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MENU COSTS, THE PRICE GAP DISTRIBUTION AND MONETARY NON-NEUTRALITY: THE ROLE OF FINANCIAL CONSTRAINTS

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Abstract

We study how credit constraints and the frequency of price adjustment interact. We show that a working capital constraint increases the kurtosis of the price change distribution and generates small and large price changes to co-exist in a menu cost model. Our model is consistent with firm-level evidence for Germany that relates financial constraints to the frequency and direction of price changes. Financial frictions change the propagation of aggregate nominal shocks: The frequency of price adjustments fluctuates and the average price-adjustment size falls weakening the selection effect. Monetary non-neutrality only increases when the overall level of price adjustment falls.

JEL Classification: E31, E44

Keywords: Frequency of price adjustment, Financial Frictions, menu cost model

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Almut Balleer, Nikolay Hristov, and Dominik Menno*

February 27, 2020

Abstract

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1 Introduction

The degree of monetary non-neutrality is not a new, but nevertheless still fervidly disputed issue in macroeconomics. In the presence of menu costs, monetary non-neutrality may be small (see e.g. Caplin and Spulber (1987), Golosov and Lucas (2007) or Karadi and Reiff (2019)) or large (see e.g. Midrigan (2011), Gertler and Leahy (2008), Nakamura and Steinsson (2010) or Alvarez and Lippi (2014). Two central aspects that underly these differences are the shape of the distribution of desired price changes of firms as well as the selection towards large price changes in response to aggregate nominal shocks. This paper adds another perspective to the ongoing discussion by considering the role of financial constraints. We investigate how credit constraints and price setting decisions of firms interact and how this interaction affects the price gap distribution, the selection effect and, hence, monetary non-neutrality.

We develop a partial-equilibrium menu cost model with heterogenous firms in which financial frictions are present in form of a working capital constraint. In this framework, financial frictions and price setting are mutually interdependent. The presence of a working capital constraint changes the shape of firms' profit functions. On the one hand, being financially constrained affects the pricing decision of a firm: firms with initially low prices that sell large quantities may be unable to finance their production inputs and therefore find it optimal to scale down production and/or adjust prices up. On the other hand, firms seeking to gain market share may want to lower their prices. However, by doing so, they may optimally choose to become financially constrained when expanding production. In a dynamic setup, firms moreover decide on whether or how much to change the price in order to avoid financial constraints today and/or in the future.

The presence of a working capital constraint therefore has important consequences: Given demand, the optimal reset price falls less with productivity which reduces gains from adjusting prices. This compresses the price gap distribution increasing its kurtosis. Hence, even though price adjusting firms tend to be financially constrained, nominal rigidities, if at all, increase when financial constraints are present. At the same time, the model replicates the coexistence of very large and very small price changes observed in German data and also documented in micro data sets for the US and other developed economies. Most standard menu-cost models fail in reproducing this coexistence and several solutions have been suggested.[1] Our model provides an alternative mechanism in this respect. Midrigan (2011) or Alvarez et al. (2016) have argued that a higher kurtosis of the distribution of price changes increases the degree of monetary non-neutrality in the menu cost model. Since financial constraints increase the kurtosis of the price distribution in the model, one would hence expect monetary non-neutrality to increase.

We calibrate our model to the German manufacturing sector. The partial-equilibrium setup of the model describes German manufacturing well, since monetary policy is determined for the Eurozone as a whole and may only partly respond to changes in production in this sector. Moreover, German manufacturing goods are exported to a large degree and, hence, consumption relevant for this sector does not directly interact with the monetary policy of the ECB. We explore rich plant-level data for German manufacturing to test implications about the relationship between financial constraints and price setting empirically. We use the ifo Business Survey, a monthly representative panel of 3600 manufacturing firms covering the years 2002-2014. The survey contains information about the extensive margin, i.e., whether and in what direction individual firms change prices. In addition, the survey provides two high-frequency, direct firm-specific measures of financial constrainedness: Firms report whether they are experiencing production shortages due to, among other reasons, financial constraints. In addition, firms give appraisals

[1] See for example Klenow and Kryvtsov (2008) or Midrigan (2011).

of their access to bank credit which is the predominant way of financing operational costs and investment externally in Germany.

It is an important implication in our model that financially constrained firms adjust prices more often than financially unconstrained firms and that they do so both upwards and, in particular, downwards. We document that this pattern holds empirically across, but also within firms taking into account various observed and unobserved sources of heterogeneity. The finding is robust with respect to various specifications of our empirical model, such as different cross-sectional subsamples and important subperiods: i.e. before, during and after the Great Recession.

Finally, we turn to the macroeconomic implications of the model and consider the responses of inflation and real output to aggregate nominal demand shocks. In a macroeconomic context our partial-equilibrium model can be interpreted as a representation of either a small open economy, an economy where monetary policy is decided for a larger monetary union, or a particular sector. Doing so, we obviously ignore important general equilibrium effects of monetary policy shocks. We nevertheless believe this to be an instructive exercise as our results exhibit the impact response of an economy through a new mechanism that has not received attention in the literature so far. Moreover, our particular interest lies in investigating the relationship between the shape of the price distribution and monetary non-neutrality which is informative also in partial equilibrium.

Financial constraints change the response of inflation to aggregate nominal shocks in the economy. First, the fraction of price-adjusting firms increases substantially in a boom and declines in a recession when financial constraints are present. Financial frictions therefore induce a cyclical variation in the degree of price stickiness which has so far not been considered in the literature.[2] This happens since the larger kurtosis of the distribution of price changes increases the mass of firms around the inaction cutoffs. Moreover, the inaction region is no longer centered around the optimal reset price (the median of the price change distribution). The optimal reset price is associated with a binding credit constraint for many firms. Hence, moving below the optimal reset price implies rationing output and induces quicker adjustment for negative compared to positive deviations from the optimal price.

Due to the larger response of the fraction of price adjusters, inflation should react more strongly to monetary policy shocks in the presence of financial constraints. Our results show, however, that this is not the case. The reason is that most of the new price adjustments are small, decreasing the average size of absolute price changes, or the intensive margin of inflation. Caplin and Spulber (1987) and Golosov and Lucas (2007) have stressed the so-called selection effect in menu cost models according to which large price changes become important after monetary policy shocks and, as a consequence, inflation reacts strongly. Our results show that financial frictions weaken the selection effect.

Our results also show that a weaker selection effect alone or a higher kurtosis of the price change distribution alone do not necessarily increase the monetary non-neutrality of the model. To increase monetary non-neutrality, a higher kurtosis must be combined with an overall lower frequency of price adjustments. In our benchmark calibration, inflation equally responds and output responds less to monetary policy shocks with compared to without financial constraints. The reason is that firms that adjust output after a monetary policy shock are generally those that do not adjust prices. In the presence of financial constraints, the possibility to expand output, e.g. after an expansionary monetary policy shock, is severely restricted and, hence, average output increases less. This can be compensated by an overall larger fraction of firms that adjust output instead of prices. In our benchmark calibration, the overall frequency of price adjustments does not change when removing financial frictions. The less

[2] Vavra (2013) and Bachmann et al. (2018) investigate the consequences of uncertainty shocks for the price distribution and the effectiveness of monetary policy.

the optimal reset price falls with productivity, the more do financial constraints induce a lower overall frequency of price adjustments in steady state. This is the case in the myopic model that we present. We show that financial frictions increase monetary non-neutrality in this case.

Financial constraints therefore have the potential to alter a central trade-off faced by the central bank: In order to engineer an increase in inflation by a certain amount the monetary authority might need to generate larger changes in real activity than in a world with frictionless financial markets. In other words, our framework implies that financial frictions can increase the slope of the aggregate supply curve in the presence of menu costs, but need not do so. In contrast, we show that other sources of nominal rigidities such as exogenous probabilities of price adjustment as in Calvo (1983) or convex price adjustment costs as in Rotemberg (1982) unambiguously generate a flattening of the aggregate supply schedule, i.e. the inclusion of financial frictions generates larger inflation and smaller output responses to aggregate shocks with compared to without financial frictions. Based on these results one may criticize that the introduction of a working capital constraint, also referred to as the "cost channel", does not to replicate sufficiently large output responses with simultaneously small inflation responses as seen in the Great Recession (similar to Gilchrist et al. (2017)). We do not argue that alternative mechanisms such as a customer market channel of pricing are not present in the data. But the endogenous link between menu costs and credit constraints may revive part of the cost channel mechanism and may therefore play a crucial role for aggregate fluctuations under certain circumstances.

Empirically, the studies closest to ours are Gilchrist et al. (2017) and Kim (2018) which both investigate the US economy.[3] Both studies focus on the direction of price changes and find that financially constrained firms increase prices more often than financially unconstrained firms. Contrary to Gilchrist et al. (2017), Kim (2018) supports our finding that financially constrained firms decrease prices significantly more often than financially unconstrained firms. Apart from providing evidence for a large Eurozone economy, a likely explanation for the difference between our results and those by Gilchrist et al. (2017) is that we measure financial constraints differently. Based on balance-sheet information, Gilchrist et al. (2017) employ a firm's liquidity ratio to assess financial constrainedness. We can replicate their findings when using the liquidity ratio available for a subset of firms in an annual sample. Several empirical studies suggest that liquidity ratios and/or similar measures of liquidity scarcity might be a highly imperfect proxy of company's financial soundness or access to credit.[4] To avoid such problems, Kim (2018) exploits a rich dataset for the U.S. containing each producer's banking relationships and constructs a proxy for the firm-specific credit supply shock occurring in 2008. We complement Kim's evidence employing a high-frequency survey based measure of financial constrainedness in a panel framework that extends the analysis beyond the Great Recession. Moreover, our study is the first to add explicit evidence on the frequency of price adjustments as such as well as its interaction with financial constraints. Closely linked to the menu cost model, we show that our empirical results both qualitatively and quantitatively match those obtained from comparable panel regressions in model-simulated data.

Similar to the empirical literature, the related theoretical studies have also focused on the interaction between financial frictions and the intensive margin of pricing decisions, i.e., they assume the fraction of

[3] Other related studies covering earlier periods are Chevalier and Scharfstein (1996) for the U.S., Gottfries (2002) and Asplund et al. (2005) for Sweden as well as Bhaskar et al. (1993) who use a small-sample one-time cross-sectional survey for small firms in the UK. Montero (2017) uses a one-time cross-sectional survey for euro area countries about the development of price markups and financial constraints conducted in 2014 to cover the period 2010-2013. de Almeida (2015) documents sectoral patterns of inflation and financial constraints for euro area countries.

[4] For example, firms that hold more cash tend to have a higher likelihood for being financially constrained, see Almeida et al. (2014) and Bates et al. (2009). Moreover, Kahle and Stulz (2013) find that during the Great Recession, U.S. firms facing an unfavourable bank-lending shock increased their liquidity (relatively more strongly), most likely due to precautionary motives.

price adjusting firms to be equal to one (see e.g. Gilchrist et al. (2017), Gottfries (1991), Chevalier and Scharfstein (1996) or Lundin and Yun (2009)). The literature on the extensive margin, i.e. considering menu costs, has in turn not focused on the interaction with financial frictions (see Barro (1972), Caplin and Spulber (1987), Dotsey et al. (1999), Golosov and Lucas (2007) or Gilchrist et al. (2017)). To the best of our knowledge we are the first to consider the interaction of the extensive margin of price adjustment and a credit constraint both empirically and theoretically.

The remainder of the paper is organized as follows. Section 2 presents the model, derives the central insights from the static model, discusses the calibration and documents the implications for the cross-section of firms. Section 3 documents the data and tests central model implications empirically. Section 4 documents and discusses the aggregate implications, compares the results to alternative sources of nominal rigidities and discusses robustness of the results. Section 5 concludes.

2 Model

In this section, we develop a simple partial-equilibrium model which combines menu costs as a source of price rigidity with a working capital constraint as a source of a financial friction. Section 2.1 presents the model and Section 2.2 develops the economic intuition of the mechanism based on a static version of the model. Section 2.3 presents the calibration and quantitative results of the dynamic model.

2.1 Baseline Model

Our model consists of a firm's problem only. There is a continuum of firms in the economy indexed by i. Each firm produces using a linear technology

$$y_{it} = z_{it} h_{it}.$$

Here, y_{it} denotes the output of the firm in period t, z_{it} denotes the productivity of the firm's labor input in period t, and h_{it} is the amount of labor hired by the firm in period t. As in Alvarez and Lucas Jr (2007), we think of the primary factor h_i as "labor-plus-productive-capital" or as "equipped labor", so that in the model total compensation of equipped labor coincides with total production costs, not just the compensation of employees. The logarithm of firm-specific productivity follows an exogenous AR(1), or

$$\log(z_{it}) = \rho_z \log(z_{it-1}) + \varepsilon^z_{it}. \tag{1}$$

Hiring a unit of equipped labor is associated with real costs equal to w. Following Nakamura and Steinsson (2008), w is assumed to be constant and equal to

$$w = \frac{W_t}{P_t} = \frac{\theta - 1}{\theta}, \tag{2}$$

where W_t denotes the corresponding nominal cost in period t. The parameter θ is the elasticity of substitution between different goods.[5]

[5]We use this normalization for simplicity, it is not essential for the quantitative results. The expression of the real costs above arises in the steady state of a general equilibrium model with a linear aggregate production function depending only on labor input and no financial constraint, monopolistic competition among firms in the goods market, and a good-specific demand function given by (3).

Demand c_{it} for the good produced by firm i in period t is assumed to be given by

$$c_{it} = a_{it}^{\theta-1} \left(\frac{p_{it}}{P_t} \right)^{-\theta} C_t, \tag{3}$$

where p_{it} is the nominal price the firm charges in period t, P_t denotes the aggregate price level in period t, C_t determines the total size of the market in period t, and a_{it} is a demand shock to which we refer to as a good-specific quality shock.[6] As in Midrigan (2011), a higher a_{it} increases the marginal utility from consuming the good but at the same time a higher a_{it} makes the good more costly to sell, as we describe below. In particular, to produce y_{it} the firm bears total real production costs of $wa_{it}h_{it}$. Aggregate consumption C_t, the aggregate nominal price level P_t, and the good-specific quality shock a_{it} are exogenously given. Following Midrigan (2011), we assume that the logarithm of the quality of good i follows a random walk:

$$\log(a_{it}) = \log(a_{it-1}) + \varepsilon_{it}^a.$$

In line with Nakamura and Steinsson (2008), the logarithm of nominal aggregate demand $S_t = P_t C_t$ follows a random walk with drift, or

$$\log(S_t) = \mu + \log(S_{t-1}) + \eta_t,$$

where μ is the average nominal demand growth rate in the economy. In the numerical simulations we assume for simplicity that the size of the market $C_t = C = 1$ is constant over time. This is without loss of generality in this partial equilibrium setting. As a consequence, the shock specification for nominal demand is equivalent to assuming that the logarithm of the price level follows a random walk. Hence, there is steady state inflation in the model.

The first friction included in our theoretical set-up is a standard menu-cost. That is, the firm has to hire an extra fixed amount of labor f in case it decides to adjust its price. We assume that the fixed cost f has to be paid at the end of the period after revenues have been realized. Hence, the menu-cost is not pre-financed and, in contrast to remaining labor costs, does not appear in the working capital constraint below. This avoids that price-adjusting firms face a tighter financial constraint through the presence of the menu cost directly.[7]

The second friction is a financial constraint in the form of a working capital constraint, i.e., we assume that payments of wages have to be made prior to the realization of revenues. Accordingly, the firm faces a cash flow mismatch during the period and has to raise funds amounting to the total costs of production $l_{it} = wa_{it}h_{it}$ in the form of an intra-period loan. However, the firm cannot borrow more than a fraction of the real liquidation value of its collateral plus a fraction of its sales:[8]

[6]The demand function reflects the optimal decision of the consumer if her consumption basket is given by the CES index:

$$C = \left(\int_{i=0}^{1} a_{it}^{1-\frac{1}{\theta}} c_{it}^{1-\frac{1}{\theta}} di \right)^{\frac{\theta}{\theta-1}}.$$

[7]In other words, the menu-cost is not pre-financed, in contrast to remaining production costs, as described below. This assumption implies that the fix cost of adjustment does not appear in the working capital constraint below. This is for simplicity. Note that quantitatively this assumption is innocuous because the menu-cost is small relative to total labor costs (approximately half of a percent of total labor costs on average).

[8]As in Jermann and Quadrini (2012), we assume that debt contracts are not enforceable as the firm can default. Default takes place at the end of the period before the intra-period loan has to be repaid. In case of default, the lender has the right to liquidate the firm's assets. However, the loan l_i represents liquid funds that can be easily diverted by the firm in case of default. The implicit assumption is that firms can divert parts of their revenues, so lenders can only access a part of the value of the firm's stock of collateral plus its current cash-flow. The lower the resale value of capital and the more cash-flow the firm can divert, the lower the recovery value of the lenders in case of default. The working capital constraint

$$wa_{it}h_{it} \leq \xi_c + \xi_s \frac{p_{it}}{P_t} z_{it}h_{it}. \tag{4}$$

The collateral in our model refers to inputs that enter the production function with a very small elasticity, such as the firm's real estate (see also Iacoviello (2005)). The collateral is normalized to one in our setup. The parameters ξ_c and ξ_s are constant and can be interpreted as the expected real liquidation value of the collateral and sales in the economy.[9] If $\xi_s = 0$, equation (4) corresponds to the working capital constraint in Jermann and Quadrini (2012) without capital and is widely used in the literature. A working capital constraint of this form (and independent of the normalization of the collateral) induces an important non-linearity in the optimal pricing decision of the firms which we discuss in detail below. If $\xi_s > 0$, sales relax the financial constraint for low price-high productivity firms. In the following, we will use $\xi_s = \xi_c = \xi$. We will set $\xi_s = 0$ in the in the robustness checks in Section 4. We show that sales in the working capital constraint improve the model fit, but do not qualitatively affect the model results.

Firms start the period with a given nominal price p_{it} and observe the exogenous realizations of the aggregate nominal price level P_t as well as idiosyncratic shocks to productivity z_{it} and quality a_{it}, respectively. Before producing, they choose whether to change the price to $q_{it} \neq p_{it}$ or to leave the nominal price unchanged. If the firm is unconstrained, the demand function pins down the desired level of output for the new price and the necessary amount of labor associated with that level of output. The financial constraint then determines whether the desired demand and therefore output level is feasible or not. If not, the financial constraint pins down the amount of labor that can be used for production and therefore determines the output level. In case the firm leaves the price unchanged, financially constrained firms might find it optimal to ration supply, in the sense that the financially constrained firm does not supply the amount demanded at the given price.

The formal structure of the firm's optimization problem is as follows: Given $(p_{it}, P_t, z_{it}, a_{it})$, the firm's real profit stream each period is given by

$$\Pi_{it} = \left(\frac{p_{it}}{a_{it}P_t} - \frac{w}{z_{it}} \right) a_{it}z_{it}h_{it}. \tag{5}$$

Let

$$\tilde{p}_{it} = \frac{p_{it}}{a_{it}P_t} \tag{6}$$

denote the quality adjusted real price of good i and denote $\tilde{y}_{it} = a_{it}y_{it} = a_{it}z_{it}h_{it}$ the respective quantity that firm i sells on the market. In analogy to Midrigan (2011), it can be shown that the firm's profits of selling good i (conditional on its quality adjusted real price) are independent of the quality of the good a_{it}, whether the financial constraint is binding or not. This feature of the process for a_{it} together with the random walk assumption allows to reduce the dimensionality of the state space and solve the firm's problem using the quality adjusted price as an endogenous state variable.[10]

can therefore be viewed as an enforcement constraint.

[9] One may think of an extension with idiosyncratic financial shocks, i.e. ξ_c and ξ_s are time-varying and follow an idiosyncratic exogenous stochastic process. Results from this extension do not change the fundamental mechanism outlined here and are available from the authors upon request.

[10] Alternatively, we could use the firm's mark-up as the endogenous state-variable where the mark-up is defined as real price over marginal costs or $m_{it} = \frac{p_{it}}{P_t} \frac{z_{it}}{wa_{it}}$. As by definition $m_{it} = \tilde{p}_{it} \frac{z_{it}}{w}$ the quality adjusted price and mark-up just differ by the proportionality factor z_{it}/w which is by assumption exogenous. For the ease of exposition, we found it more intuitive to use the quality adjusted real price as state variable.

The associated value function is

$$V\left(\frac{p_{it}}{a_{it}P_t}, z_{it}\right) = \max\left\{V^a(z_{it}), V^{na}\left(\frac{p_{it}}{a_{it}P_t}, z_{it}\right)\right\} \tag{7}$$

with

$$V^{na}\left(\frac{p_{it}}{a_{it}P_t}, z_{it}\right) = \max_{\tilde{y}_{it}} \left\{ \begin{array}{l} \left(\frac{p_{it}}{a_{it}P_t} - \frac{w}{z_{it}}\right)\tilde{y}_{it} + \beta E_t V\left(\frac{p_{it}}{a_{it+1}P_{t+1}}, z_{it+1}\right) \\ s.t. \quad \tilde{y}_{it} \leq \left(\frac{p_{it}}{a_{it}P_t}\right)^{-\theta} C \\ \frac{w}{z_{it}}\tilde{y}_{it} \leq \xi\left(1 + \frac{p_{it}}{a_{it}P_t}\tilde{y}_{it}\right) \end{array} \right\} \tag{8}$$

and

$$V^a(z_{it}) = \max_{q_{it}\neq p_{it}, \tilde{y}_{it}} \left\{ \begin{array}{l} \left(\frac{q_{it}}{a_{it}P_t} - \frac{w}{z_{it}}\right)\tilde{y}_{it} - wf + \beta E_t V\left(\frac{q_{it}}{a_{it+1}P_{t+1}}, z_{it+1}\right) \\ s.t. \quad \tilde{y}_{it} \leq \left(\frac{q_{it}}{a_{it}P_t}\right)^{-\theta} C \\ \frac{w}{z_{it}}\tilde{y}_{it} \leq \xi\left(1 + \frac{q_{it}}{a_{it}P_t}\tilde{y}_{it}\right) \end{array} \right\} \tag{9}$$

where V^a and V^{na} are the firm's value functions in the case the firm adjusts its nominal price (V^a) or leaves the nominal price unchanged (V^{na}), respectively. The fix cost f needs to be paid if the firm decides to change its price. Note that through $y_{it} \leq c_{it}$ we allow the firm to produce less than the amount of goods demanded.

2.2 Special Case: Myopic Firms

The most important insights from the model can be discussed in a simpler version of the model where firms are perfectly myopic, or $\beta = 0$. To enhance readability we abstract from quality shocks, so that $a_{it} = 1$ for all i, t and drop time indexes wherever appropriate. The parameterization follows the calibration strategy outlined in detail for the dynamic model in Section 2.3.1.[11]

Optimal reset price and inaction regions. When firms adjust their price and are financially unconstrained, their optimal reset price is given by

$$\frac{q^{uc}}{P} = \frac{\theta}{\theta - 1}\frac{w}{z} = \frac{1}{z}, \tag{10}$$

where the last equation follows from the definition of the real costs of production. Hence, financially unconstrained firms optimally charge a constant mark-up over marginal costs. Figure 1 exhibits the relationship between the real optimal price q^{uc}/P and productivity z (blue dashed line).

In Online Appendix A.2 we show that if the firm decides to adjust the price, demand is always satisfied with equality, independent of whether the firm is financially constrained or not. Hence, when the financial constraint is binding, the optimal reset price is given by:

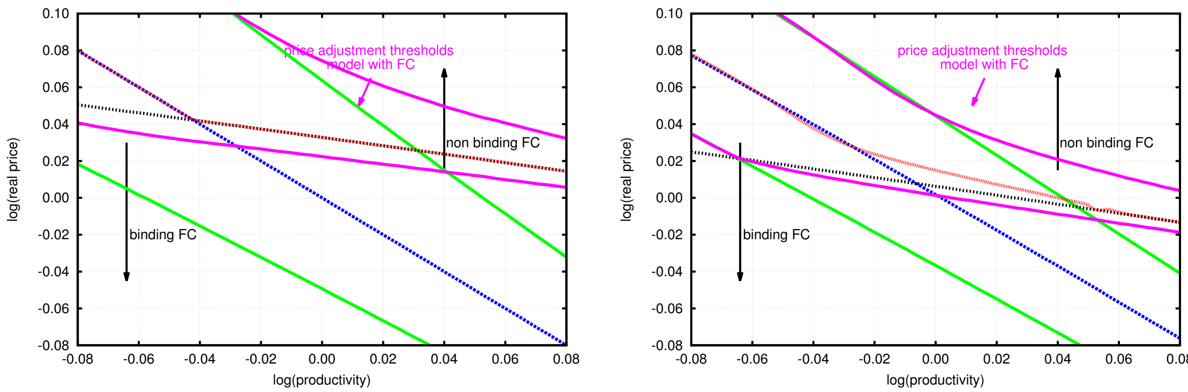
$$\frac{q^{fc}}{P} = \frac{(1+\mu)}{(1+\mu\xi)}\frac{\theta}{\theta - 1}\frac{w}{z} \tag{11}$$

where $\mu \geq 0$ is the Lagrangian multiplier associated with the financial constraint. This means that the financially constrained firm charges a mark-up over marginal costs w/z that is larger than the mark-up

[11] Note that the calibration of the myopic and the dynamic version of the model delivers parameters that are very similar.

Figure 1: Pricing policy function

(a) Myopic firms ($\beta = 0$) (b) Dynamic Model (benchmark)



Notes: The x-axis displays the logarithm of the productivity levels z_i and the y-axis shows the logarithm of the quality adjusted real price of the firm $\tilde{p_i} = p_i/(a_i P)$. Panel (a) shows the policy function in the model with myopic firms. See Online Appendix A.6 for the parameterization. Panel (b) shows the policy function for the benchmark calibration of the dynamic model. See Table 1 for the parametrization.
The blue and green lines refer to the case without financial constraints: The blue dashed line is the optimal reset price. The green lines limit the inaction region in which a firm with a pair $(z, \tilde{p})$ will optimally not adjust its price.
The red and magenta lines refer to the case with financial constraints: The red dashed line displays the optimal reset price. The magenta lines limit inaction region in which a firm with a pair $(z, \tilde{p})$ will optimally not adjust its price. The black dashed line displays the price for which both the financial constraint and demand are binding with equality.

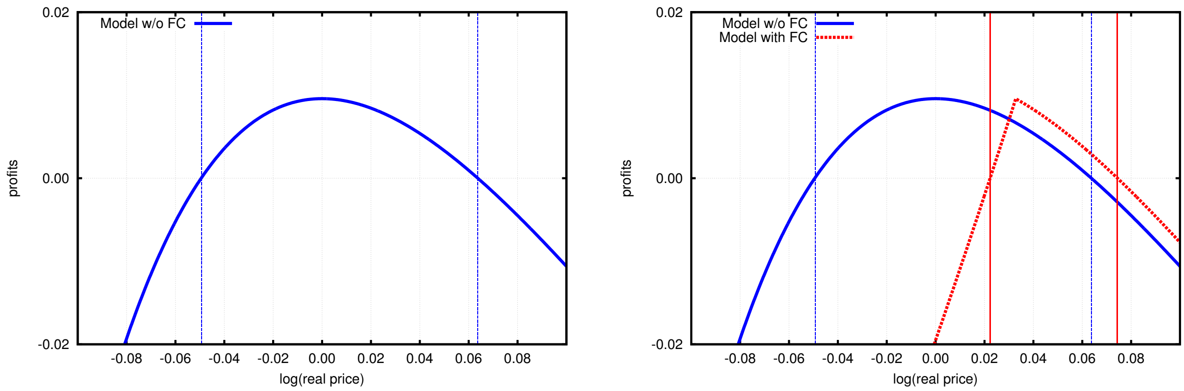
of unconstrained firms whenever μ is strictly positive and $\xi < 1$.[12] Further, it can be shown that μ is increasing in productivity if $\xi < 1$.[13] Accordingly, any increase in productivity has two opposing effects on the financially constrained firms' effective marginal costs: it decreases them via the standard marginal cost channel by reducing the term w/z but it also increases them via the Lagrangean multiplier μ as the borrowing constraint becomes more painful. Consequently, the elasticity of the financially constrained optimal price q^{fc} with respect to productivity z is smaller than (or at most as large as) the corresponding elasticity of the optimal price without a financial constraint q^{uc}.[14]

Figure 1 illustrates this result graphically. Panel a) shows the myopic case, panel b) shows the respective policy function in the benchmark dynamic model which we will describe in more detail below. The optimal reset price in the model without financial constraint is the blue dashed line (equation (10)). The black fine dashed line displays price-productivity combinations for which both the financial constraint and the firm's demand schedule is binding at the same time. This means that price-productivity combinations exactly on as well as below the black dashed line are associated with a binding financial constraint, price-productivity combinations above the black dashed line imply that the constraint is slack. Note that to the right of the intersection between the black fine dashed and the blue dashed line, the unconstrained profit maximum can no longer be achieved. For each productivity level, the red line displays the optimal reset price in the model with financial constraint (equation (11)). Figure 1 illustrates that being financially constrained may affect the pricing decision of a firm: firms with initially low prices that sell large quantities may not be able to finance their production inputs and may therefore find it optimal to scale down production and/or to adjust prices up. Firms with initially high prices seeking to gain market share may want to lower their prices. However, by doing so, they may run into financial constraints when expanding production.

[12] Henceforth we will assume that the condition $\xi < 1$ is satisfied.
[13] See Online Appendix A.2 for a formal proof.
[14] Online Appendix A.2 shows that revenues per unit labor employed qz are increasing in productivity. This means that the elasticity of the price with respect to productivity is less than unity for financially constrained firms, while it is equal to unity for unconstrained firms.

Figure 2: Gain of non-adjustment for $z = 1$, model with myopic firms ($\beta = 0$)

(a) Model without financial constraint (b) Model with financial constraint



Notes: Red dashed lines refer to the model with financial constraints in the model with myopic firms. Blue solid lines refer to the model when removing the financial constraint, keeping all other parameters constant. Note that for illustrative purposes the profit curves are normalized such that the maxima in the model with and without financial constraint have the same numerical value.

In addition, Figure 1 exhibits the inaction regions for all different price-productivity combinations as the area in between the green lines (for the economy without financial constraint) and the magenta lines (for the economy with financial constraint). Firms initially located off the optimal reset price but still within the inaction region will decide not to change their prices as the corresponding gain in profits would be smaller than the menu costs associated with the price adjustment.

Price adjustment and non-adjustment. The above documents that in the presence of financial constraints, the optimal reset price implies binding financial constraints for a substantial number of productivity levels. Right of the kink of the optimal reset price, each price-adjusting firm becomes (or remains) financially constrained. In contrast, only a fraction of the non-adjusting firms in this productivity range is characterized as constrained: firms with low prices and rationed demand, located below the black dotted line but still above the magenta line in Figure 1. At productivity levels left of the kink, both price adjusters and non-adjusters are financially unconstrained. Consequently, the introduction of the financial friction increases the share of unconstrained firms within the group of non-adjusting firms relative to the same share within the group of price-adjusting firms. We will test this implication of the model empirically in Section 3.

At the same time, the introduction of the financial friction reduces the overall frequency of price changes in the economy. To understand this, consider a firm located at its profit maximum. Due to the lower elasticity of the optimal reset price, the same change in productivity will put the firm in a situation in which the distance to the optimal reset price is smaller than in a world without financial frictions. Since the gain in profit is small, the firm is more likely not to adjust its price in a world with compared to a world without financial constraints. Appendix A.2 contains a formal proof of this model property for the static model. Interesting is the case of those firms that experience a positive change in productivity. The positive productivity shock relaxes the constraint, since the firm can produce the same output at lower costs. These firms could potentially gain market share by reducing their price, but decide not to do this in the presence of financial frictions. Hence, financial frictions do not only affect those firms that adjust prices and for which the constraints bind, but also those firms that are unconstrained and do not adjust prices.

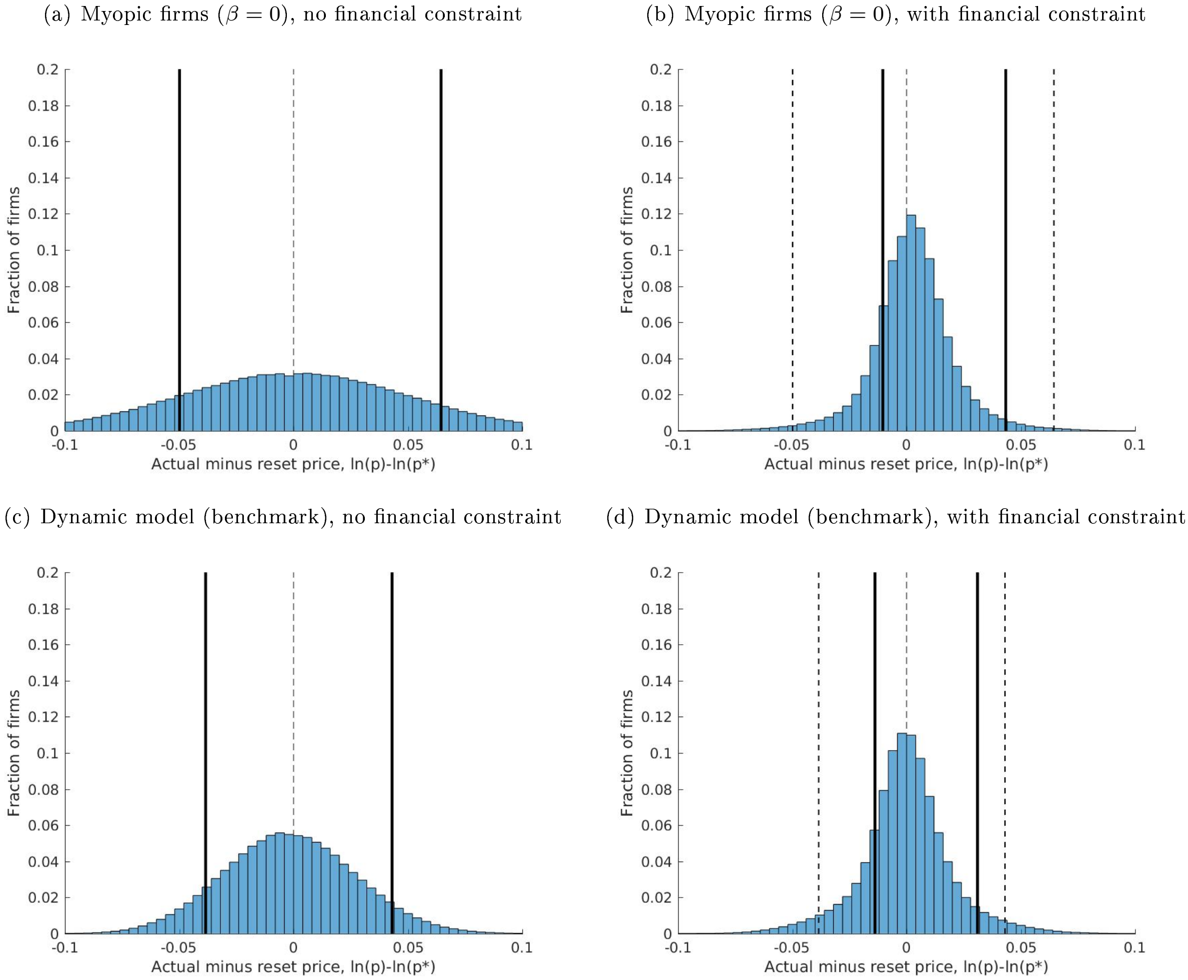
Profit function. The introduction of the working capital constraint changes the shape of the profit function of the firm. This is illustrated in Figure 2 for an exemplary productivity level of $\log(z) = 0$ and our benchmark parametrization. In Panel (a), the concave solid blue line corresponds to the profit of a financially unconstrained firm as a function of the logarithm of its real price $\tilde{p}$. The profit function has its maximum at $\tilde{p} = 1$ which corresponds to the optimal price in a world with fully flexible prices. The vertical dashed lines around the maximum mark the inaction region. Profit functions for different productivity levels are shown in Online Appendix A.4.

Panel (b) compares profits in an economy without financial frictions (solid blue) and with financial frictions (dashed red). The red profit function displays a kink at the price where both the financial constraint and demand hold with equality. As shown in the Online Appendix A.2, this point corresponds to the constrained optimal reset price in the myopic model (for the productivity level $\log(z) = 0$). Prices lower than the price at (or to the left of) the kink correspond to binding financial constraints. This means that for smaller prices, firms cannot finance, produce and sell more output. Instead, demand is slack and output is rationed. For prices higher than the price at (or to the right of) the kink, the constrained profit function has the same slope as the unconstrained one. But since the constrained optimal reset price is higher than the unconstrained optimal reset price, profits fall more quickly when prices increase relative to the optimal reset price. Left of the kink, profits are substantially steeper than in the unconstrained case. For the simplest possible way to illustrate this result, consider the special case of non-pledgable sales, i.e., a constraint of the form $wh_i \leq \xi$. In that case, the profit function becomes linear in the real price. With a non-binding constraint right of the kink of the profit function, price adjustments induce changes in unit profits of the same sign which however, are partly offset by an opposite reaction of demand. In contrast, to the left of the kink, there is no offsetting change in demand.

Distribution of desired price changes. Figure 3 shows the distribution of desired price changes, the so-called price gap distribution, for a model with financial constraints (Panel (b)) and without financial constraints (Panel (a)) in the myopic case (first row) and the dynamic benchmark economy (second row). By visual inspection of the graphs as well as by considering the calibration output in Table 1, one can see that financial constraints induce a larger kurtosis and skewness of the price gap distribution. The price distribution hence reflects the stronger concavity of the profit function. Moreover, the aforementioned asymmetry of the profit function causes the optimal reset price to be located towards the lower bound of the inaction region (see Figure 2). Consequently, the mode of the price gap distribution is also located towards the lower bound of the inaction region (In Figure 3, the solid vertical lines show the inaction bounds for the average productivity of $\log(z) = 0$). As a consequence, the mass of firms at the lower inaction bound exceeds the mass of firms at the higher inaction bound. Online Appendix A.4 shows that the effect of financial frictions on price gap distributions is similar at different productivity levels.

Financial constraints and productivity. From Figure 1, it is easy to see that the presence of financial constraints implies on average higher prices and lower output compared to a situation without financial constraints. Obviously, for price adjusting firms, the model implies that firms with a relatively high productivity are more likely to be constrained. The intuition straightforwardly stems from the working capital constraint: a higher productivity level is associated with lower marginal costs and thus, with stronger relative competitiveness. Accordingly, high productivity firms will be willing to expand by lowering prices and thus attracting more demand. However, the desired expansion is associated with a higher labor input, a higher wage bill, a higher level of borrowing and a higher likelihood of being constrained.

Figure 3: Price-gap distribution



Notes: The histograms display the distribution of the price gap, defined as the actual (pre-adjustment) price minus the optimal reset price, or $\log(p_i) - \log(p_i^*)$, where p_i^* is firm i's optimal reset price and p_i is firm i's price *before* price adjustment. The solid vertical lines mark the inaction region for a firm with average productivity (i.e. $log(z) = 0$) in the model with and without financial constraint, respectively. The dashed line at zero shows the location of the optimal reset price. The dotted lines in Panels (b) and (d) are the same as the vertical solid lines for the 'No FC'-model shown in Panels (a) and (c), respectively.

It is important to point out that the prediction that more productive firms are the ones that are financially constrained only applies to firms that optimally choose to adjust their price. Among the firms that optimally decide not to adjust the price, the relationship is reversed: relatively less productive firms will be financially constrained. These are firms that draw a negative productivity shock that is large enough to make their financial constraint bind (due to their increased wage bill) but not large enough to drive them out of the inaction region, so they do not find it optimal to adjust the price.[15]

The literature on financial constraints has predicted a positive a positive relationship between the level of idiosyncratic productivity and the likelihood of being constrained – conditional on the firm specific capital stock (see Cooley and Quadrini (2001), Azariadis and Kaas (2016), Buera et al. (2013), Khan and Thomas (2013) or Midrigan and Xu (2014)). In these models, firms receiving a sequence of favorable productivity shocks tend to accelerate the accumulation of capital which, in the long run, enables them to outgrow the credit constraint. This mechanism is absent here as capital is assumed to be fixed. We view this as a reasonable simplification since our focus is on short-run aspects of firm

[15] See Online Appendix A.2 for a formal proof of these claims in the model with myopic firms.

behavior. Furthermore, it is well documented that the level of capital adjusts only slowly over time, both at the aggregate as well as the firm level.[16] Finally, the implications of our theoretical model do not depend on the normalization of the collateral to one. In Section 3, we document that the relationship between pricing decisions and credit constraints is qualitatively unaffected by controlling for firm size or restricting the sample to small or large firms only which suggests that the amount of firm-specific capital is not a major determinant of pricing behavior.

2.3 Dynamic Model

In the previous sub-section, we have documented that the interaction between financial frictions and the pricing decisions of firms works in both directions. On the one hand, the presence of the credit constraint affects the policy function of firms and the price gap distribution of firms. On the other hand, the optimal pricing decision determines whether the firm will end up facing a binding or a slack financial constraint. In a dynamic set-up with forward looking firms ($0 < \beta < 1$), firms now trade-off the effect of their pricing decision on current and expected profits. Unlike in the model with myopic firms, the flex-price optimum in a dynamic economy does no longer necessarily coincide with the maximum of the current profit function.

As Figure 1 shows, the optimal constrained and unconstrained reset prices differ in the static and the dynamic model, in particular in the neighborhood of the average productivity level of $\log(z) = 0$. The reason is that in the dynamic model, the firm trades off maximizing current profits against operating near the static profit maximum and avoiding to pay menu costs in the future. Doing this, the firm takes into account expected productivity realizations. If the autocorrelation of idiosyncratic productivity is relatively high, it is optimal to set a price higher than the one maximizing current profits. This way, the reset price is located further away from the lower bound of the inaction region, since future deviations from the profit maximum and the associated payments of menu costs can be avoided for a longer period of time. As a consequence, the reset price is more elastic with respect to productivity than in the myopic case.

We calibrate the model to the German manufacturing sector, since we will test some of the model implications in German manufacturing data (see Section 3). The partial equilibrium setup can be viewed as a good approximation of the impact response of German manufacturing to monetary policy surprises. First, monetary policy is determined for the Eurozone as a whole and may, if at all, only partly react to production in German manufacturing. Second, German manufacturing goods are exported to a large degree which means that consumption relevant for this sector does not directly respond or interact with monetary policy in the Eurozone.

2.3.1 Calibration and Parametrization

Preset parameters. We assume that time is measured in months which is consistent with the frequency of our data. The elasticity of substitution between individual goods θ is set to 7.25. This value implies an average mark-up of prices over marginal costs of about 16 percent which corresponds to the estimate provided by Christopoulou and Vermeulen (2012) for the German manufacturing sector. Producer mark-ups in the German manufacturing sector are relatively small compared to the European average and the U.S. as well as relative to the typical mark-ups in other sectors of the German economy like services (53%) and construction (20%). Therefore, the value for the elasticity θ is higher relative to what is typically used in the literature. We discuss implications of the high value of θ below. Without loss

[16] See e.g. Khan and Thomas (2013).

of generality, we assume that $C = 1$, so that the change in the log of aggregate nominal demand is equal to aggregate inflation.[17] The shock to nominal aggregate demand is calibrated to match the average growth rate and the standard deviation of the month to month growth rate of the seasonally adjusted German manufacturing producer price index between the years 2001 and 2015, hence we set $\mu = 0.001$ and $\sigma_\eta = 0.002$. In addition, we set the discount factor β at $0.96^{1/12}$ which is a value commonly used in the literature. We set $\xi_c = \xi_s = \xi$.[18]

Given the frequency of price adjustment and the size distribution of price changes we have available in the data, it is not possible to separately identify the persistence of the idiosyncratic productivity shock ρ_z simultaneously with the standard deviation of idiosyncratic permanent quality shock σ_{ε_a} and the standard deviation of the idiosyncratic temporary productivity shocks σ_{ε_z}. This is a known issue in the literature, see Nakamura and Steinsson (2008) for a discussion. Both a high persistence of $\rho_z = 0.95$ and a low persistence of $\rho_z = 0$ deliver an almost equally good match of our calibration targets based on the distance measure explained below. We choose $\rho_z = 0.95$ as a baseline due to the slightly better fit of the non-targeted moments. The persistence of the productivity shocks is important in the model, since firms take into account how quickly their position in the productivity–price diagram will change in the following months. We will address this when discussing the robustness of the results below.

Calibration. The remaining four model parameters, i.e. the menu cost f, the standard deviation of the permanent idiosyncratic quality shock σ_{ε_a}, the standard deviation of the idiosyncratic productivity process σ_{ε_z}, and the parameter shaping the borrowing limit ξ are calibrated to match the following moments. We match the frequency of price adjustment and the frequency of price increases from the ifo Business Survey as documented in Section 3 (rows 1 − 2 in Table 1). The literature highlights the importance of matching the size distribution of price changes for aggregate predictions of menu-cost economies.[19] We therefore complement the extensive margin of price adjustment with moments from the size distribution of price changes (rows 3 − 10). These are based on absolute non-zero price changes of German manufacturing firms for the sample period 2005.M1 − 2016.M12 which form the basis of the official Producer Price Index for industrial products released by the German Federal Statistical Office.[20]

A key feature of the German data is that there is a large heterogeneity in the size of price changes. This has been documented for other countries as well (see e.g. Nakamura and Steinsson, 2008; Midrigan, 2011; Alvarez et al., 2016, and references therein). The mean absolute price change (row 3) of 3.5 percent is relatively large. Rows 4 − 8 report several percentiles of the size distribution of price changes. Notice that a quarter of all non-zero price changes are less than 1 percent in absolute value. Hence, a lot of price changes are very small. Similarly, many price changes are very large: the 75th percentile of all non-zero price changes is 4.4 percent in absolute value, while the 90th percentile of all non-zero price changes is 7.8 percent in absolute value. These findings line up almost perfectly with the findings by Vermeulen et al. (2012) who show quartiles of the size distribution of producer prices in Germany and

[17] Recall that aggregate demand is defined by $S_t = P_t C_t$. With $C_t = 1$, $S_t = P_t$ for all t.

[18] Monthly changes in the valuation of firms' real liquidation value of the collateral and sales could be captured by idiosyncratic shocks to the tightness of the working capital constraint (ξ). Results to this extension of the model are very similar to the benchmark model. Results are available upon request from the authors.

[19] Midrigan (2011) and Alvarez et al. (2016) are prominent recent examples that focus on the size distribution of price adjustment for retail prices.

[20] See https://www.destatis.de/EN/FactsFigures/NationalEconomyEnvironment/Prices/IndexProducerPricesIndustrialProducts/IndexProducerPricesIndustrialProducts.html for a description of the data. The same data is used in Bachmann et al. (2018), however, aggregated at the quarterly frequency. The data is not available before 2005. Price changes are computed as the log-difference in nominal prices (price per unit, as unlike in scanner data package size might vary). The data do not include price changes due to sales and the Federal Statistical Office controls for product improvement. We drop price changes whose absolute value is smaller than 0.1 percent and we remove observations with log-price changes larger in absolute value than the 99th percentile of absolute log price changes.

Table 1: Calibration

	Data	(1) FC	(2) No FC	(3) No FC recalibr.
A. Parameter values				
Assigned				
θ		7.25	7.25	7.25
β		$0.96^{1/12}$	$0.96^{1/12}$	$0.96^{1/12}$
μ (percent)		0.10	0.10	0.10
σ_η (percent)		0.20	0.20	0.20
C		1	1	1
k		1	1	1
ρ_z		0.95	0.95	0.95
Calibrated				
f (percent of wages)		1.098	1.098	0.190
σ_{ε_z} (percent)		2.547	2.547	1.083
σ_{ε_a} (percent)		0.227	0.227	0.108
ξ		0.360	-	-
B. Moments				
Targeted in calibration				
1. $Pr(\Delta p \neq 0)$	0.19	0.18	0.19	0.19
2. $Pr(\Delta p > 0)$	0.11	0.13	0.10	0.11
3. Mean abs. price change	0.032	0.02	0.06	0.02
4. P10 abs. price change	0.003	0.009	0.040	0.018
5. P25 abs. price change	0.008	0.012	0.045	0.020
6. P50 abs. price change	0.02	0.017	0.053	0.023
7. P75 abs. price change	0.044	0.025	0.063	0.027
8. P90 abs. price change	0.078	0.049	0.074	0.032
9. Kurtosis abs. price change	7.21	6.29	4.29	4.79
10. Skewness abs. price change	2.18	1.88	0.99	1.23
Distance		0.052	0.079	0.067
Non-targeted moments				
11. Std. dev. abs. price change	0.035	0.016	0.014	0.005
12. P5 abs. price change	0.002	0.008	0.038	0.018
13. P95 abs. price change	0.103	0.061	0.082	0.035

Notes: Values refer to monthly frequency unless indicated otherwise. Data on the frequency of price adjustment (rows 1 – 2) come from the ifo Business Survey. Data on the size distribution of price changes (rows 3 – 10 and 11 – 13) are from the Producer Price Index for Industrial Products from the German Statistical Office. The benchmark model in column (1) is calibrated on the empirical moments listed in rows 1 – 10. Model (2) has the same calibration as the benchmark model but removing the financial constraint. In model (3), the parameters (f,σ_{ε_a},σ_{ε_z}) are re-calibrated using the moments listed in rows 1 – 10 under the assumption that the financial constraint is absent.

other European countries (focusing on a different sample covering the mid-90s and early 2000s).[21] Rows 9 and 10 report the kurtosis and the skewness of the size distribution of non-zero price changes. The kurtosis in the German data of 7.21 is slightly higher than in the U.S. (between 3-5) but comparable to the kurtosis of 8 for France computed from CPI micro data as reported in Alvarez et al. (2016).[22]

Implementation. The criterion function we use to calibrate the four model parameters $(f, \sigma_{\varepsilon_z}, \sigma_{\varepsilon_a}, \xi)$ is the square root of the sum of squared deviations of the moments in the simulated model from those in the data, those listed in rows 1 to 10.[23] The respective values of the distance measure are displayed in Table 1. To approximate the value and policy functions we iterate the value function on a discretized state space. The latter has two dimensions - one with respect to idiosyncratic productivity z_i and the other for the individual beginning-of-period quality-adjusted real price $p_i/(a_i P)$ conditional on current-period's realization of the idiosyncratic permanent shock a_i and aggregate inflation (entering through the aggregate price level P).[24]

2.3.2 Results

Our benchmark model delivers the moments that minimize our criterion function. The resulting parameter values and moments are documented in the column (1) 'FC' in Table 1. The menu cost is 1.098 percent in terms of average revenues which lies towards the upper end but within the range of fix costs found previously in the literature (see e.g. Midrigan, 2011, and references therein). The standard deviation of the temporary idiosyncratic shocks is equal to 2.547 percent while the standard deviation of the permanent idiosyncratic shock is equal to 0.227 percent. In addition to our benchmark model, Table 1 exhibits the parameters and output from the model without financial frictions. In the first version (column (2)), we keep all parameters from the benchmark and set ξ such that the financial constraint never binds. In the second version (column (3)), we recalibrate the parameters to match the targeted moments in the data.

Nominal rigidities The three economies summarized in columns (1) – (3) of Table 1 quite closely match the average frequency of price changes (row 1) as well as the frequency of price increases (row 2). Unlike in the myopic model in Section 2.2, financial frictions do not affect the overall frequency of price adjustments in the economy in the dynamic model. As discussed above, this model property is closely linked to the elasticity of the reset price with respect to productivity. A lower elasticity reduces potential price changes and profit gains from price adjustment. Reducing the autocorrelation of the idiosyncratic shocks as well as rendering sales not pledgable reduces the elasticity of the reset price with respect to productivity. In these economies, the frequency of price adjustment increases when removing financial constraints (see Online Appendix A.6).

Small and large price changes Table 1 documents substantial differences between the three economies regarding the ability to match the distribution of absolute price changes, depicted in rows 3 – 13. As

[21] Klenow and Kryvtsov (2008), Klenow and Malin (2010) and Midrigan (2011) also document the coexistence of many large and small price changes in the US retail sector.

[22] Note that these studies typically report the moments of the distribution of standardized price changes in order to correct for product heterogeneity. Also, these studies typically focus on retail prices. Here, we show the kurtosis of non-standardized price changes from producer prices in the manufacturing sector.

[23] We do not use a weighting matrix. However, since the kurtosis and skewness are two orders of magnitude higher than the price changes, in the criterion function we divide the kurtosis in the model and in the data by 100. Alternatively, we could have multiplied the price changes by 100, so that frequencies and price changes are in percent.

[24] See Online Appendix A.3 for further details on the numerical solution and model simulation.

indicated by the distance measure, our benchmark model with a financial friction outperforms the ones with a frictionless credit market. Switching off the financial friction but leaving all other parameters unchanged results in a model largely at odds with the empirically observable distribution of price changes (see column (2) in Table 1). In particular, it is no longer possible to generate small price adjustments. Column (3) in Table 1 shows that a recalibrated model without financial frictions faces similar difficulties in reproducing the coexistence of large and small price changes. In particular, the recalibration implies a lower menu-cost parameter f and smaller volatilities of the idiosyncratic shocks σ_{ϵ_z} and σ_{ϵ_a}. The reduction in f is needed to reduce the average absolute magnitude of price adjustments. This has to be combined with less volatile shocks to prevent an overstatement of the frequency of such adjustments (column (3)).

Our calibration exercises documents the well-known fact that standard menu-cost models typically have a hard time to reproduce the presence of small price adjustments.[25] The literature has proposed several remedies like sectoral heterogeneity in menu costs (Klenow and Kryvtsov, 2008), multi-product firms combined with special distributions of the exogenous shocks (Midrigan, 2011), smooth transition between state and time dependent pricing (Costain and Nakov, 2011b) or precautionary motives (Costain and Nakov, 2015). Here we show that the non-linearity introduced by a simple working capital constraint may also serve as an explanation of the presence of both, very large and very small price changes.

Kurtosis of price changes Comparing columns (1) – (3) in Table 1 exhibits another important aspect of our study: The model with financial frictions generates a kurtosis and skewness of price changes much closer to the one in the data than the recalibrated version of the model without financial frictions. This reflects what has been discussed above: The presence of financial constraints increases the kurtosis and skewness of the distribution of desired and actual price changes (see Figure 3). Unlike in the myopic model, the kurtosis of the price distribution increases from low to high productivity levels in the dynamic model (see plots in Appendix A.4).

Alvarez et al. (2016) argue that the kurtosis as such as well as the kurtosis relative to the frequency of price changes presents a sufficient statistic for the real effects of monetary policy shocks in menu cost models. This means that we should expect larger real effects in response to monetary policy shocks when credit constraints are present. We will explore this further in Section 4. Note that extensions of the baseline menu cost model also generate a larger kurtosis of price changes, e.g. in Midrigan (2011). Unlike in this paper, our model does not generate the larger kurtosis with non-normal idiosyncratic shocks. Instead, we use normal idiosyncratic shocks and produce the higher kurtosis through our mechanism only.

Testable implications Our calibration strategy does not target any empirical moments related to financial constraints and the relationship between financial constraints and the price setting of firms. Given the calibration, the model implies that 26% of firms are financially constrained. Moreover, the model implies that firms adjust prices more often when constrained compared to when unconstrained. Since firms are heterogenous with respect to the idiosyncratic component as well as the initial price in our model, we can use model-simulated data to estimate the within-firm difference between being financially constrained and unconstrained with respect to the pricing decision of the firm. We document that becoming financially constrained increases the probability to adjust the price, at all, but also both upwards and downwards. The dynamic model hence exhibits what has already been discussed in Section 2.2: For a substantial range of idiosyncratic productivity levels, the optimal reset price is associated with

[25] This is discussed in Midrigan (2011), Costain and Nakov (2011a) and Costain and Nakov (2015) among others.

a binding financial constraint, see panel (b) of Figure 1. However, for the same range of productivity levels, only part of the non-adjusters face a binding borrowing limit and hence only a small share of non-adjusting firms are financially constrained.[26] We will compare these model implications qualitatively and quantitatively to measures in German manufacturing in Section 3.

3 Empirical Evidence

3.1 Data

We use data from the ifo Business Survey which is a representative sample of 3600 plants in the German manufacturing sector in 2002-2014. The survey starts as early as the 1950's, but our sample is restricted by the fact that the questions about financial constrainedness were added in 2002. The main advantages of the dataset relative to data used in other studies on price stickiness are twofold. First, it enables us to link individual plant's pricing decisions to both direct survey-based measures of plant-specific financial constrainedness and to indirect proxies for the financial situation based on balance sheet information. Second, the survey is conducted on a monthly basis which enables us to track important aspects of a plant's actual behavior over time as it undergoes both phases of easy and subdued access to credit while at the same time facing the alternating states of the business cycle. Since plants respond on a voluntary basis and, thus, not all plants respond every month, the panel is unbalanced.

In particular, we have monthly information about the extensive margin of price adjustment, i.e. whether and in what direction firms adjust prices. More precisely, firms answer the question: ”Have you in the last month increased, decreased or left unchanged your domestic sales prices?”.[27] More than 97% of the cross-sectional units in our sample fill in a questionnaire for a single-product only, usually the one corresponding to their main field of activity. Additionally, some plants submit separate questionnaires for each product (product group) they produce. In what follows, we therefore use the terms ”firm”, ”plant” and ”product” interchangeably. Since we do not have information about the intensive margin of price adjustment in our dataset, the calibration uses additional information based micro-level price data provided by the German Federal Statistical Office (for details, see Section 2).

The ifo survey encompasses two questions regarding the financial constrainedness of firms. Our baseline measure is derived in two steps. First, we use all firms who respond positively or negatively to the question: “Are your domestic production activities currently constrained?”. Financially constrained firms are then those firms who answer positively to the previous question and positively to the subsequent question of whether the production constraints are ”due to difficulties in financing”. Relating financial and production constraints, this question is very close to the definition of financial constraints that we use in the economic model presented below. However, it is only available at quarterly frequency.

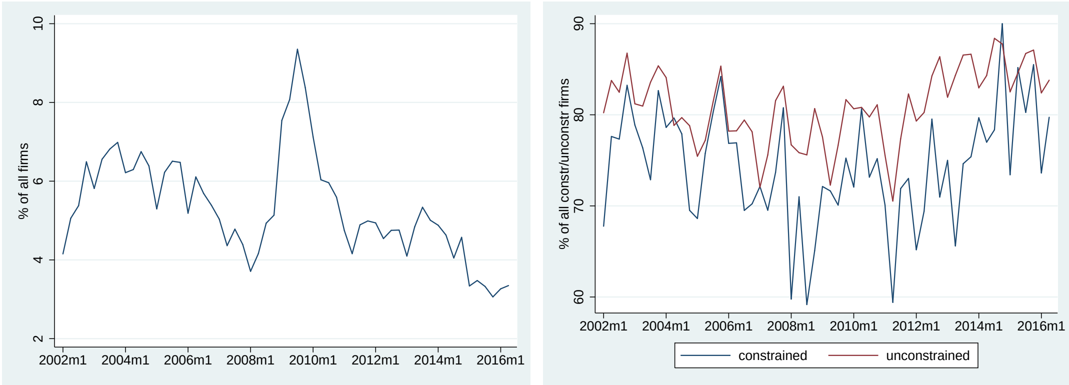
A second question in the survey asks firms about their access to bank lending: ”Are you assessing the willingness of banks to lend as restrictive, normal or accommodating?”. We flag firms as financially constrained when they state that bank lending is restrictive. This is potentially important in Germany due to its predominantly bank-based financial system.[28] Note that a restrictive answer to the survey

[26] In the Online Appendix A.4 we show a decomposition by productivity and this confirms that the result is driven primarily by the firms located in this range of productivity levels.

[27] These prices are home country producer prices and refer to the baseline or reference producer price (not to sales, etc.). Bachmann et al. (2018) have used the same dataset to assess the effect of uncertainty shocks on price setting. Strasser (2013) uses the dataset to study the role of financial frictions for the exchange rate pass through of exporting firms.

[28] Bank lending is the key financing channel in Germany. Online Appendix A.1 exhibits information about the financing structure in Germany in general and in the ifo dataset in particular. Generally, German firms show a much higher share of loans in their balance sheets than their US counterparts, while the equity share is comparable. External financing through securities and bonds is marginal in Germany. Further, a flow-of-funds analysis of the Bundesbank documents that within

Figure 4: Fraction of constrained firms and constant prices over time



Notes: ifo Business survey, production constraint measure, sample 2002:1 - 2014:12. Left panel: Fraction of constrained firms in all firms. Right panel: Fraction of firms not changing prices within the subgroups of financially constrained (blue) and unconstrained (red) firms

might imply that firms perceive a certain bank-lending behavior in general, but do not necessarily need to borrow more or have not been declined credit. This means that they are potentially not constrained in the way they invest, hire or produce.[29] However, as happens in our model, assessing the current situation as one with restricted access to credit may still affect firm behavior, e.g. not changing the price in order to avoid a binding financial constraint. Our bank lending measure is available semi-annually from 2003:7 and at monthly frequency from 2009 onwards.

Our sample exhibits an average of 5% of constrained firms according to the production measure and of about 25% of constrained firms according to the banking measure. A fraction of 84% of all observations that qualify as restricted according to the banking measure also qualify as restricted according to the production shortage question. As argued above, the banking measure may overstate the number of actually restricted firms in the sample. However, due to a relatively low response rate to the question about production constraints, the production measure may understate the number of actually restricted firms. Evidence from the ECB on small and medium-sized enterprizes delivers a similar range for the share of financially constrained firms for Germany.[30] Our model calibration in Section 2.3 delivers a fraction of 26% of financially constrained firms which is just at the upper bound of the empirical range documented here.

Figure 4 shows a time-series plot of the fraction of constrained firms (In Online Appendix A.1 we show the corresponding plot for the banking lending question). One can see that this fraction is always above zero and time varying, reaching a maximum of about 9% at the height of the Great Recession (about 45% in the case of bank lending). Also, it is visible that nominal rigidities in the economy do not increase in the Great Recession. If at all, they decrease. This is consistent with our model results. The literature has discussed that small rather than large firms tend to be financially constrained.[31] For

equity, internal financing works through retaining profits, while market-financing plays almost no role, not even in the Great Recession (see DeutscheBundesbank (2013) and DeutscheBundesbank (2014)). Restrictions in bank lending therefore pose serious constraints to the firms in our sample.

[29] Based on a similar survey with a similar question about refinancing conditions for Austria Fidrmuc et al. (2017) confirm that a firm's own recent experience regarding credit negotiations with banks is by far the main driver of its appraisals of banks' willingness to lend. In contrast, aggregate or sector-specific conditions are of minor importance.

[30] Survey on the access to finance of enterprizes (SAFE), ECB: Semi-annual survey for 2009-2017. For Germany, an average of about 10% of firms state access to finance as their most important problem, 7% of firms stated various obstacles to receiving a bank loan, 27% of firms categorize access to finance as obstacle to production of high importance. See http://www.ecb.europa.eu/stats/ecb_surveys/safe/html/index.en.html

[31] See Carpenter et al. (1994) for an early contribution on the topic.

Table 2: Financial Constraints and Price Setting

	data		baseline model calibration	
	unconstrained	constrained	unconstrained	constrained
$\Delta p = 0$	80%	75%	83%	77%
$\Delta p < 0$	8%	12%	4%	10%
$\Delta p > 0$	11%	13%	13%	13%

Notes: ifo Business survey, production constraint measure, sample 2002:1 - 2014:12. Numbers shown are sample averages of fractions of price changes within unconstrained and constrained firms.

our baseline measure of constrainedness, we confirm this result in terms of employment, sales and total assets. The relationship between size and the share of financially constrained firms is less direct in case of the banking measure. We also show that, with respect to both measures, the share of firms facing financial difficulties varies greatly across sectors.[32]

Existing evidence on financial constraints is primarily based on balance sheet data rather than survey data. For a subsample of the firms in our survey, we have access to annual balance sheet information and we can calculate liquidity ratios similar to Gilchrist et al. (2017).[33] The corresponding balance-sheet based measure defines firms to be financially constrained if they are below the median liquidity ratio with respect to all firms in the sample. Liquidity ratios are generally lower for firms that are constrained according to our survey questions. The difference is small, however, and a substantial fraction of firms that are constrained according to our survey exhibit very high liquidity ratios (see Online Appendix A.1). Generally, a low liquidity ratio can be the result of easy access to credit, while not affecting production possibilities of firms. It may therefore not measure financial constraints per se. For example, consider a firm experiencing a sudden decline in its marginal costs. Such a firm will typically try to scale up the level of operation by decreasing its price and attracting more demand. However, if this requires external funding but the firm is unable to borrow, it might be unable to expand its production capacity at all. In this case, the firm will be financially constrained, however, it may still enjoy a relatively high liquidity ratio due to the higher unit profits. Hence, one may wrongly conclude that it is financially unconstrained today. Several recent papers indeed show that firms in financial difficulties tend to hold more liquidity relative to their financially strong counterparts (Bates et al., 2009; Kahle and Stulz, 2013; Almeida et al., 2014).

Table 2 shows the relationship between price adjustments and being financially constrained for our baseline measure. In general, a relatively small share of German firms, around 20%, adjust their prices on a monthly basis. Out of these, about half of the prices that change increase and half of the prices decrease respectively (not shown in the Table). Relative to their unconstrained counterparts, financially constrained firms adjust their prices more often, both up- and downwards. As in the model, this difference is larger for price decreases. Figure 4 shows that this difference in price-setting behavior is stable over time, and also holds during the Great Recession.[34]

[32] See Online Appendix A.1 for detailed results.

[33] The data source here is the EBDC-BEP (2012): Business Expectations Panel 1/1980 12/2012, LMU-ifo Economics and Business Data Center, Munich, doi: 10.7805/ebdc-bep-2012. This dataset links firms' balance sheets from the Bureau van Dyk (BvD) Amadeus database and the Hoppenstedt database to a subset of the firms in the ifo Business Survey. See Kleemann and Wiegand (2014) for a detailed description of this data source. Liquidity ratios are defined as cash and cash equivalents over total assets.

[34] In the Online Appendix A.1 we show time series plots for up- and downwards adjustments as well as time series plots for the bank lending measure.

3.2 Estimation

The moments in Table 2 and the time series variation of pricing decisions may be driven by different factors: the business cycle itself, sector-specific aspects or a possible selection of firms over the business cycle. We address this by estimating three separate equations in order to decompose the correlation between the different pricing decisions and the financial constrainedness of firm i and sector j at time t

$$\mathcal{I}(\Delta p_{ijt} = 0) = \beta_{FC}^{cons}\ \mathcal{I}(FC_{ijt} = 1) + \gamma' x_{ijt,t-1} + c_j + \theta_t + u_{ijt} \quad (12)$$

$$\mathcal{I}(\Delta p_{ijt} > 0) = \beta_{FC}^{up}\ \mathcal{I}(FC_{ijt} = 1) + \gamma' x_{ijt,t-1} + c_j + \theta_t + u_{ijt} \quad (13)$$

$$\mathcal{I}(\Delta p_{ijt} < 0) = \beta_{FC}^{down}\ \mathcal{I}(FC_{ijt} = 1) + \gamma' x_{ijt,t-1} + c_j + \theta_t + u_{ijt} \quad (14)$$

The dependent variable is binary and indicates whether a firms has left prices unchanged relative to all other pricing decisions (equation (12)), or increased or decreased prices relative to all other pricing decisions (equations (13) and (14) respectively). The coefficient β_{FC} then measures how being financially constrained (as given by the indicator $\mathcal{I}(FC_{ijt} = 1)$ as described above[35]) affects the probability to take one of these pricing decisions. Note that this coefficient should not be interpreted as causal, since it may well be that price adjustments influence whether a firm is financially constrained or not (as is motivated in the introduction and documented in detail in Section 2 below). Instead, this specification seeks to control for variation over time, i.e., business cycle effects, possible selection of firms into being financially constrained or not and other aspects that could have influenced the sample averages in Table 2.

Table 3: Financial Constraints and Price Setting: Various Subsamples

price	model	data baseline	SMEs	west	exporting	post 2009	pre 2009	single product
→	-0.060	-0.056***	-0.049***	-0.072***	-0.069***	-0.068***	-0.046***	-0.056***
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
↑	0.007	0.034***	0.031***	0.041***	0.039***	0.036***	0.032***	0.033***
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
↓	0.053	0.023***	0.018***	0.031***	0.030***	0.032***	0.015***	0.023***
		(0.000)	(0.003)	(0.000)	(0.000)	(0.000)	(0.003)	(0.000)
Observations		119871	49050	97301	95324	54697	65174	117850

Notes: ifo Business survey, production constraint measure, sample: 2002:1 - 2014:12. OLS estimation with time t and sector j fixed effects. The numbers show estimated values of coefficient β_1 in equations ((12)-(14)). Standard errors in parentheses, *** p < 0.01, ** p < 0.05, * p < 0.1. The rows show the separate regressions for no price changes, price increases and price decreases (indicated by the arrows). The first column documents the coefficients estimated from simulated data from the baseline model. The remaining columns refer to the empirical estimates in the baseline and different subsamples: small and medium-sized firms only (50-250 employees), west only, exporting firms only, before and after 2009, single product firms. Results including very small firms (below 250) are not shown in the table, but available upon request.

We separately estimate the three linear probability models taking into account sector (c_j) and time fixed effects (θ_t) and include a constant and the lagged discrete pricing decision as the main control variable ($x_{ijt,t-1}$) in order to take into account that firms may have been affected by different shocks previously. The first column in Table 3 shows the results from estimating equations (12)-(14) using

[35] Here, we interpolate all financial measures to monthly frequency throughout the sample. Specifically, we interpolate the financial measure to be the same in the month before and after it is measured.

simulated panel data from the model, using the baseline calibration, presented in Section 2. The second column contains the respective baseline results in the actual data using our production constraint measure of financial constraints. The empirical patterns mirror those in the model: Financially constrained firms adjust prices more often than unconstrained firms, the difference in probability is about 5.6 percentage points. Empirically, this difference is composed of financially constrained firms increasing prices about 3.4 percentage points more often and decreasing prices about 2.3 percentage points more often than unconstrained firms. This replicates the patterns in the model which understates the price increases and overstates the price decreases compared to the data. All of these differences are highly significant. The Table further documents that the results are robust to various subsamples. Small and medium sized firms may be particularly affected by restricted bank lending, exporting firms may be less affected. West German firms are potentially less affected by financial frictions and single-product firms may be less able to shift funds to avoid restrictions. In addition, we consider two subsamples that end and start before and after the Great Recession period respectively.

In Online Appendix A.1 we show further results investigating robustness along a number of dimensions. First of all, our results do not depend on the specification being linear nor on the choice of the base category in the different specification. The Online Appendix A.1 contains the results relating price increases and decreases to prices constant only[36] and shows the corresponding logit and mlogit results. In addition, we add various control variables that could affect both price setting and whether firms are financially constrained or not. These include firm size, receiving wage subsidies in the form of short-time work programmes, lagged and current assessment of the state of business, current assessment of the state of orders and future assessment of commercial operations. All of these variables stem from the ifo survey and are answered qualitatively according to three categories: improved, unchanged, worsened. We also conduct robustness with respect to different specifications. Among others, we add seasonal (quarterly) fixed effects and an interaction term between sector j and seasonal fixed effects. We further cluster the standard errors at the sectoral level and allow for product-specific (i.e. individual) fixed effects rather than sectoral fixed effects. In order to investigate possible effects of attrition of the sample, we consider a long-coverage panel (firms are in panel at least 8 years) and a completely-balanced panel. We have also replicated all of the above results using our bank lending measure for financial constrainedness. Generally, the difference in the frequency of price adjustment between financially constrained and unconstrained firms is slightly smaller in this measure, but still significant. As before, financially constrained firms adjust prices more often than unconstrained firms, but the difference is now equally driven more by downward price adjusters.

In Online Appendix A.1 we show results when using the annual liquidity ratio defined as described above in order to measure financial constrainedness. In line with Gilchrist et al. (2017), constrained firms are those with liquidity ratios below the median value of all firms. Our analysis shows that our results support the results by Gilchrist et al. (2017) as financially constrained firms increase and decrease prices more often, but only the price increases are statistically significant. Note that potentially, our results could be very different from Gilchrist et al. (2017), since we consider a central European economy, the manufacturing sector only and many small firms in addition to large publicly traded firms. Based on the liquidity ratio, we nevertheless confirm that financially constrained firms change prices significantly more often than unconstrained firms (a finding not mentioned explicitly in Gilchrist et al.).

[36] Since over 80% of the firms leave their prices unchanged every month, the base is almost identical.

4 Aggregate Implications

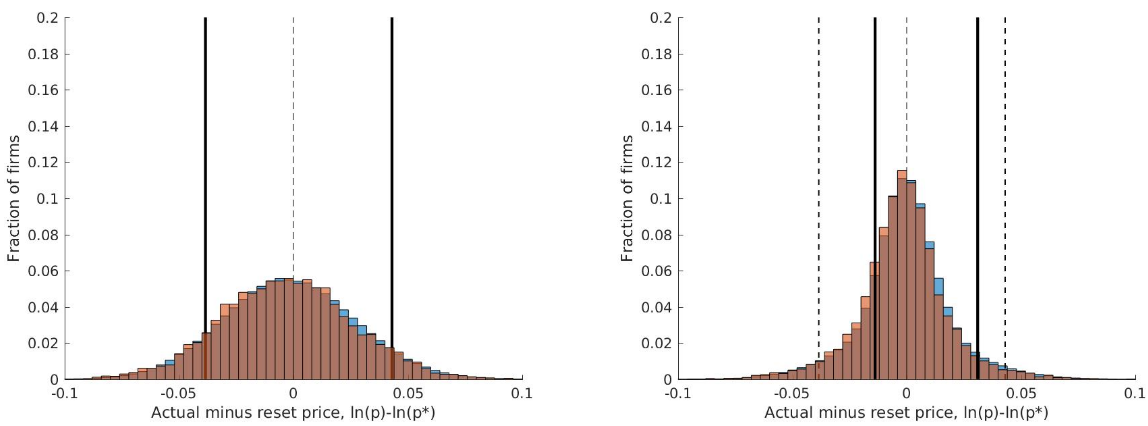
4.1 Shocks to Nominal Aggregate Demand

In our partial equilibrium setup, shocks to nominal aggregate demand should be understood as sudden shifts in the nominal value of demand outside the economy or sector considered. We believe this to be a realistic description of the response of the German manufacturing sector to, e.g., monetary impulses from the ECB. Figure 5 illustrates how the price gap distribution shifts to the left in response to an expansionary monetary policy shock. As inherent in any menu cost model, more firms adjust their prices upwards while fewer firms adjust downwards. In the model without financial constraints, these two effects nearly offset each other and the overall fraction of price changes only mildly reacts to aggregate shocks. In the presence of financial constraints, the mass of prices at the lower bound of the inaction region is larger than at the upper bound. This is due to both the higher kurtosis of the price distribution and the fact that the optimal reset price is no longer located at the center of the inaction region (see section 2). As a consequence, more firms newly increase than no longer decrease their prices after an expansionary monetary policy shock and the fraction of price changes goes up. Table 4 documents that the increase in price changes amounts to about 4 percentage points in our baseline calibration. Likewise, the frequency of price adjustments declines after a negative demand shock (not shown).[37]

Figure 5: Price distribution and positive demand shocks

(a) Model without financial constraint

(b) Model with financial constraint



Notes: The histograms display the price gap distribution, defined as the actual (pre-adjustment) price minus the optimal reset price, or $\log(p_i) - \log(p_i^*)$, where p_i^* is firm i's optimal reset price and p_i is firm i's price *before* price adjustment. The solid vertical lines mark the inaction region for a firm with average productivity (i.e. $log(z) = 0$) in the model with and without financial constraint, respectively. The dashed line at zero shows the location of the optimal reset price. The dotted lines in panel (b) are the same as the vertical solid lines for the 'No FC'-model shown in Panel (a). The blue bars show the ergodic distribution. The red bars show the distribution conditional on high demand (nominal demand greater or equal to one-standard deviation above average).

The second column of Table 4 depicts the responses of inflation to the aggregate nominal disturbance. Average inflation is defined as the monthly percentage change of the average price $\bar{P}_t = \sum_{i=1}^{N} p_{it}$, where N is the number of firms. Note that the inflation responses on impact in the model with and without financial constraints are identical. This response is driven by two margins of price adjustment: The frequency of price adjustment, or the extensive margin, and the size of price adjustments, or the intensive margin. As discussed before, the presence of financial constraints leads to an increase of the extensive margin. Since inflation does not increase by more when financial frictions are present, the intensive

[37]For details on how impulse responses are constructed, see Online Appendix A.3

margin must have decreased in response to the aggregate shock. As visible in Figure 5, the firms that newly adjust prices do so by very small amounts. In the case of the myopic model, the response of the intensive margin dominates the one of the extensive margin and inflation increases by less if financial constraints are present compared to without.

The last column of Table 4 shows the response of average output, defined as $\bar{y}_t = \sum_{i=1}^{N} y_{it}$. First, note that due to the presence of menu costs, both models imply some degree of nominal non-neutrality, since the response of average inflation is weaker than the shock itself which translates into a non-zero reaction in average real output. For our benchmark calibration, this non-neutrality is weaker when the economy is subject to the working capital constraint: The presence of the financial friction is associated with a relatively weaker increase in output, even though the reaction of inflation is similar to that in the model without financial constraints. In the myopic model, for comparison, the reverse is true: The presence of the financial friction strengthens the monetary non-neutrality relative to a similar economy without financial frictions.

To understand this, note that the firms that adjust output in response to an aggregate shock are generally those that do not adjust prices. For these firms, a positive aggregate demand shock implies a lower real price and higher output following the demand schedule. In the presence of financial constraints, higher output is not feasible in all cases (see discussion in Section 2.1). Put differently, a fraction of the firms that move towards the lower bound of the inaction region run into the financial constraint and are forced to choose a lower individual production level than a similar non-adjusting firm in an otherwise identical environment without financial imperfections. Consequently, if price adjustment plans were to be revised by exactly the same amount in the two economies, output would increase by less when a borrowing constraint is present. If however, as in the myopic model, the number of price adjustments is smaller when financial constraints are present, more firms adjust output and less firms adjust prices. Hence, output reacts more, while inflation reacts less in the model with compared to without financial constraints.

One can view the results in this section through the lens of a textbook macroeconomic model representing the equilibrium as the intersection of an aggregate demand and an aggregate supply curve. Note that the models with and the one without financial frictions are identical regarding the economy wide demand schedule. The latter is governed by only one parameter, the demand elasticity θ, and one exogenous variable, the aggregate nominal price level P_t. Moreover, the financial friction leaves the demand side of the economy completely unaffected. Hence, the aggregate shock shifts the demand schedule by exactly the same amount in each of the two models. Along identical demand curves, a mildly stronger inflation increase can be only associated with a less pronounced increase in output and vice versa. The results in Table 4 indicate that for our benchmark calibration the presence of the working capital constraint implies a steeper supply curve relative to an economy with a frictionless credit market. Accordingly, the financial friction alters a central trade-off faced by the central bank: In order to engineer an increase in real activity by a certain amount, the monetary authority needs to accept a larger rise in inflation. However, the opposite holds in myopic economies: In that case the introduction of the working capital constraint is associated with a flattening of the aggregate supply curve.

Our results speak to the recent debate about monetary non-neutrality in the menu cost model. Golosov and Lucas (2007) have emphasized that monetary non-neutrality is small due to the so-called selection effect: After an expansionary monetary policy shock, price adjustments are selected towards large price increases, inflation reacts strongly and output very little. We show that the presence of financial constraints weakens the selection effect as the size of price increases falls after an expansionary shock. Alvarez et al. (2016) have argued that the kurtosis of the price distribution as well as the kurtosis

Table 4: Impulse responses to a positive aggregate nominal demand shock

A: Responses for benchmark and myopic model			
Model	Fraction of price adj. impact	Inflation impact	Output impact
Benchmark			
w/ FC	3.58	0.12	0.51
w/o FC	0.45	0.12	0.60
Myopic model			
w/ FC	3.06	0.11	0.47
w/o FC	0.23	0.16	0.31
B: Comparison to Calvo and Rotemberg model			
Model	Fraction of price adj. impact	Inflation impact	Output impact
Calvo			
w/ FC	0.00	0.04	0.71
w/o FC	0.00	0.04	1.15
Rotemberg			
w/ FC	0.00	0.09	0.55
w/o FC	0.00	0.04	1.15

Notes: Impact responses to a one-time one-standard deviation positive aggregate nominal demand shock. The label 'w/FC' refers to the simulated model with financial constraints, 'w/o FC' refers to the model without financial constraint (leaving all other parameter values constant).

relative to the frequency of price changes constitutes a sufficient statistic for monetary non-neutrality in menu cost models: A higher kurtosis can be associated with stronger monetary non-neutrality. We have documented in Section 2 that the presence of financial constraints increases the kurtosis of the price distribution. Our baseline calibrated documents, however, that a weaker selection effect or a higher kurtosis of the price distribution alone is not a sufficient condition for stronger monetary non-neutrality. The real effects of monetary policy only increase when the frequency of price adjustment falls in addition to the higher kurtosis and weaker selection effect, as documented in the myopic model.

4.2 Comparison to other models of price stickiness

In this section, we compare the aggregate implications of our partial equilibrium economy with a fixed menu cost to those of economies with alternative sources of price rigidity: convex price adjustment costs (Rotemberg (1982)) or a Calvo-type nominal friction, i.e. an exogenous probability of being allowed to adjust prices (Calvo (1983)). Depending on the persistence of idiosyncratic productivity shocks, the introduction of the financial constraint might lead to a steepening or a flattening of the aggregate supply curve. In contrast, the latter unambiguously becomes steeper in the presence of Rotemberg adjustment costs or Calvo frictions. The lower panel of Table 4 compares the impact responses to an aggregate positive nominal shock in the benchmark menu-cost model, the Calvo model and the Rotemberg model.[38]

While monetary non-neutrality can in- or decrease in the menu cost model, the inclusion of the borrowing constraint in a Calvo or Rotemberg setup unambiguously weakens the response of average output to aggregate nominal shocks. At the same time, the reaction of average inflation is amplified (or remains unchanged in the Calvo model). From this, one can draw three main conclusions. First, the

[38] See Online Appendix A.5 for details of the models and the calibration. Full impulse-responses can be provided by the authors upon request.

precise modeling of price stickiness is of crucial importance when discussing the effects of working capital constraints. Second, the qualitative difference between the menu-cost model and the Rotemberg/Calvo specifications suggests that allowing for an endogenous probability of price adjustment with the associated selection effect is of primary importance. Recall that, in the presence of menu costs, the introduction of a credit constraint affects the average fraction of firms that change prices as well as the intensive margin of price adjustment.[39] In the Rotemberg model the fraction of price adjusting firms is always equal to 100%, while price adjusters are selected randomly with an exogenously fixed probability in the Calvo model. Hence, in these frameworks, there is no link between the presence of a financial constraint on the one hand and the extensive margin of price adjustment and a selection effect on the other. Third, it has been repeatedly stressed that the degree of monetary non-neutrality generated by menu-cost models with an empircally plausible calibration is significantly weaker than that implied by the Calvo or Rotemberg mechanisms.[40] Our results suggest that this discrepancy almost disappears when our borrowing constraint is present. In particular, Table 4 shows that the impact response of output is very similar across the models.

While the dynamics in the Rotemberg model and Calvo model are similar, the underlying mechanism is inherently different. Since price adjusting firms are randomly selected in the Calvo model and the probability of price adjustment is exogenous, there exists no interaction between financial constraints and the composition of price adjusting firms. Furthermore, the firms allowed to change prices completely pass through permanent increases in nominal aggregate demand to their individual prices, irrespective of whether they are financially constrained or not. As a consequence, the inflation response to aggregate nominal shocks is independent of whether firms face a borrowing constraint or not. This can be seen in Table 4. The difference between the economy with and the one without financial frictions then only concerns aggregate output and stems solely from the behavior of firms who are not allowed to adjust prices in the period of the shock and its immediate aftermath. In particular, in the presence of our borrowing constraint, the non-adjusters that face a binding credit restriction will be forced to produce off their demand schedule and ration output. The fraction of such firms tends to increase when positive aggregate nominal shocks hit the economy and the fraction of price adjusters cannot adjust at the same time. The opposite happens for negative demand shocks. These time varying output losses due to rationing dampen the output response relative to a Calvo-economy without financial frictions.

In the case of Rotemberg adjustment costs, firms facing a binding financial constraint pass changes in the aggregate price level completely through to their individual prices. The reason is that the borrowing restriction acts as a capacity limit. As soon as "full capacity" is reached, the firm-specific supply curve is approximately vertical and any further demand increases can only be accompanied by raising prices. In contrast, the degree of pass-through is incomplete for unconstrained firms. Accordingly, as long as the fraction of financially constrained firms is larger than zero, the pass-through of economy-wide nominal demand shocks to the average price level will be stronger relative to an economy without financial frictions. Consequently, the response of average output will be lower in an economy with compared to one without financial frictions. To summarize, price-adjusting firms in the Calvo model pass-through nominal shocks completely independent of their financial status, but ration output when financially constrained. In the Rotemberg model, no firm rations output, but financially constrained firms pass through nominal shocks to a larger extent than unconstrained firms. See Online Appendix A.5 for a more detailed discussion.

[39] The selection mechanism is present in general, while the direction of the intensive margin depends on the strength of the selection effect.

[40] See for example Golosov and Lucas (2007), Klenow and Kryvtsov (2008).

4.3 Robustness

We have conducted a variety of robustness checks for two purposes. First, to understand which parameters/model elements are important to qualitatively and quantitatively explain the moments from the micro data we have documented in the empirical section of this paper. Second, whether and how the aggregate implications are affected by different parameter values. The robustness section in the Online Appendix A.6 reports detailed tables on the calibrated parameter values, the implied moments, the model fit to the micro data, and the implied on impact impulse responses to an aggregate demand shock for all model versions considered here.

Persistence of the idiosyncratic shock. We have already discussed the implications of a static versus a dynamic setup for the model results. A related issue is the persistence of the idiosyncratic shock. For a lower autocorrelation in idiosyncratic productivity, the optimal reset price becomes flatter. In this case, the firm rationally anticipates that its productivity will quickly converge towards the mean $\log(z) = 0$ in the following periods. It is therefore optimal to set prices not too far away from the price that maximizes profits at average productivity in order to avoid to pay future menu costs. The resulting lower elasticity of the reset price with respect to productivity has similar consequences as in the myopic model. Removing financial frictions in the model with low autocorrelation substantially increases the frequency of price adjustments and monetary non-neutrality is larger than in the benchmark calibration. Low persistence does not imply a direct link between productivity, output and being financially constrained. The reason is that the constraint spans a wider interval of productivity levels and firms may be constrained also at low productivity levels.

Model where sales are not collateralizable. Sales as collateral relax the financial constraint for low price-high productivity firms. Laxer constraints induce a larger elasticity of the constrained optimal price compared to a situation without sales as a collateral. Sales as collateral are therefore qualitatively and quantitatively important to explain the firm level pricing moments, in particular to explain the fact that financially constrained firms adjust prices more often upwards than unconstrained firms. Without sales in the constraint, the model fit worsens, and the aggregate implications are qualitatively similar to the benchmark.

Elasticity of substitution. A crucial parameter in this model is the elasticity of substitution. A lower elasticity implies more symmetric profits and therefore more symmetric price gap distributions in a world without financial frictions. The introduction of financial frictions therefore changes the price gap distribution to a larger extent. We repeat the calibration exercise for a lower and a higher demand elasticity, so that implied average mark-ups in those alternative calibrations are 12.5 and 20 percent, respectively. The model fit does not improve compared to the benchmark model. Furthermore, the model with lower demand elasticity generates quantitatively too much price adjustment of financially constrained firms while the model with higher demand elasticity generates too little price adjustment of financially constrained firms (in particular upward adjusters) relative to unconstrained firms and therefore performs less well in this respect than the benchmark model. The aggregate implications are qualitatively similar to the benchmark model.

Idiosyncratic financial shocks. In an earlier working version of this paper, we have added idiosyncratic financial shocks to the model. This is a reduced form way to capture that heterogeneity in firm financing possibilities even after controlling for the collateral and sales. While the insights were qualitatively identical with the models presented here, the financial shock did not improve the model fit to the data. The results of this model version are available upon request from the authors.

5 Conclusion

This paper investigates how credit constraint and price setting interact. Based on a partial-equilibrium menu cost model with a working capital constraint, we document that financial constraints increase the kurtosis in the cross-sectional distribution of price gaps - defined as the deviation between the firm's actual and desired price. As a result, the model can replicate the coexistence of very large and very small price changes documented in several studies on micro data. The model also implies that financially constrained firms adjust prices more often than unconstrained firms, both upwards and downwards. We support this implication empirically based on new firm-level evidence for Germany. One may expect that the property that financially constrained firms increase prices more often than unconstrained firms leads to a higher frequency of price adjustments when financial constraints are present. We show that this is not the case. If at all, financial constraints increase nominal rigidities in the economy, since firms choose prices higher than optimal in order to avoid the financial constraint and the associated price adjustment in the future.

Monetary non-neutrality in menu cost models has been debated in the economic literature. One central aspect in this debate is the question whether price adjustments are selected towards large price changes in response to aggregate shocks (see Golosov and Lucas (2007)). Another aspect refers to the properties of the price gap distribution. Alvarez et al. (2016) relate a higher kurtosis of the price gap distribution to a larger degree of monetary non-neutrality in the menu cost model. We document that the presence of financial constraints changes the response of inflation to aggregate nominal shocks only mildly, while the aggregate frequency of price adjustment now substantially moves. This means that the average price change falls (more) in response to aggregate shocks when financial constraints are present and, hence, financial constraints weaken the selection effect. Since the selection effect is weaker and the kurtosis of the price distribution is larger, one would now expect larger real effects in response to aggregate nominal shocks when financial constraints are present. We show that this is not necessarily true. In fact, real effects only increase when the overall nominal rigidity in the economy is larger.

We show that the inclusion of the financial constraint might induce a flattening or a steepening of the aggregate supply curve. This is of primary relevance for the effectiveness of monetary policy: Our benchmark calibration implies that the monetary authority needs to accept a larger rise in inflation in order to achieve a given increase in real output. But the opposite happens in the myopic model. We further show that other sources of nominal rigidities such as exogenous probabilities of price adjustment as in Calvo (1983) or convex price adjustment costs as in Rotemberg (1982) unambiguously imply that the inclusion of financial frictions generates larger inflation and smaller output responses to aggregate shocks with compared to without financial frictions. The source of the nominal rigidity therefore matters for the real effects of monetary policy when interacted with financial constraints.

To conclude, our paper shows that the endogenous link between the frequency of price adjustment and credit constraints is important to understand aggregate fluctuations and the effectiveness of monetary policy. In future research we plan to explore the implications from our model further. This includes to consider the full dynamics when allowing for general equilibrium effects. This also includes testing empirically how financial constraints are directly related to smaller average price changes. Balleer and

Zorn (2019) have estimated impulse-responses of various pricing margins to monetary policy shocks and documented substantial real effects. Future work plans to condition these responses on financial frictions and compare these to the model-inherent dynamics directly.

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