how often material constraints and financial constraints overlap in our sample. While the probability to face financial constraints is higher for material constrained firms than for firms facing no material constraints, still the two constraints overlap in ten percent of the cases only.

[30]Note that publicly available industry-level information from the "Joint harmonised EU programme of business and consumer surveys" conducted by the European Commission would in principle allow to check our results across countries. However, the commission combines the answers on "material constraints" and "technical capacities", thus combining the different types of constraints, the difference between which we highlight here.

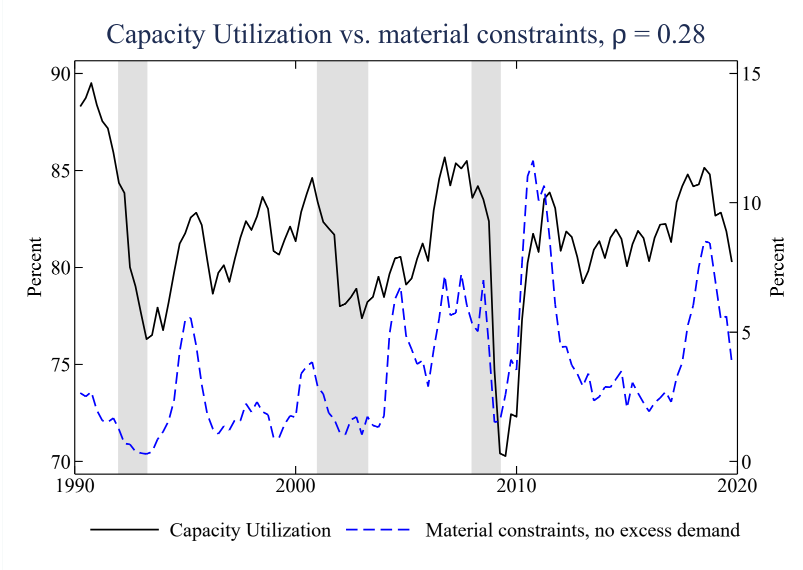

FIGURE C.6: Capacity utilization and material constraints without excess demand over the business cycle

Notes: Sample period 1990 to 2019. ρ is the correlation coefficient between the two series. Material constraints, no excess demand (blue dashed line, right axis) are the fraction of firms reporting material constraints but no excess demand. Capacity utilization (black solid line, left axis) is the average capacity utilization rate over all firms. Grey shaded areas correspond to recessionary periods 1992Q1-1993Q2, 2001Q1-2003Q2, and 2008Q1-2009Q2 as indicated by the German Council of Economic Experts (see Breuer *et al.*, 2022).

TABLE C.7: Material constraints and financial constraints

	Material constraint		
Financial constraint	0	1	Total
0	95.42	89.33	95.02
1	4.58	10.67	4.98
Total	100.00	100.00	100.00

Notes: Sample period: 2002 to 2019. Material constraint counts firms which state material constraints (1) or no material constraints (0) in a given quarter. Financial constraint counts firms that state financial constraints (1) or no financial constraints (0) in a given quarter.

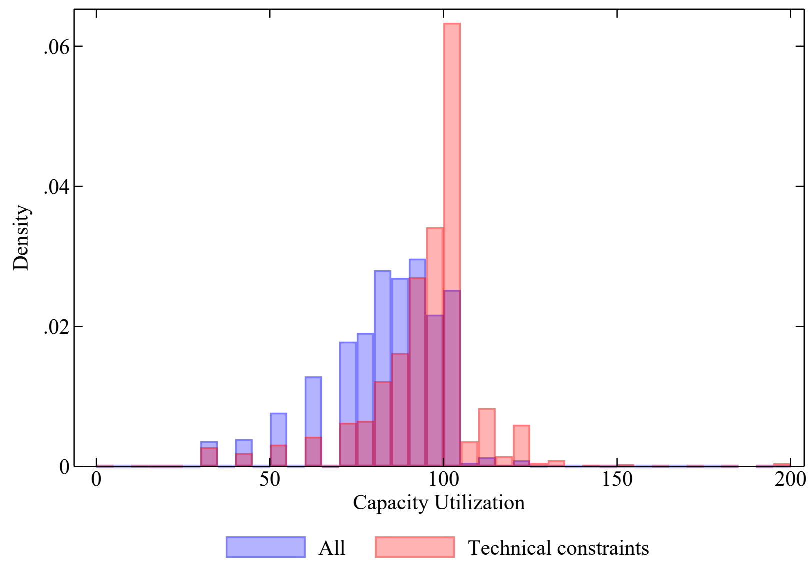

FIGURE C.7: Capacity utilization with technical constraints

Notes: Sample period: 1990 to 2019. Capacity utilization is a firm's stated utilization rate (in percent) in a given quarter. "Technical constraints" refers to firms stating insufficient technical capacity.

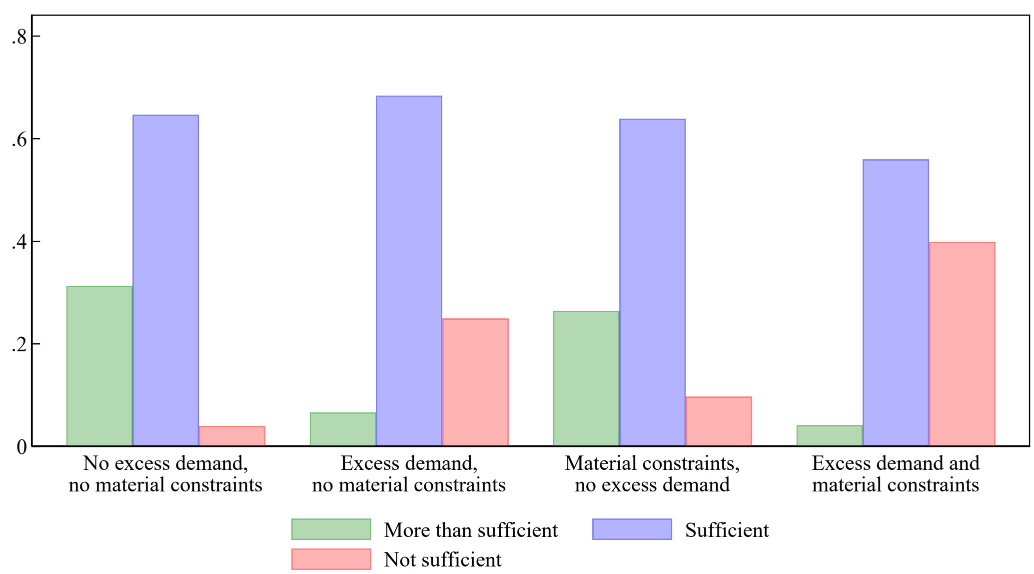

FIGURE C.8: Assessment of capacity by material constraints and excess demand

Notes: Sample period: 1990 to 2019. Fraction of firms answering "More than sufficient", "Sufficient", or "Not Sufficient" to the question "Taking into account our current order backlog and the new orders we expect for the next 12 months, we expect our technical capacities to be ... ". Details are provided in Appendix A. Excess demand counts firms stating their current order book levels to be relatively high. Material constraints counts firms stating that their current production is limited by a lack of raw or pre-materials.

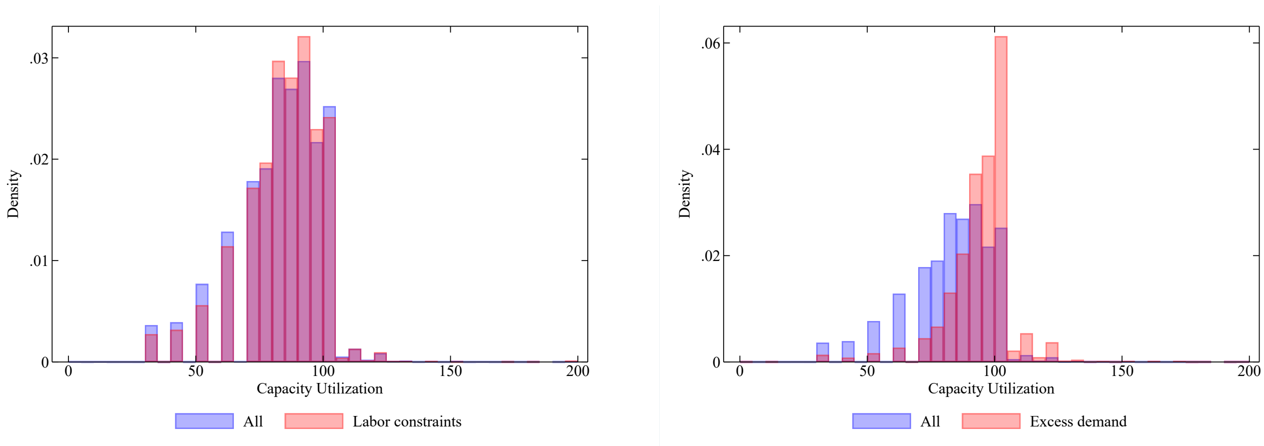

FIGURE C.9: Capacity utilization with labor constraints and excess demand

Notes: Sample period: 1990 to 2019. Capacity utilization is a firm's stated utilization rate (in percent) in a given quarter. Excess demand counts firms stating their current order book levels to be relatively high. Labor constraints refer to firms stating that their current production is limited by a lack of skilled employees but no excess demand. "Excess demand" refers to firms stating excess demand but no lack of skilled employees.

C.4 A model with material constraints and capacity constraints

In this section, we conceptualize the relationship between capacity utilization and material constraints more formally and in line with the empirical facts documented in the previous subsection.

C.4.1 Model setup

We use a simplified version of the model of Fagnart *et al.* (1999) in order to describe the relationship between capacity utilization and material constraints more formally. This model forms the basis of the studies by Alvarez-Lois (2004, 2006), Kuhn and George (2019), or Boehm and Pandalai-Nayar (2022).[31] Our model is equivalent to Boehm and Pandalai-Nayar (2022) except for an extension to the production function. In this framework, intermediate goods producers choose their capacity (capital and/or labor) given expectations about demand for their goods, and then choose variable production inputs (material) and set prices when demand is observed. We relate the decisions of intermediate goods producers to firm decisions in our data. Monopolistically competitive intermediate goods producers maximize the present value of profits

$$\max_{\left\{p_{\ell t}^{y,\bar{\nu}}, y_{\ell t}, v_{\ell t}\right\}} p_{\ell t}^{y,\bar{\nu}} y_{\ell t} - p_t^v v_{\ell t} \tag{5}$$

subject to

$$y_{\ell t} = \omega_{\ell t} Y_t \left(\frac{p_{\ell t}^{y,\bar{\nu}}}{P_t^Y}\right)^{-\theta} \tag{6}$$

$$y_{\ell t} = q_{\ell t} \min\left[\nu, \bar{\nu}\right]. \tag{7}$$

Here, (6) is the demand for goods of a firm in industry ℓ for a price $p_{\ell t}^{y,\bar{\nu}}$ which is determined by a competitive representative firm which aggregates intermediate goods into a final good.[32] Y_t and P_t^Y are then the aggregate output and price level. Demand varies with $\omega_{\ell t}$ which is i.i.d and observed at the beginning of each period.

Production is described by equation (7) and assumes complementarity between production factors that determine capacity $q_{\ell t}$ and variable inputs $\nu_{\ell t}$. Capacity utilization is then defined by $\nu_{\ell t} = \frac{y_{\ell t}}{q_{\ell t}}$, i.e. $\nu_{\ell t} \in [0, 1]$. In line with the "engineering concept" defined above, capacity is pre-determined, while variable inputs can be adjusted freely. Capacity is fixed within the period and can therefore be thought to reflect machinery (capital, investment goods) or skilled labor (for which hiring takes time). While this setup is fully static, the model can be extended to a dynamic setup by allowing for capital accumulation of the firm, which determines capacity in the next period. Boehm and Pandalai-Nayar

[31] Other model classes incorporate search-and-matching frictions in the goods market (Ghassibe and Zanetti, 2022), negligible marginal costs (Murphy, 2017), or over-investment in capacity due to competition (Sun, 2023) to generate periods of low capacity utilization or excess capacity. Auerbach, Gorodnichenko and Murphy (forthcoming) provide new facts on the effects of demand shocks on the economy which cannot be explained by standard models. They extend the Murphy (2017) model and conclude that a model of slack is needed to reconcile their evidence with theory.

[32] See Appendix C.4 for the derivation

(2022) show that the optimal capital choice is independent of the price setting decision in the current period. We therefore abstract from this extension here. Inputs can be freely available ($\bar{\nu} = 1$) or can be unexpectedly constrained ($\bar{\nu} < 1$). An unexpected unavailability of material due to a supply-chain disruption is an example.[33] Material constraints are not taken into account when planning capacity.[34] Our data exhibits variation of material constraints (reflected by variation in $\bar{\nu}$) both across and within industries.

C.4.2 Model predictions

Following Boehm and Pandalai-Nayar (2022), we can derive the optimal price $p_{lt}^{y,\bar{\nu}}$ from a static problem in two steps: First, we solve the cost minimization problem of the firm; second, we derive the optimal price $p_{lt}^{y,\bar{\nu}}$.

Since monopolistic competition leads to prices set above marginal costs, it is profitable to produce as much as possible, i.e. firms serve all their demand at the given price. Idiosyncratic uncertainty about $\omega_{\ell t}$ then generates different utilization rates across firms. Aggregate demand shifts such as monetary policy shocks shift the distribution of $\omega_{\ell t}$. If $\bar{\nu} = 1$ and a firm faces demand $\tilde{y}$ such that $\tilde{y} > q_{lt}$, then it is optimal for the firm to operate at full capacity ($\nu_{lt} = 1$ and hence $y_{lt} = q_{lt}$). Since production cannot be increased to meet all demand, the firm is capacity-constrained. If the firm faces demand $\tilde{y}$ such that $\tilde{y} \leq q_{lt}$, then it is optimal for the firm to operate at $\tilde{y} = \nu_{lt} q_{lt} \leq q_{lt}$. In this case, the firm is not capacity-constrained. Capacity utilization is then purely demand driven and low utilization rates are interpreted as a situation of idleness in which production can be increased easily.

If $\bar{\nu} < 1$ and a firm faces demand $\tilde{y}$ such that $q_{lt}\bar{\nu} < \tilde{y} < q_{lt}$, then it is optimal for the firm to produce at $y_{lt} = q_{lt}\bar{\nu} < q_{lt}$. The firm's production is then constrained due to the unavailability of inputs albeit operating at low levels of capacity utilization. Our formulation can therefore describe situations in which capacity utilization is not informative about supply constraints which replicates our empirical facts in Section 2. Note that this formulation is different from the model extension shown in Boehm and Pandalai-Nayar (2022), supplementary appendix S1.1. In their extension $\bar{\nu}$ is a choice variable and affects a firm's production capacity. A similar wedge between the co-movement of demand and capacity utilization as formulated here can be generated by exogenous shocks to capacity q. Comin *et al.* (2023) use shocks of this type.

Optimal price setting delivers

$$p_{\ell t}^{y,\bar{\nu}} = \frac{\theta}{\theta - 1}\left(mc_{\ell t} + \lambda_{\ell t}^{\bar{\nu}}\right), \tag{8}$$

[33] Meier and Pinto (2024) apply a similar concept of material constraints to model supply-chain disruptions during the Covid recession.

[34] This is a simplifying assumption. Alternatively, the firm can expect material constraints and take these into account when planning capacity. The simplified model here then describes a situation in which the availability of material input is lower than expected.

where, from complementary slackness, $\lambda_{\ell t}^{\bar{\nu}} \geq 0$ satisfies

$$\lambda_{\ell t}^{\bar{\nu}} = \begin{cases} 0 & \text{if } y_{\ell t} < q_{\ell t}\bar{\nu} \\ \frac{\theta-1}{\theta} P_t^Y \left(\frac{\omega_{\ell t} Y_t}{q_{\ell t}\bar{\nu}}\right)^{\frac{1}{\theta}} - mc_{\ell t} & \text{if } y_{\ell t} = q_{\ell t}\bar{\nu}. \end{cases} \tag{9}$$

Here, cost minimization delivers that $mc_{\ell t} = \frac{p_t^{\nu}}{q_{\ell t}}$. Equations (8) and (9) document that in case of excess demand, i.e., $\tilde{y} > q_{\ell t}\bar{\nu}$, prices are higher. Prices decrease in $\bar{\nu}$, i.e., excess demand binds earlier and prices are higher in case of material constraints ($\bar{\nu} < 1$) than in a situation with a capacity constraint ($\bar{\nu} = 1$).

Profits are given by

$$\pi_{\ell t} = \left(p_{\ell t}^{y,\bar{\nu}} - mc_{\ell t}\right) y_{\ell t}. \tag{10}$$

We can write down profits separately for binding and non binding constraints as follows

$$\pi_{\ell t} = \begin{cases} \left(p_{\ell t}^{y,\bar{\nu}} - mc_{\ell t}\right) \omega_{\ell t} Y_t \left(\frac{p_{\ell t}^{y,\bar{\nu}}}{P_t^Y}\right)^{-\theta} & \text{if } \lambda_{\ell t}^{\bar{\nu}} = 0 \\ \left(p_{\ell t}^{y,\bar{\nu}} - mc_{\ell t}\right) q_{\ell t}\bar{\nu} & \text{if } \lambda_{\ell t}^{\bar{\nu}} > 0. \end{cases} \tag{11}$$

Unconstrained profits follow the usual convex shape where the curvature is determined by the demand elasticity parameter θ. Starting from the optimal price, profits fall. When demand changes, e.g. due to shocks, firms re-adjust their price to the optimal price. Production changes accordingly to satisfy demand. In the presence of frictions, e.g. menu costs, firms decide to change their price when the increase in profits due to changing the price exceeds the menu cost. The higher the curvature of the profit function, the more likely it is that firms adjust their price after demand shifts. By contrast, when firms are constrained, profits are linear in the price. The slope depends on capacity $q_{\ell t}$ and the degree of material constraints $\bar{\nu}$. If this linear slope is steeper than that of unconstrained profits, constrained firms are more likely to adjust prices. All else equal, a higher capacity $q_{\ell t}$ is associated with a lower capacity utilization (see definition above). Hence, within the group of constrained firms, those firms with lower capacity utilization are more likely to adjust prices for the same degree of material constraints.

D Additional Results Section 3

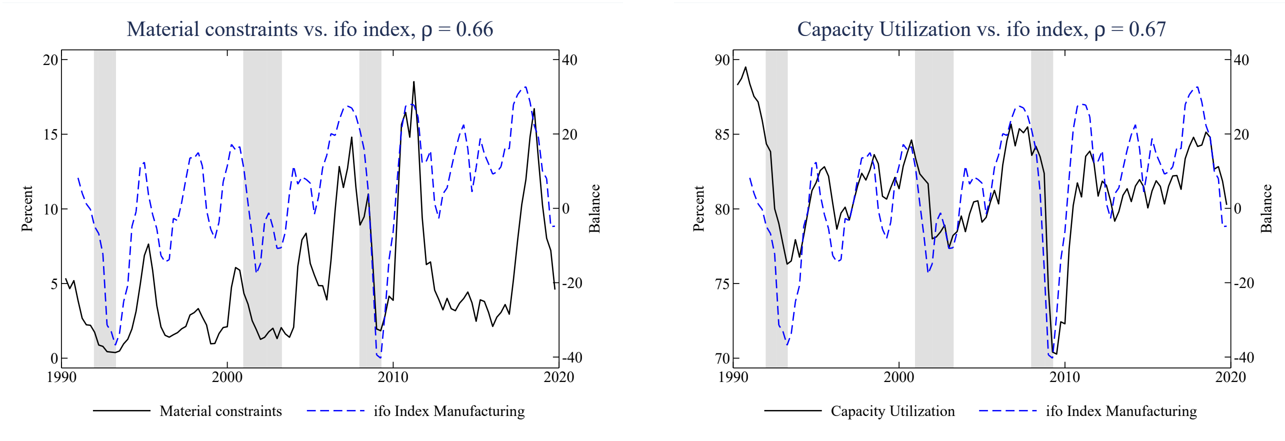

FIGURE D.1: Capacity utilization and material constraints vs. ifo index

Notes: Sample period 1990 to 2019. ρ is the correlation coefficient between the two series. Material constraints (black solid line, left panel, left axis) are the fraction of firms reporting material constraints. Capacity utilization (black solid line, right panel, left axis) is the average capacity utilization rate over all firms. ifo Index Manufacturing (blue dashed line, right axis) is the ifo Business Climate index for the manufacturing sector. Details are provided in Appendix A. Grey shaded areas correspond to recessionary periods 1992Q1-1993Q2, 2001Q1-2003Q2, and 2008Q1-2009Q2 as indicated by the German Council of Economic Experts (see Breuer *et al.*, 2022).

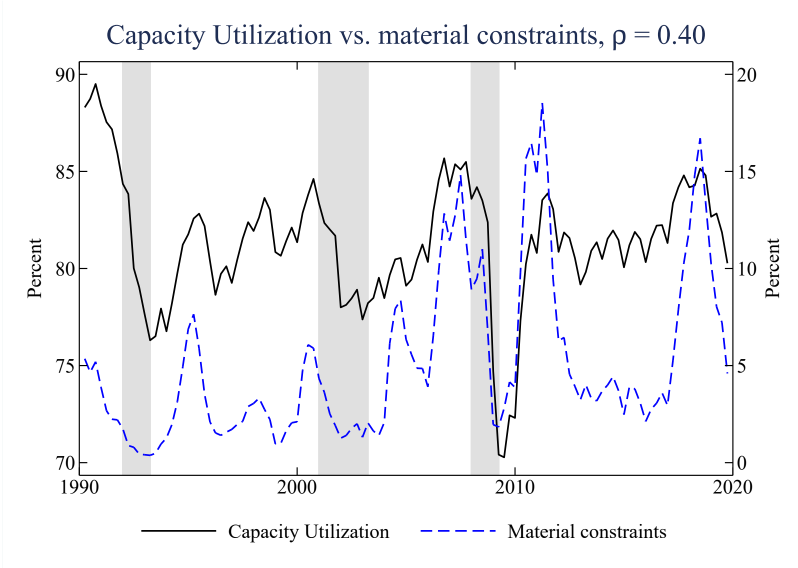

FIGURE D.2: Capacity utilization and material constraints over the business cycle

Notes: Sample period 1990 to 2019. ρ is the correlation coefficient between the two series. Material constraints (blue dashed line, right axis) are the fraction of firms reporting material constraints. Capacity utilization (black solid line, left axis) is the average capacity utilization rate over all firms. Grey shaded areas correspond to recessionary periods 1992Q1-1993Q2, 2001Q1-2003Q2, and 2008Q1-2009Q2 as indicated by the German Council of Economic Experts (see Breuer *et al.*, 2022).

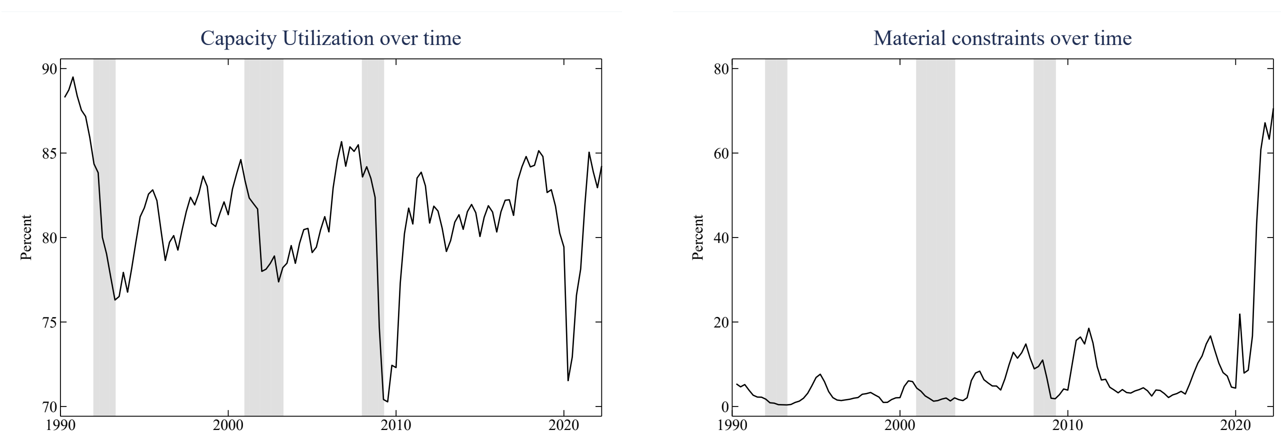

FIGURE D.3: Capacity utilization and material constraints over the business-cycle: 1990-2022

Notes: Sample period: 1990 to 2022. The left panel shows for each quarter the fraction of firms reporting material constraints. The right panel shows for each quarter the average capacity utilization rate over all firms. Grey shaded areas correspond to recessionary periods 1992Q1-1993Q2, 2001Q1-2003Q2, and 2008Q1-2009Q2 as indicated by the German Council of Economic Experts (see Breuer *et al.*, 2022).

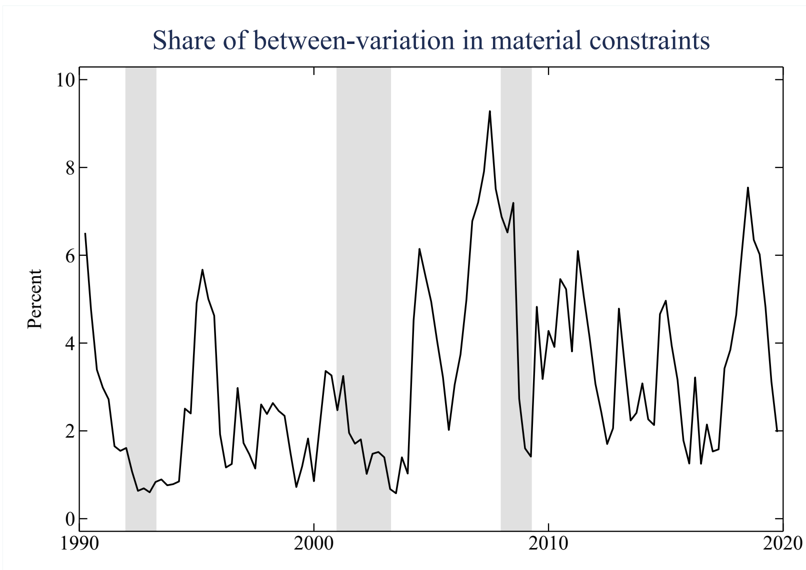

Figure D.4: Decomposing variation material constraints within and between industries

Notes: Sample period: 1990 to 2019. Share of variation in material constraints that is explained by between-industry variation. Decomposition is based on Equation (1). Grey shaded areas correspond to recessionary periods 1992Q1-1993Q2, 2001Q1-2003Q2, and 2008Q1-2009Q2 as indicated by the German Council of Economic Experts (see Breuer *et al.*, 2022).

Table D.1: AR(1) coefficients of material constraints at industry-level

	AR(1) coeff.
Industry 10: Food	0.604^{***}
Industry 11: Beverages	0.417^{**}
Industry 12: Tobacco	0.0943
Industry 13: Textiles	0.787^{***}
Industry 14: Wearing apparel	0.300^{*}
Industry 15: Leather	0.483^{***}
Industry 16: Wood	0.830^{***}
Industry 17: Paper	0.736^{***}
Industry 18: Printing	0.518^{***}
Industry 19: Coke	0.0224
Industry 20: Chemicals	0.830^{***}
Industry 21: Pharmaceutics	0.652^{***}
Industry 22: Rubber and plastic	0.725^{***}
Industry 23: Non-metallic minerals	0.760^{***}
Industry 24: Basic metals	0.637^{***}
Industry 25: Fabricated metal products	0.842^{***}
Industry 26: Computer and electronic	0.836^{***}
Industry 27: Electrical equipment	0.885^{***}
Industry 28: Machinery and equipment	0.901^{***}
Industry 29: Motor vehicles	0.792^{***}
Industry 30: Other transport	0.684^{***}
Industry 31: Furniture	0.529^{***}
Industry 32: Other	0.499^{***}
Industry 33: Repair	0.555^{***}

Notes: Separate industry-level regressions of $Y_t = \beta_0 + \beta_1 Y_{t-1} + u_t$, where Y_t denotes industry-level material constraints. Standard errors are Newey-West with one lag. Due to gaps in the time series for industries 12, 21, and 33 we just control for heteroskedasticity in these cases. Stars indicate significance at the 10 percent (*), 5 percent (**), and 1 percent (***) level, respectively.

E Additional Results Section 4

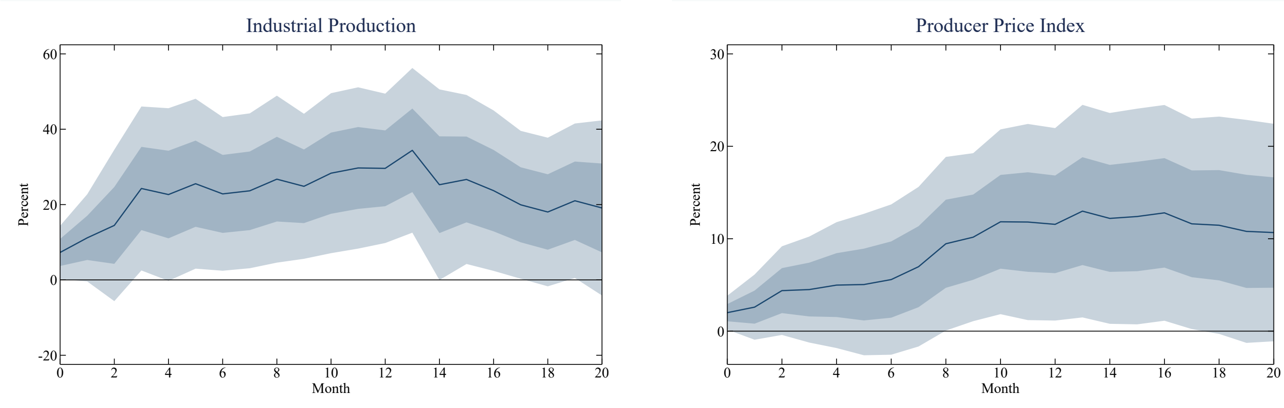

Figure E.1: Responses of industrial production and producer price index to monetary policy shock

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock based on $y_{t+h} = \alpha_h + \beta_h \times shock_t + \psi_h(L)\ y_{t-1} + \varepsilon_{t+h}$, with lag-length set to twelve. Dependent variable is the logarithm of the producer price index for the German manufacturing sector (left panel), and the logarithm of the German producer price index. Both indices are provided by DESTATIS, see Section A for details. Standard errors are Newey-West with $h+1$ lags. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

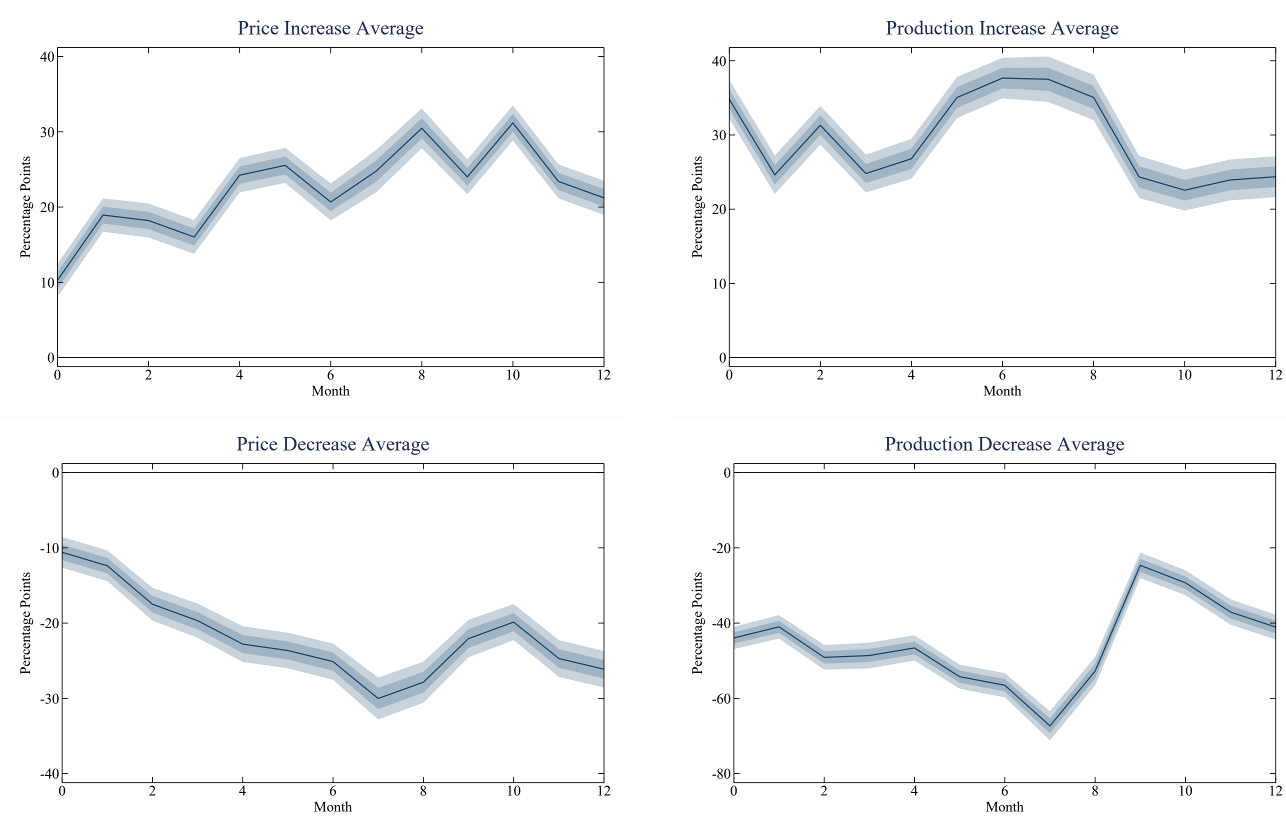

FIGURE E.2: Average Price and production increases and decreases

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock based on a linear version of Equation (3), i.e. $y_{ij,t+h} = \alpha_h + \beta_h \times shock_t + \gamma_h \ Z_{ij,t-1} + \delta_{j,h} + \delta_{t,h} + \varepsilon_{ij,t+h}$. Dependent variable is a dummy indicating price increases (top left panel), production increases (top right panel), price decreases (bottom left panel), or production decreases (bottom right panel). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

Table E.1: Firms' pricing decisions in response to monetary policy: Robustness

	Price change			Price Increase			Price Decrease		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Driscoll and Kraay (1998) standard errors									
MP, material	0.289**	0.318**	0.296**	0.368**	0.325**	0.288**	-0.0794	-0.00657	0.00856
	(0.124)	(0.125)	(0.121)	(0.150)	(0.136)	(0.132)	(0.0639)	(0.0498)	(0.0536)
MP, no material	-0.0258	0.0220	-0.0102	0.0882	0.0465	-0.00781	-0.114*	-0.0245	-0.00238
	(0.0641)	(0.0600)	(0.0594)	(0.0736)	(0.0633)	(0.0667)	(0.0585)	(0.0382)	(0.0385)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	588597	586399	586399	588597	586399	586399	588597	586399	586399
Panel B: Two-way clustered standard errors									
MP, material	0.289*	0.318*	0.296*	0.368*	0.325*	0.288*	-0.0794	-0.00657	0.00856
	(0.170)	(0.174)	(0.163)	(0.203)	(0.187)	(0.171)	(0.0705)	(0.0550)	(0.0546)
MP, no material	-0.0258	0.0220	-0.0102	0.0882	0.0465	-0.00781	-0.114*	-0.0245	-0.00238
	(0.0778)	(0.0760)	(0.0734)	(0.0878)	(0.0773)	(0.0725)	(0.0589)	(0.0402)	(0.0397)
Constant	0.170***	0.129***	0.126***	0.0908***	0.0758***	0.0712***	0.0791***	0.0527***	0.0546***
	(0.00314)	(0.00320)	(0.00322)	(0.00309)	(0.00267)	(0.00263)	(0.00279)	(0.00221)	(0.00226)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	588597	586399	586399	588597	586399	586399	588597	586399	586399
Panel C: Firm fixed effects									
MP, material	0.182***	0.195***	0.175**	0.298***	0.255***	0.223***	-0.116***	-0.0598	-0.0484
	(0.0689)	(0.0685)	(0.0686)	(0.0622)	(0.0621)	(0.0623)	(0.0375)	(0.0371)	(0.0370)
MP, no material	-0.0213	0.00924	-0.0210	0.0788***	0.0380***	-0.0135	-0.100***	-0.0287***	-0.00754
	(0.0140)	(0.0139)	(0.0138)	(0.0114)	(0.0111)	(0.0109)	(0.0103)	(0.00998)	(0.00983)
Constant	0.171***	0.139***	0.137***	0.0911***	0.0800***	0.0756***	0.0803***	0.0592***	0.0611***
	(0.000252)	(0.00127)	(0.00129)	(0.000262)	(0.000937)	(0.000958)	(0.000154)	(0.000961)	(0.000972)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	591203	588998	585938	591203	588998	585938	591203	588998	585938
Panel D: Quarters in which supply constraints are reported									
MP, material	0.0114	0.0367	0.0184	0.331***	0.256**	0.221**	-0.319***	-0.219***	-0.203***
	(0.121)	(0.120)	(0.120)	(0.111)	(0.110)	(0.109)	(0.0651)	(0.0645)	(0.0645)
MP, no material	-0.0809***	-0.00746	-0.0379	0.116***	0.0550***	-0.00328	-0.197***	-0.0624***	-0.0347*
	(0.0250)	(0.0249)	(0.0249)	(0.0189)	(0.0188)	(0.0188)	(0.0183)	(0.0179)	(0.0180)
Constant	0.173***	0.132***	0.129***	0.0922***	0.0778***	0.0723***	0.0806***	0.0542***	0.0568***
	(0.00222)	(0.00260)	(0.00261)	(0.00137)	(0.00170)	(0.00167)	(0.00176)	(0.00197)	(0.00202)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	206150	205332	205332	206150	205332	205332	206150	205332	205332

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Table E.1: Firms' pricing decisions in response to monetary policy: Robustness (cont.)

	Price change			Price Increase			Price Decrease		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel E: Previous and next month of reported supply constraints									
MP, material	0.253***	0.283***	0.262***	0.356***	0.316***	0.281***	-0.103***	-0.0334	-0.0187
	(0.0719)	(0.0716)	(0.0713)	(0.0669)	(0.0668)	(0.0664)	(0.0383)	(0.0377)	(0.0377)
MP, no material	-0.0233	0.0240*	-0.00707	0.0844***	0.0439***	-0.00889	-0.108***	-0.0199*	0.00182
	(0.0142)	(0.0141)	(0.0140)	(0.0112)	(0.0110)	(0.0108)	(0.0107)	(0.0104)	(0.0102)
Constant	0.170***	0.129***	0.126***	0.0910***	0.0758***	0.0712***	0.0793***	0.0531***	0.0550***
	(0.00219)	(0.00247)	(0.00247)	(0.00133)	(0.00157)	(0.00153)	(0.00173)	(0.00191)	(0.00194)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	601356	599093	599093	601356	599093	599093	601356	599093	599093
Panel F: Material constraints without financial constraints									
MP, material	0.310***	0.347***	0.320***	0.380***	0.326***	0.288***	-0.0696	0.0209	0.0321
	(0.0860)	(0.0857)	(0.0856)	(0.0798)	(0.0795)	(0.0795)	(0.0435)	(0.0434)	(0.0434)
MP, no material	-0.0218	0.0335*	-0.00398	0.104***	0.0466***	-0.00656	-0.126***	-0.0131	0.00258
	(0.0185)	(0.0185)	(0.0184)	(0.0143)	(0.0139)	(0.0138)	(0.0139)	(0.0137)	(0.0135)
Constant	0.177***	0.134***	0.130***	0.0953***	0.0790***	0.0728***	0.0814***	0.0550***	0.0569***
	(0.00243)	(0.00281)	(0.00281)	(0.00151)	(0.00182)	(0.00176)	(0.00192)	(0.00216)	(0.00220)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	484952	482876	482876	484952	482876	482876	484952	482876	482876
Panel G: Small firms									
MP, material	0.149*	0.161**	0.135*	0.295***	0.253***	0.212***	-0.146***	-0.0913**	-0.0770*
	(0.0779)	(0.0776)	(0.0777)	(0.0697)	(0.0698)	(0.0700)	(0.0446)	(0.0443)	(0.0442)
MP, no material	-0.0164	0.0156	-0.0162	0.0905***	0.0524***	-0.00115	-0.107***	-0.0368***	-0.0150
	(0.0159)	(0.0156)	(0.0155)	(0.0125)	(0.0123)	(0.0121)	(0.0118)	(0.0114)	(0.0113)
Constant	0.175***	0.141***	0.138***	0.0920***	0.0815***	0.0769***	0.0834***	0.0592***	0.0612***
	(0.000291)	(0.00150)	(0.00151)	(0.000297)	(0.00108)	(0.00110)	(0.000176)	(0.00115)	(0.00116)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	452480	450875	447983	452480	450875	447983	452480	450875	447983
Panel H: Large firms									
MP, material	0.237*	0.246*	0.243*	0.250**	0.210*	0.204*	-0.0126	0.0361	0.0386
	(0.130)	(0.129)	(0.129)	(0.120)	(0.119)	(0.118)	(0.0604)	(0.0590)	(0.0589)
MP, no material	-0.0281	-0.00997	-0.0316	0.0392*	-0.00469	-0.0438*	-0.0674***	-0.00528	0.0122
	(0.0270)	(0.0272)	(0.0271)	(0.0234)	(0.0229)	(0.0225)	(0.0188)	(0.0182)	(0.0177)
Constant	0.158***	0.137***	0.134***	0.0886***	0.0765***	0.0727***	0.0699***	0.0600***	0.0616***
	(0.000458)	(0.00219)	(0.00222)	(0.000478)	(0.00178)	(0.00183)	(0.000290)	(0.00159)	(0.00162)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	138691	138091	137923	138691	138091	137923	138691	138091	137923

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TABLE E.1: Firms' pricing decisions in response to monetary policy: Robustness (cont.)

	Price change			Price Increase			Price Decrease		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel I: Without industries 12, 19, 30, and 33									
MP, material	0.182***	0.195***	0.174**	0.302***	0.258***	0.225***	-0.120***	-0.0631*	-0.0514
	(0.0683)	(0.0679)	(0.0680)	(0.0617)	(0.0616)	(0.0617)	(0.0373)	(0.0369)	(0.0367)
MP, no material	-0.0239*	0.00650	-0.0239*	0.0747***	0.0344***	-0.0170	-0.0985***	-0.0279***	-0.00693
	(0.0138)	(0.0137)	(0.0136)	(0.0112)	(0.0110)	(0.0107)	(0.0102)	(0.00986)	(0.00972)
Constant	0.171***	0.139***	0.137***	0.0909***	0.0797***	0.0753***	0.0805***	0.0594***	0.0613***
	(0.000254)	(0.00128)	(0.00130)	(0.000263)	(0.000944)	(0.000966)	(0.000155)	(0.000970)	(0.000981)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	583744	581586	578526	583744	581586	578526	583744	581586	578526

Notes: Sample period: 1999 to 2019. Estimation results for α_0 (Constant), $\beta_{1,0}$ (MP, material), and $\beta_{2,0}$ (MP, no material) based on Equation (3). The dependent variable is a dummy indicating price changes (columns 1 to 3), price increases (columns 4 to 6), or price decreases (columns 7 to 8). Controls Business include a firm's assessment of its current and future business situation. Control Input is a measure of firm's input costs at the industry-level. Standard errors in parentheses are adjusted following Driscoll and Kraay (1998) (Panel A), two-way clustered at the firm-level and over time (Panel B), or clustered at the firm-level (Panels C and D). Stars indicate significance at the 10 percent (*), 5 percent (**), and 1 percent (***) level, respectively.

TABLE E.2: Firms' production decisions in response to monetary policy: Robustness

	Prod. change			Prod. Increase			Prod. Decrease		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Driscoll and Kraay (1998) standard errors									
MP, material	0.150	0.191	0.197	0.452***	0.303**	0.287**	-0.302***	-0.112	-0.0902
	(0.114)	(0.116)	(0.120)	(0.156)	(0.124)	(0.122)	(0.0993)	(0.0762)	(0.0867)
MP, material	-0.118	-0.00858	0.000182	0.329***	0.199**	0.176**	-0.447***	-0.207***	-0.175**
	(0.0806)	(0.0633)	(0.0611)	(0.0914)	(0.0801)	(0.0788)	(0.128)	(0.0734)	(0.0720)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	589796	587513	587513	589796	587513	587513	589796	587513	587513
Panel B: Two-way clustered standard errors									
MP, material	0.150	0.191	0.197	0.452**	0.303*	0.287*	-0.302**	-0.112	-0.0902
	(0.138)	(0.139)	(0.142)	(0.206)	(0.166)	(0.161)	(0.127)	(0.0891)	(0.0894)
MP, no material	-0.118	-0.00858	0.000182	0.329***	0.199***	0.176***	-0.447***	-0.207***	-0.175***
	(0.0737)	(0.0546)	(0.0539)	(0.0931)	(0.0662)	(0.0636)	(0.134)	(0.0708)	(0.0663)
Constant	0.327***	0.186***	0.187***	0.142***	0.0800***	0.0780***	0.184***	0.106***	0.109***
	(0.00393)	(0.00422)	(0.00425)	(0.00328)	(0.00275)	(0.00275)	(0.00489)	(0.00301)	(0.00315)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	589796	587513	587513	589796	587513	592873	589796	587513	587513
Panel C: Firm fixed effects									
MP, material	0.122	0.153*	0.156*	0.407***	0.275***	0.258***	-0.285***	-0.122**	-0.102*
	(0.0839)	(0.0816)	(0.0818)	(0.0697)	(0.0673)	(0.0676)	(0.0641)	(0.0590)	(0.0593)
MP, no material	-0.104***	-0.0129	-0.00525	0.311***	0.198***	0.173***	-0.416***	-0.211***	-0.178***
	(0.0182)	(0.0175)	(0.0174)	(0.0135)	(0.0130)	(0.0130)	(0.0155)	(0.0141)	(0.0141)
Constant	0.329***	0.214***	0.215***	0.143***	0.0943***	0.0922***	0.186***	0.120***	0.123***
	(0.000284)	(0.00159)	(0.00161)	(0.000263)	(0.00113)	(0.00114)	(0.000201)	(0.00112)	(0.00114)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	592410	590119	587052	592410	590119	587052	592410	590119	587052
Panel D: Quarters in which supply constraints are reported									
MP, material	0.150	0.182	0.185	0.316**	0.0645	0.0473	-0.166	0.117	0.138
	(0.145)	(0.140)	(0.140)	(0.125)	(0.116)	(0.116)	(0.106)	(0.0947)	(0.0946)
MP, no material	-0.0898***	0.115***	0.121***	0.340***	0.168***	0.139***	-0.430***	-0.0528**	-0.0181
	(0.0315)	(0.0304)	(0.0305)	(0.0228)	(0.0223)	(0.0224)	(0.0268)	(0.0244)	(0.0244)
Constant	0.329***	0.189***	0.189***	0.143***	0.0816***	0.0789***	0.186***	0.107***	0.110***
	(0.00271)	(0.00287)	(0.00288)	(0.00183)	(0.00179)	(0.00178)	(0.00203)	(0.00184)	(0.00188)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	206598	205734	205734	206598	205734	205734	206598	205734	205734

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Table E.2: Firms' production decisions in response to monetary policy: Robustness (cont.)

	Prod. change			Prod. Increase			Prod. Decrease		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel E: Previous and next month of reported supply constraints									
MP, material	0.120	0.162**	0.168**	0.404***	0.259***	0.244***	-0.284***	-0.0971*	-0.0759
	(0.0840)	(0.0821)	(0.0821)	(0.0725)	(0.0688)	(0.0688)	(0.0621)	(0.0571)	(0.0572)
MP, no material	-0.115***	-0.00687	0.00250	0.320***	0.194***	0.172***	-0.435***	-0.201***	-0.169***
	(0.0181)	(0.0173)	(0.0173)	(0.0134)	(0.0129)	(0.0128)	(0.0155)	(0.0140)	(0.0139)
Constant	0.327***	0.186***	0.187***	0.143***	0.0797***	0.0777***	0.184***	0.106***	0.109***
	(0.00264)	(0.00268)	(0.00268)	(0.00175)	(0.00156)	(0.00154)	(0.00196)	(0.00166)	(0.00168)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	602555	600206	600206	602555	600206	600206	602555	600206	600206
Panel F: Material constraints without financial constraints									
MP, material	0.183*	0.236**	0.243***	0.418***	0.231***	0.216***	-0.235***	0.00459	0.0277
	(0.0958)	(0.0918)	(0.0918)	(0.0851)	(0.0802)	(0.0803)	(0.0690)	(0.0605)	(0.0606)
MP, no material	-0.136***	-0.00721	0.00301	0.274***	0.0944***	0.0725***	-0.410***	-0.102***	-0.0695***
	(0.0229)	(0.0215)	(0.0214)	(0.0166)	(0.0153)	(0.0153)	(0.0193)	(0.0169)	(0.0167)
Constant	0.321***	0.167***	0.168***	0.142***	0.0718***	0.0692***	0.179***	0.0955***	0.0993***
	(0.00285)	(0.00285)	(0.00285)	(0.00193)	(0.00169)	(0.00167)	(0.00213)	(0.00179)	(0.00181)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	486081	483925	483925	486081	483925	483925	486081	483925	483925
Panel G: Small firms									
MP, material	0.0727	0.108	0.109	0.333***	0.210***	0.190**	-0.260***	-0.103	-0.0810
	(0.0952)	(0.0928)	(0.0932)	(0.0789)	(0.0760)	(0.0764)	(0.0744)	(0.0683)	(0.0687)
MP, no material	-0.0891***	0.0000175	0.00480	0.302***	0.194***	0.170***	-0.391***	-0.194***	-0.165***
	(0.0207)	(0.0198)	(0.0198)	(0.0152)	(0.0147)	(0.0147)	(0.0176)	(0.0161)	(0.0161)
Constant	0.345***	0.221***	0.222***	0.147***	0.0958***	0.0938***	0.198***	0.126***	0.128***
	(0.000300)	(0.00185)	(0.00186)	(0.000283)	(0.00127)	(0.00128)	(0.000234)	(0.00133)	(0.00135)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	452764	451107	448209	452764	451107	448209	452764	451107	448209
Panel H: Large firms									
MP, material	0.263	0.285*	0.287*	0.595***	0.455***	0.451***	-0.332***	-0.170	-0.164
	(0.160)	(0.156)	(0.156)	(0.134)	(0.132)	(0.132)	(0.115)	(0.107)	(0.107)
MP, no material	-0.130***	-0.0448	-0.0284	0.313***	0.197***	0.172***	-0.443***	-0.242***	-0.200***
	(0.0347)	(0.0337)	(0.0335)	(0.0269)	(0.0257)	(0.0256)	(0.0293)	(0.0267)	(0.0265)
Constant	0.279***	0.193***	0.195***	0.133***	0.0897***	0.0873***	0.147***	0.104***	0.108***
	(0.000655)	(0.00290)	(0.00294)	(0.000585)	(0.00219)	(0.00222)	(0.000397)	(0.00191)	(0.00195)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	139615	138981	138812	139615	138981	138812	139615	138981	138812

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Table E.2: Firms' production decisions in response to monetary policy: Robustness (cont.)

	Prod. change			Prod. Increase			Prod. Decrease		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel I: Without industries 12, 19, 30, and 33									
MP, material	0.128	0.158*	0.161**	0.406***	0.272***	0.254***	-0.278***	-0.115**	-0.0936
	(0.0830)	(0.0807)	(0.0810)	(0.0690)	(0.0667)	(0.0669)	(0.0636)	(0.0584)	(0.0587)
MP, no material	-0.102***	-0.0106	-0.00278	0.308***	0.196***	0.172***	-0.410***	-0.207***	-0.174***
	(0.0180)	(0.0172)	(0.0172)	(0.0133)	(0.0129)	(0.0128)	(0.0153)	(0.0139)	(0.0139)
Constant	0.330***	0.215***	0.215***	0.143***	0.0945***	0.0924***	0.187***	0.120***	0.123***
	(0.000284)	(0.00161)	(0.00162)	(0.000265)	(0.00113)	(0.00114)	(0.000202)	(0.00113)	(0.00115)
Seasonal FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls Business	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Control Input	No	No	Yes	No	No	Yes	No	No	Yes
Observations	584916	582674	579607	584916	582674	579607	584916	582674	579607

Notes: Sample period: 1999 to 2019. Estimation results for α_0 (Constant), $\beta_{1,0}$ (MP, material), and $\beta_{2,0}$ (MP, no material) based on Equation (3). The dependent variable is a dummy indicating production changes (columns 1 to 3), production increases (columns 4 to 6), or production decreases (columns 7 to 8). Controls Business include a firm's assessment of its current and future business situation. Control Input is a measure of firm's input costs at the industry-level. Standard errors in parentheses are adjusted following Driscoll and Kraay (1998) (Panel A), two-way clustered at the firm-level and over time (Panel B), or clustered at the firm-level (Panels C and D). Stars indicate significance at the 10 percent (*), 5 percent (**), and 1 percent (***) level, respectively.

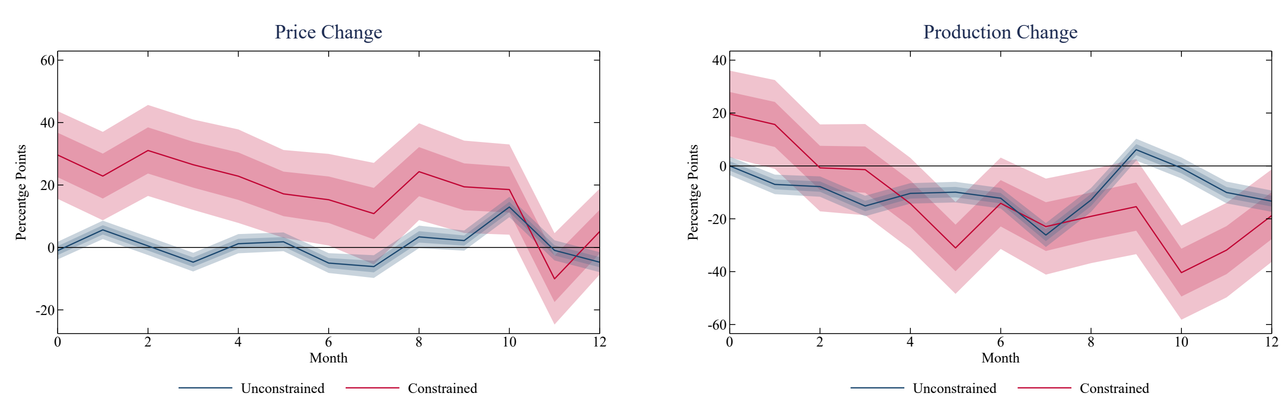


Figure E.3: Price and production changes conditional on material constraints

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for material-constrained (red) and not material-constrained (blue) firms based on estimating Equation (3). Dependent variable is a dummy indicating price changes (left panel) and production changes (right panel). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

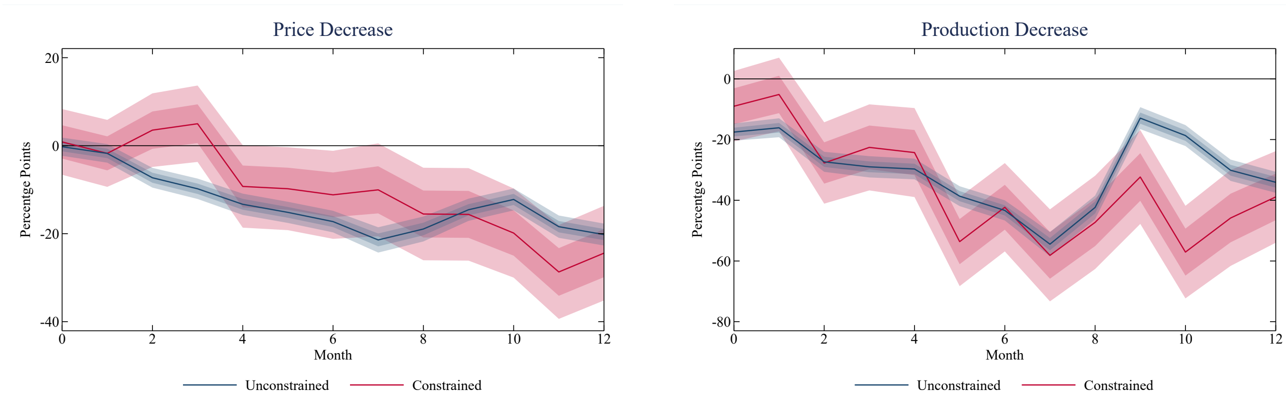


FIGURE E.4: Price and production decreases conditional on material constraints

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for material-constrained (red) and not material-constrained (blue) firms based on estimating Equation (3). Dependent variable is a dummy indicating price decreases (left panel) and production decreases (right panel). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

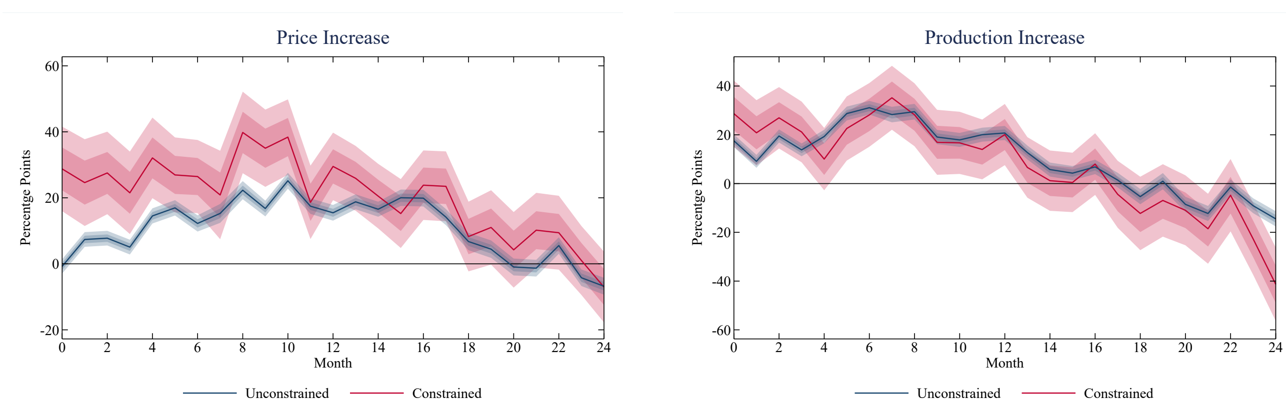


FIGURE E.5: Price and production increases conditional on material constraints: Long horizon

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for material-constrained (red) and not material-constrained (blue) firms based on estimating Equation (3). Dependent variable is a dummy indicating price increases (left panel) and production increases (right panel). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

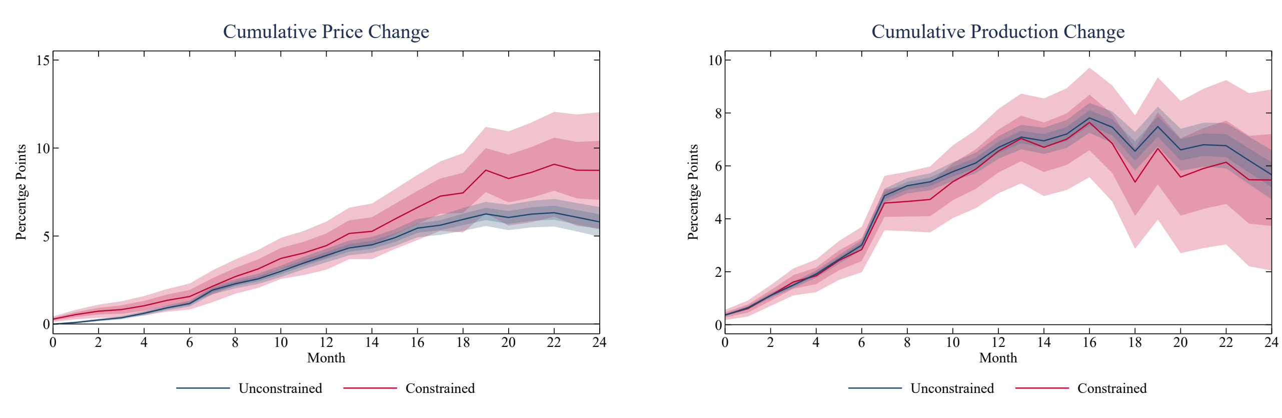


FIGURE E.6: Cumulative price and production changes conditional on material constraints

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for material-constrained (red) and not material-constrained (blue) firms based on estimating Equation (3). Dependent variable is defined as $\sum_{k=0}^{h} \mathbb{I}(y_{ij,t+k})$ and $\mathbb{I}(y_{ij,t+k}) \in \{-1, 0, 1\}$ indicates whether a firm decreases (-1), does not change (0), or increases (1) its price (left panel) or production (right panel). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

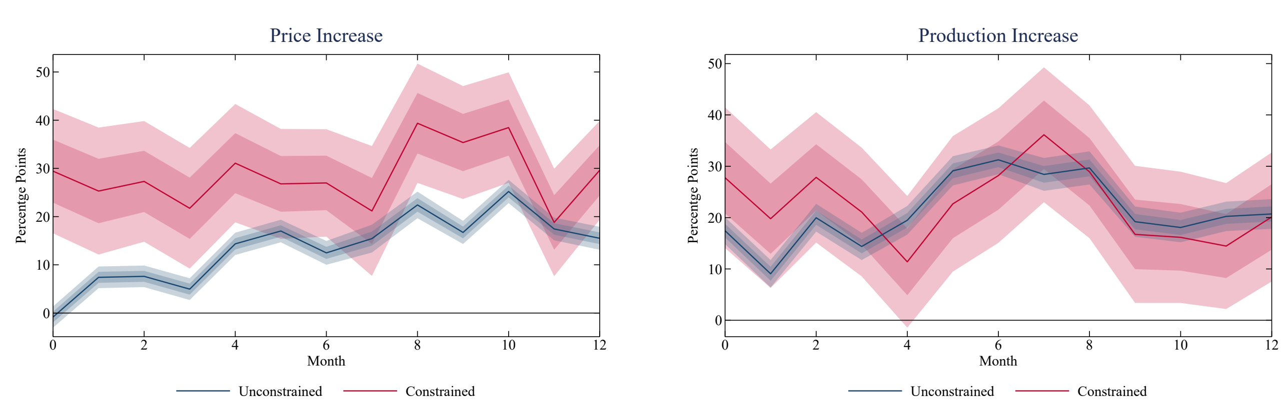


FIGURE E.7: Price and production increases conditional on material constraints: Restricted sample

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for material-constrained (red) and not material-constrained (blue) firms based on estimating Equation (3). Dependent variable is a dummy indicating price increases (left panel) and production increases (right panel). The sample is restricted to firms that we observe for at least two years. Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

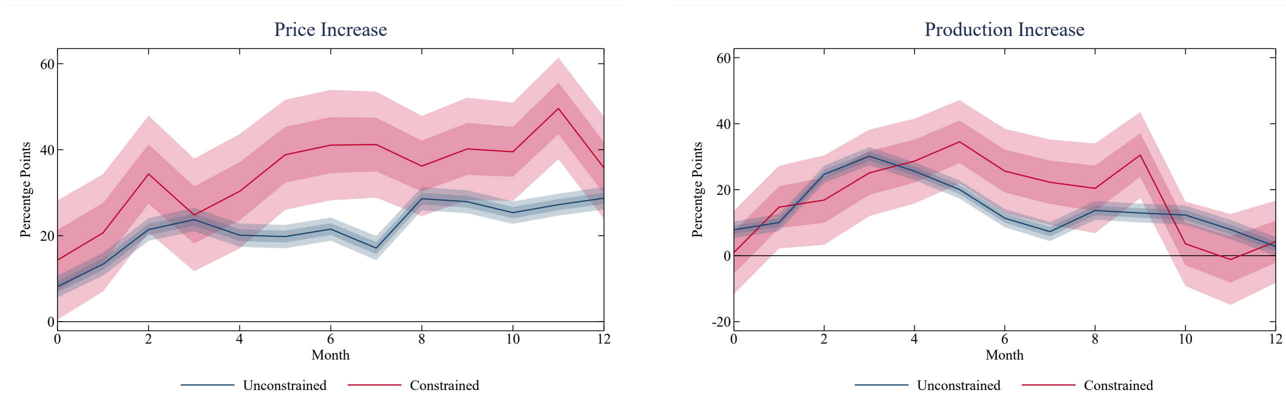


FIGURE E.8: Planned Price and production increases conditional on material constraints

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for material-constrained (red) and not material-constrained (blue) firms based on estimating Equation (3). Dependent variable is a dummy indicating planned price increases (left panel) and planned production increases (right panel). Details are provided in Appendix A. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

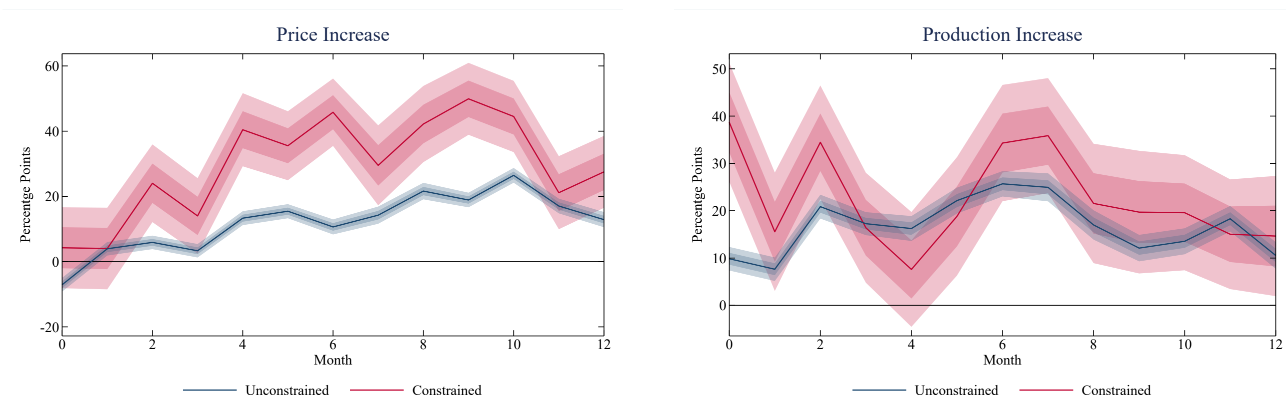


FIGURE E.9: Price and production increases conditional on material constraints: 1999-2022

Notes: Sample period: 1999 to 2022. Impulse response functions in response to a one-standard deviation monetary policy shock for material-constrained (red) and not material-constrained (blue) firms based on estimating Equation (3). Dependent variable is a dummy indicating price increases (left panel) and production increases (right panel). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

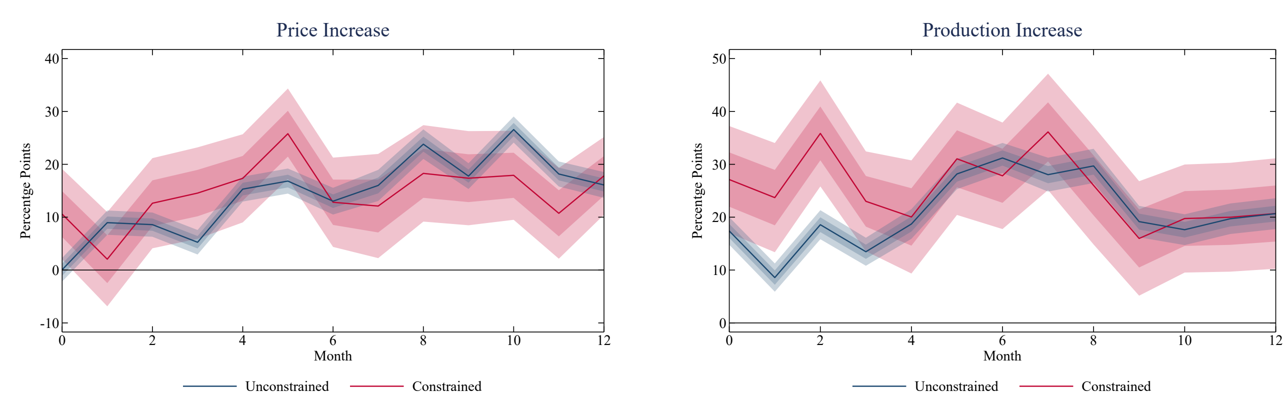
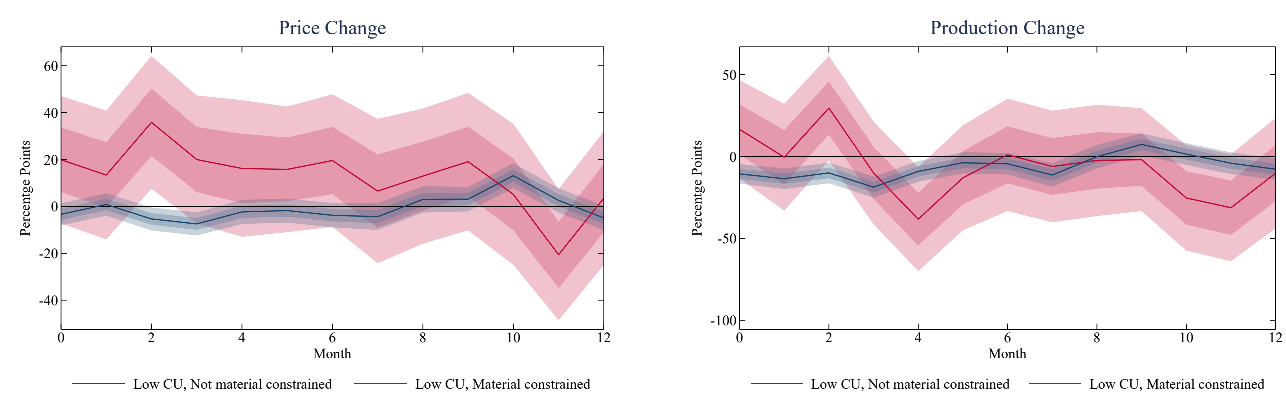


Figure E.10: Price and production increases conditional on labor constraints

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for labor-constrained (red) and not labor-constrained (blue) firms based on estimating Equation (3). Dependent variable is a dummy indicating price increases (left panel) and production increases (right panel). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

Low capacity utilization



High capacity utilization

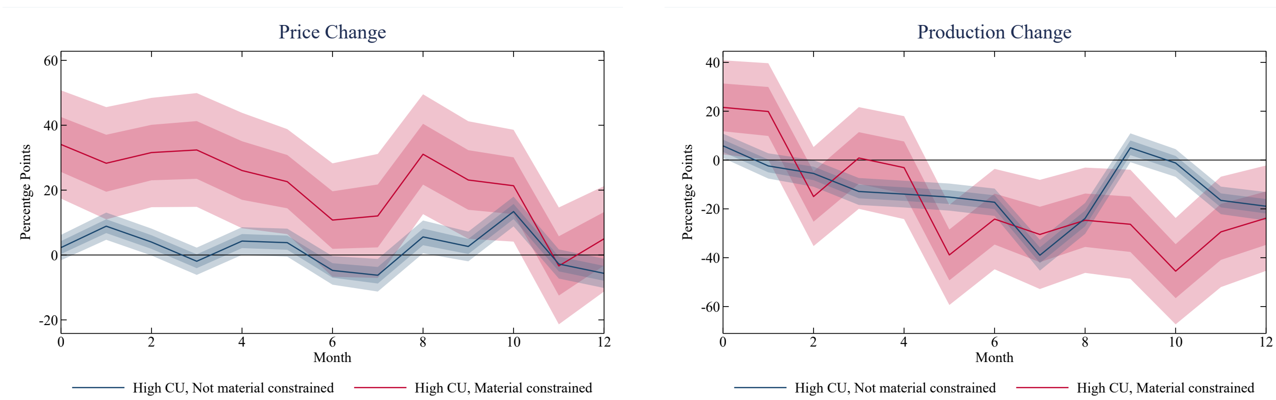


FIGURE E.11: Price and production changes conditional on material constraints for high and low capacity utilization

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for material-constrained (red) and not material-constrained (blue) firms within the groups of firms operating at low (top row) and high (bottom row) capacity utilization. Estimation is based on Equation (4). Dependent variable is a dummy indicating price changes (left column) and production changes (right column). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

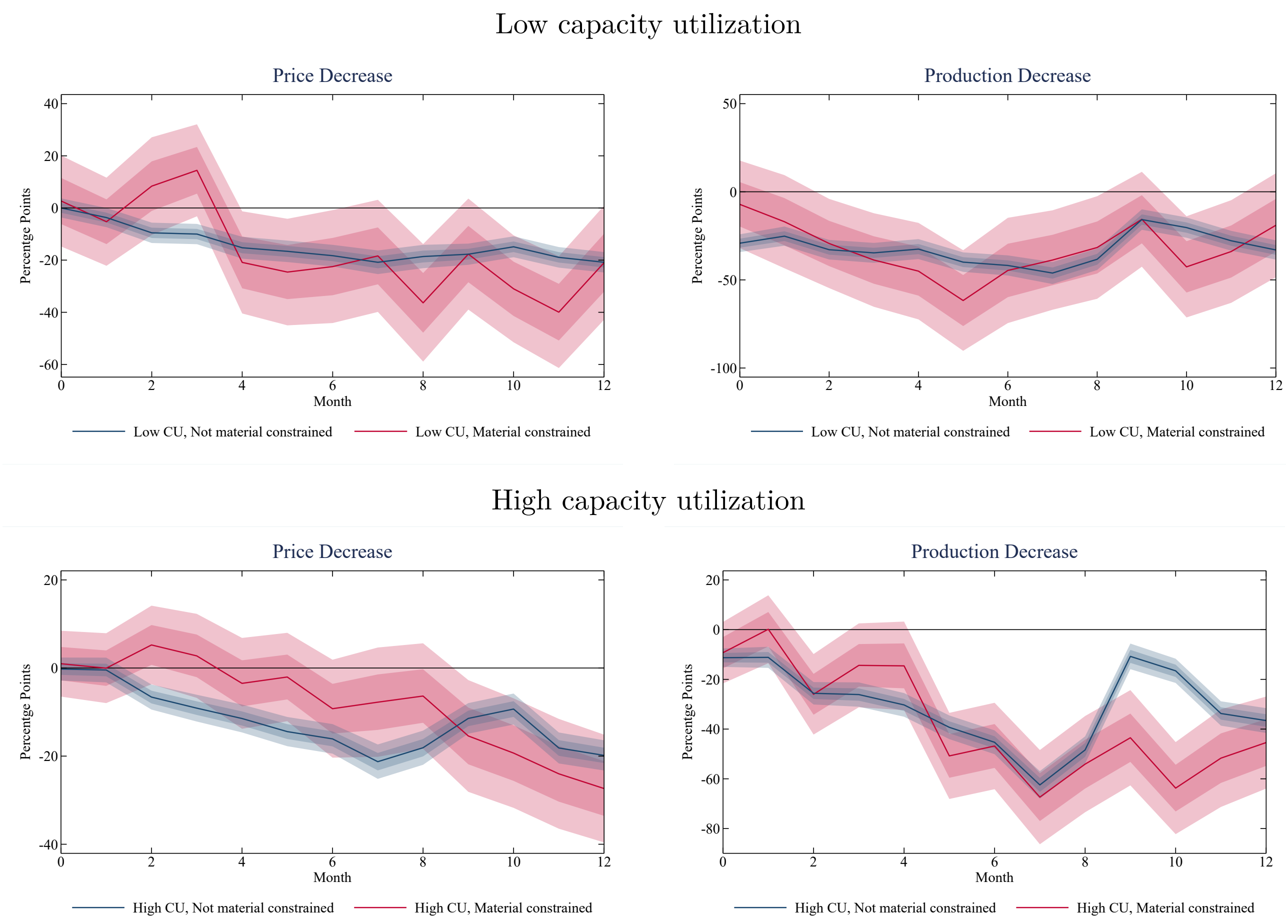


FIGURE E.12: Price and production decreases conditional on material constraints for high and low capacity utilization

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for material-constrained (red) and not material-constrained (blue) firms within the groups of firms operating at low (top row) and high (bottom row) capacity utilization. Estimation is based on Equation (4). Dependent variable is a dummy indicating price decreases (left column) and production decreases (right column). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

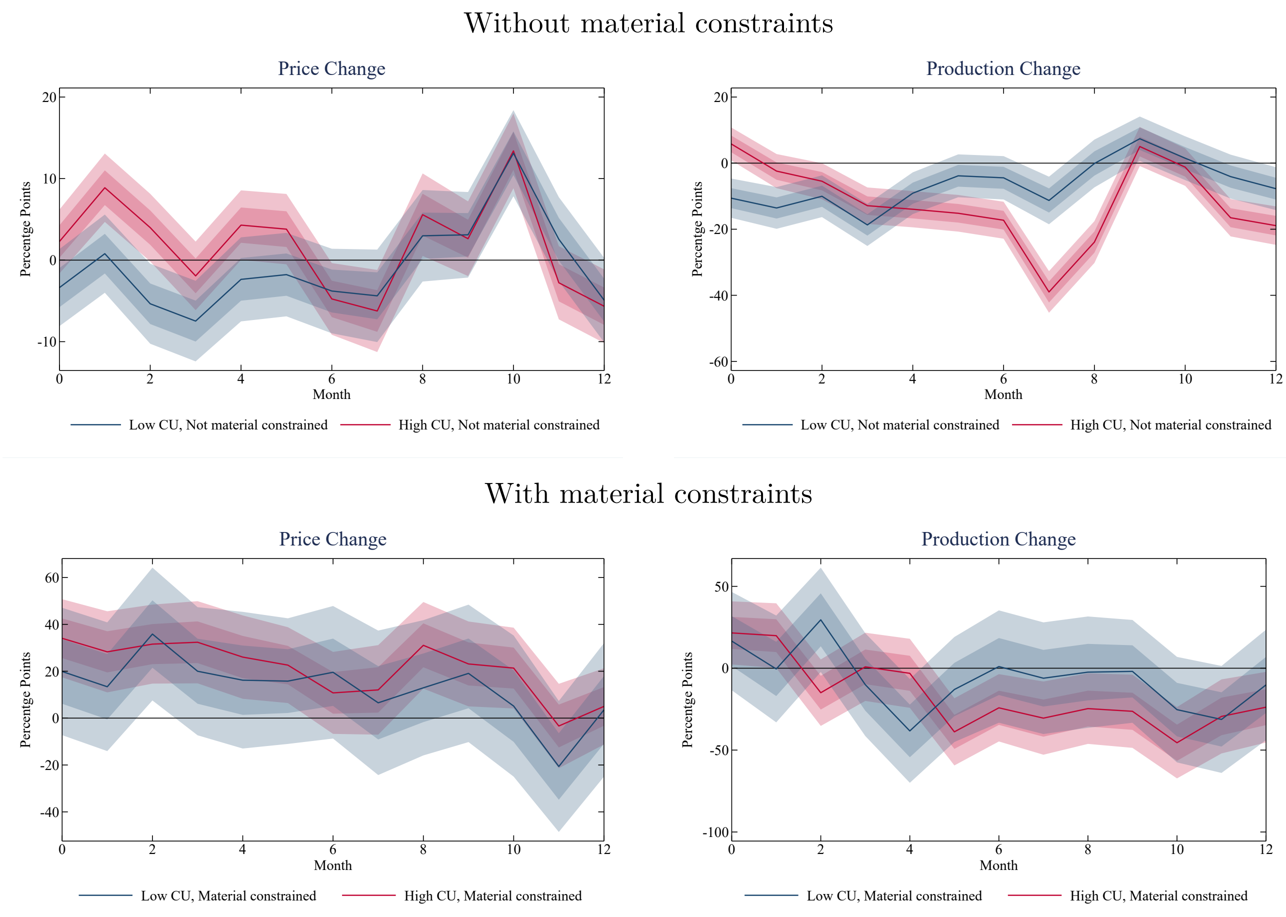


FIGURE E.13: Price and production changes conditional on capacity utilization with and without material constraint

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for firms operating at high (red) and not low (blue) capacity utilization within the groups of material constrained firms (bottom row) and not material constrained firms (top row). Estimation is based on Equation (4). Dependent variable is a dummy indicating price changes (left column) and production changes (right column). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

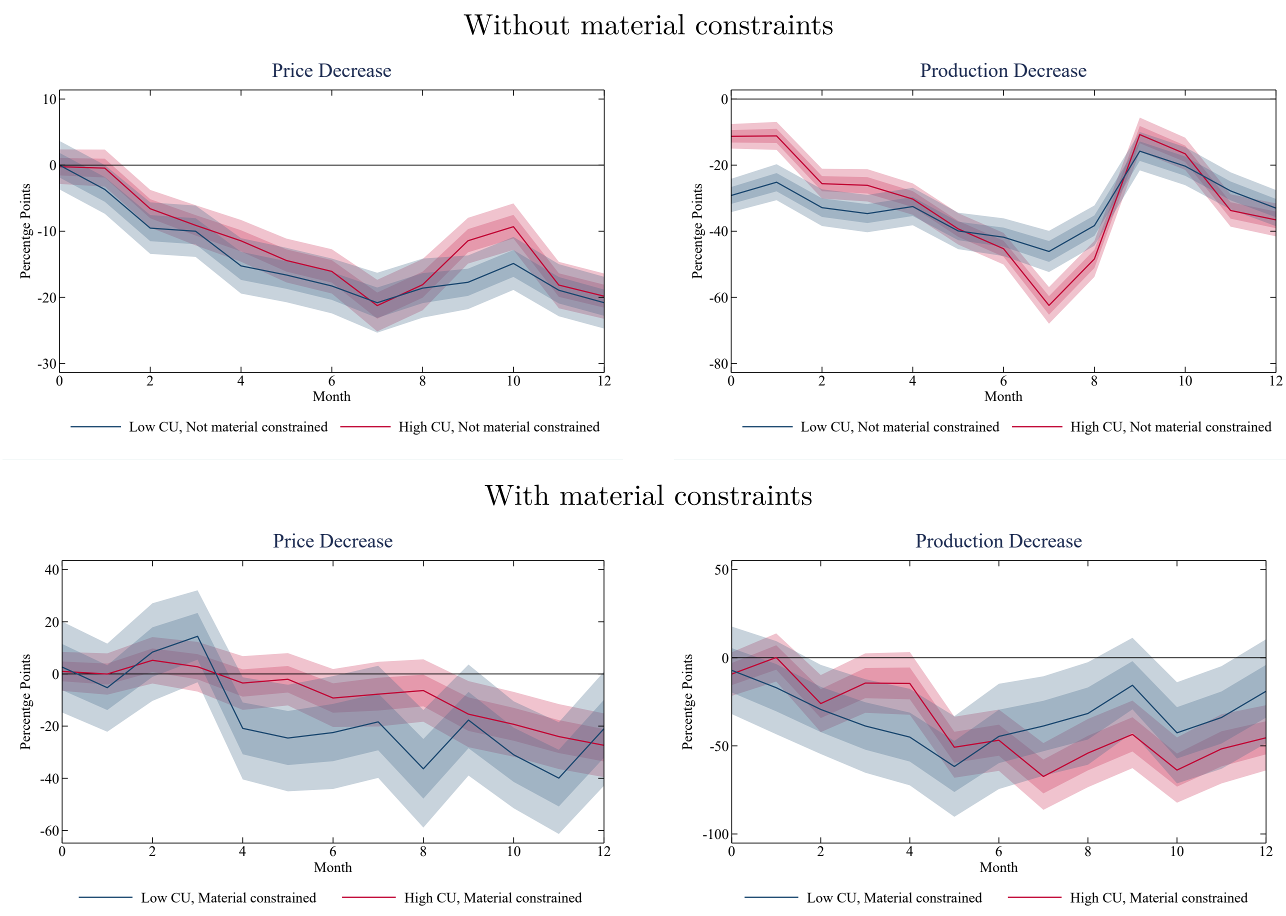


FIGURE E.14: Price and production decreases conditional on capacity utilization with and without material constraint

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for firms operating at high (red) and not low (blue) capacity utilization within the groups of material constrained firms (bottom row) and not material constrained firms (top row). Estimation is based on Equation (4). Dependent variable is a dummy indicating price decreases (left column) and production decreases (right column). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.

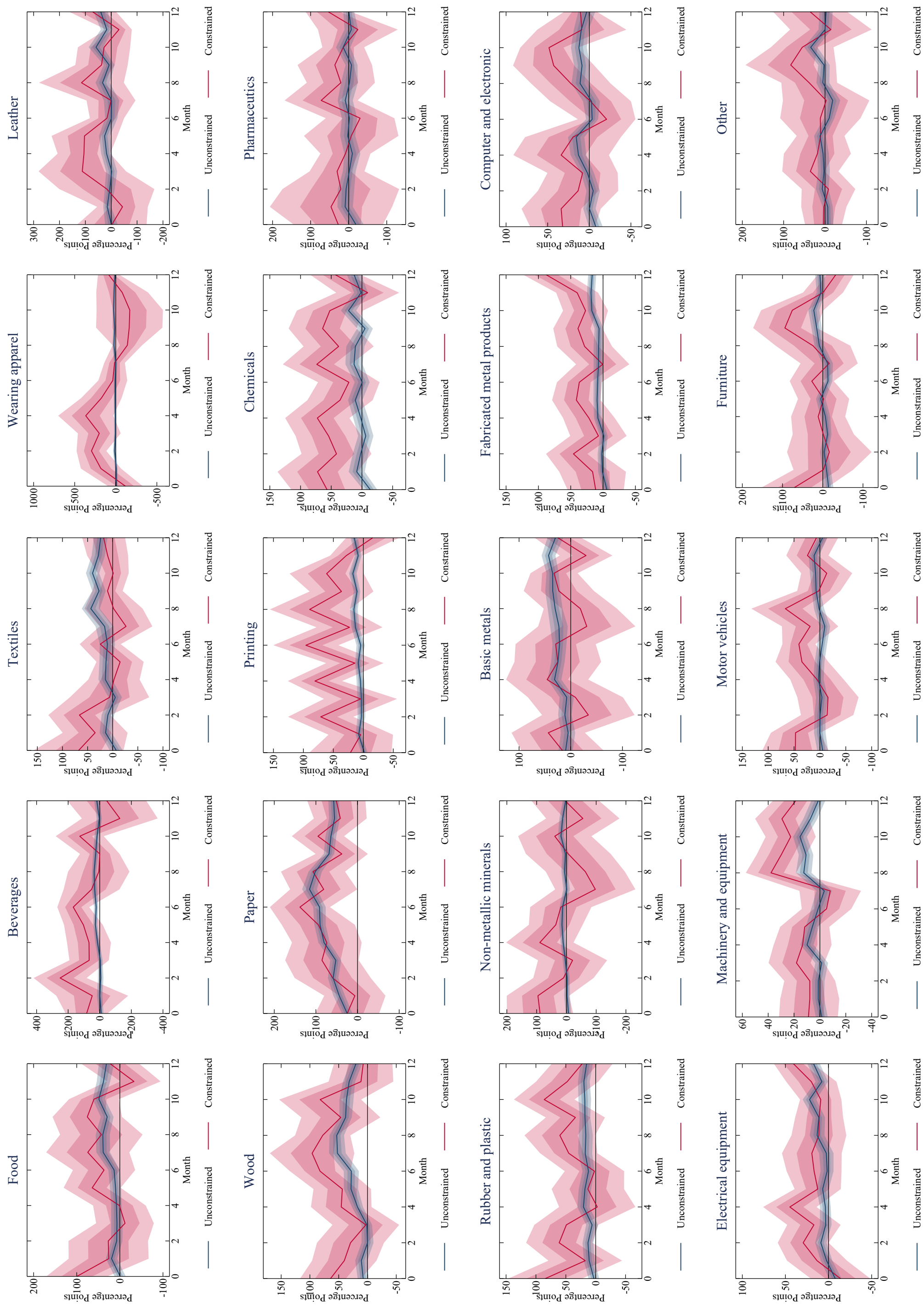


FIGURE E.15: Price increases conditional on material constraints for different industries

Notes: Sample period: 1999 to 2019. Impulse response functions in response to a one-standard deviation monetary policy shock for material-constrained (red) and not material-constrained (blue) firms based on estimating Equation (3) separately for each two-digit industry for which we observe at least twenty firms on average over our sample period. Dependent variable is a dummy indicating price increases (left panel) and production increases (right panel). Standard errors are clustered at the firm-level. Light-shaded and dark-shaded areas are one and two standard error confidence bands, respectively.