Monetary Policy, Firms' Extensive Margin, and Productivity*

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This paper explores the effect of conventional monetary policy on aggregate productivity through firms' decisions to enter into or exit production. In a general equilibrium model with heterogeneous firms, we show that a monetary easing lowers productivity if it raises corporate profits: a rise in profitability allows low-productivity incumbents to remain active and unproductive new firms to enter production. Empirically, we find that expansionary monetary policy indeed raises profits, reduces firm exit, and increases entry. However, we do not find compelling evidence of an associated fall in aggregate productivity. Productivity decreases for small firms only. Entry and exit of unproductive firms induced by monetary policy hence appear of less quantitative importance for aggregate productivity than the theory suggests.

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1. Introduction

Since the Global Financial Crisis, the U.S. economy has featured two prominent characteristics: a protracted slowdown of productivity growth and an unprecedented degree of monetary stimulus. This

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observation has sparked considerable interest in the role of central banks in driving productivity. The existing literature finds several channels favoring a *positive* effect in the sense that expansionary monetary policy increases productivity (Evans 1992; Moran and Queralto 2018; Garga and Singh 2021). These explanations focus on the extent to which monetary policy affects the productivity of *incumbent* firms. In contrast, the influence of monetary policy on the *composition* of actively producing firms and their individual productivity has received limited attention. This is fairly surprising given that the long-known notion of "zombification" (Hoshi and Kashyap 2004; Caballero, Hoshi, and Kashyap 2008)—which recently regained prominence amid the COVID-19 pandemic—is potentially associated with a *negative* productivity effect: expansionary monetary conditions might facilitate the survival of unproductive "zombie firms."

In this paper, we explore the influence of conventional monetary policy on the decisions of firms of heterogeneous productivity to enter into or exit production. The key idea is that monetary policy inherently affects corporate profitability whenever it alters aggregate demand and production costs. Changes in corporate profitability, in turn, have repercussions on firms' decisions about whether to produce or to become idle. This *firm-extensive margin* determines the *composition* of active production units and alters aggregate productivity—in addition to effects on incumbents—if entering and exiting firms differ in their productivity.[1]

As a first contribution, we showcase this notion in a dynamic stochastic general equilibrium (DSGE) model with heterogeneous firms and endogenous entry and exit. Upon entry into the market, firms draw an individual productivity level. This remains constant throughout their entire life cycle. We thereby isolate the composition channel and eliminate effects on the productivity of incumbents. Firms that are unable to generate profits in a given period remain

[1] We use the term firm-extensive margin to refer to firms' decisions to produce actively or to be inactive, similar to Bergin and Corsetti (2008) and analogous to the canonical extensive margins of labor supply (Heckman 1993) and exports (Hummels and Klenow 2005). We label these decisions as (production) entry and exit. Our theoretical model features a second form of entry and exit (into and out of the market) in the sense that some firms are newly created or closed down permanently.

inactive. As profits are strictly increasing in individual productivity, production entry and exit depend on a productivity threshold: only firms that feature a higher productivity than the threshold are profitable and produce actively.

We show that this framework is able to generate opposing views on how entry and exit shape the role of conventional monetary policy for productivity. If an expansionary interest rate shock raises profitability, it lowers aggregate productivity: higher corporate profitability allows unproductive incumbents to remain active and new low-productivity firms to start production. As a result, exit rates fall while entry increases. This scenario occurs with sticky wages, which implies that the effect of higher sales on profits outweighs the rise in production costs.[2] The converse case of expansionary monetary policy increasing aggregate productivity requires that the rise in production costs dominates such that corporate profitability decreases, which happens in the absence of wage rigidities. In this scenario of a "survival of the fittest," exit increases and entry declines.

As a second contribution, we test these theoretical predictions empirically by analyzing the dynamic effects of monetary policy on corporate profits, firm dynamics, and productivity. We employ a structural macrofinancial vector autoregression (VAR) based on sign restrictions and high-frequency asset price movements to identify monetary policy shocks, similar to Jarociński and Karadi (2020). We find that expansionary monetary policy increases corporate profits and affects both sides of the firm-extensive margin: Following an exogenous decrease in nominal interest rates, entry rises whereas exit initially declines and then overshoots in the medium run. These empirical findings regarding entry and exit are in line with the first model variant featuring wage stickiness.

However, we do not find compelling evidence of a systematic effect of monetary policy on aggregate productivity: Our empirical results feature insignificant responses of aggregate measures of productivity (derived from growth accounting) and of average firm-level productivity (estimated from firm-level balance sheet data) to monetary policy shocks. As such, the empirical results regarding overall productivity are not in line with either variant of the model.

[2]This case is also studied by Colciago and Silvestrini (2022) and Hamano and Zanetti (2022); see below for a discussion of similarities and differences.

If anything, the productivity effect of monetary policy seems to be empirically relevant and negative for small firms (classified according to sales), and especially for the two largest sectors, manufacturing and services.

What can be learned from our findings? First, expansionary monetary policy reduces average productivity across small firms in the data. The simple view of firm heterogeneity in the theoretical framework thus appears to be an appropriate representation for smaller firms. Second, however, aggregate productivity does not fall in the data following a monetary easing, contrary to the model predictions. This suggests a quantitatively limited importance of entry and exit of unproductive firms for the overall productivity effect of monetary policy. It also indicates that the theoretical framework misses a key dimension of reality. One obvious element that our model is deliberately silent on is the notion that monetary policy affects firms' productivity at different stages of their life cycle.

A third insight is hence that our findings also feature implications for the complementary literature on monetary policy's effect on the productivity of incumbent firms. This research strand argues that a monetary easing raises productivity through various mechanisms such as increased variable capital utilization (Christiano, Eichenbaum, and Evans 2005), enhanced incentives for research and development (Moran and Queralto 2018; Garga and Singh 2021), lower financial frictions (Midrigan and Xu 2014; Moll 2014),[3] or heterogeneous price pass-throughs (Meier and Reinelt 2022). A possible interpretation of the insignificant response of aggregate productivity in the data is thus that productivity-raising channels for incumbents (from which our theoretical framework abstracts) and the firm-extensive margin are simultaneously active in the real world. For small firms, the latter may dominate, implying that a monetary easing reduces productivity. Across all firms, the impact on incumbents and firm dynamics counteract each other, potentially explaining an overall productivity effect near zero.

Besides the literature on monetary policy and productivity, this paper connects to existing research on firm dynamics in general

[3]These papers posit a negative effect of financial frictions on productivity, and expansionary monetary policy typically alleviates financial frictions (Bernanke, Gertler, and Gilchrist 1999; Gertler and Karadi 2011).

equilibrium models along the lines of Hopenhayn (1992), Melitz (2003), and Ghironi and Melitz (2005).[4] Assuming exogenous exit, such models have been used to study the influence of endogenous entry on business cycles (Jaimovich and Floetotto 2008; Bilbiie, Ghironi, and Melitz 2012), the transmission of monetary policy (Lewis 2009; Lewis and Poilly 2012), and optimal monetary policy (Bergin and Corsetti 2008; Lewis 2013; Bilbiie, Fujiwara, and Ghironi 2014; Cacciatore, Fiori, and Ghironi 2016). In the context of endogenous exit, several papers analyze aggregate productivity shocks (Clementi and Palazzo 2016; Hamano and Zanetti 2017, 2018; Rossi 2019). In contrast to these papers, we investigate the transmission of monetary policy in a framework featuring endogenous entry and exit to analyze the effect on productivity. A similar approach is taken in two recent studies by Colciago and Silvestrini (2022) and Hamano and Zanetti (2022), who focus on market concentration and optimal monetary policy, respectively. In comparison, we discuss the flexibility of this framework to generate opposing views on aggregate productivity and provide empirical evidence on the role of entry and exit for productivity.

Lastly, this paper relates to the banking literature on "zombie lending." The key notion within this literature is that banks may grant new credit or prolong existing loans to financially distressed corporate borrowers (Hoshi and Kashyap 2004; Peek and Rosengren 2005). Existing studies explore whether policy choices such as non-standard monetary policy measures (Acharya et al. 2019; Antoni and Sondershaus 2021; Bittner, Fecht, and Georg 2021) and bank regulation (Andrews and Petroulakis 2019; Acharya, Lenzu, and Wang 2021) encourage lending to "zombie firms." Our analysis complements this microeconometric research by providing a different and macroeconomic perspective: we investigate whether expansionary conventional interest rate policy allows unproductive firms to remain active through its effect on firm profits and the associated implications for productivity.

The rest of the paper is structured as follows. Section 2 outlines the theoretical framework. In Section 3, we discuss the interplay

[4]Hopenhayn (1992) considers perfect competition, whereas the latter two papers introduce monopolistic competition and focus on international trade, i.e., entry and exit to export markets.

between monetary policy, profits, firm dynamics, and productivity within the model. Section 4 presents the empirical analysis and results. Section 5 discusses policy implications and concludes.

2. Theoretical Framework

We first present our theoretical framework, a DSGE model with endogenous firm entry and exit à la Hopenhayn (1992), Melitz (2003), and Ghironi and Melitz (2005). The economy is populated by a continuum of households that consume a variety of differentiated goods. These goods are produced by heterogeneous firms, who enter and exit production according to their (expected) profits. Exit from production takes two forms: firms can decide to suspend production temporarily (be idle) or may be forced to close down permanently due to an exogenous exit shock. In line with this, entry also takes two forms: entering the market for the first time and returning from idleness. Upon entry into the market for the first time, firms have to pay fixed entry costs and draw an individual productivity level, which remains constant throughout their life cycle. A firm that is alive (i.e., has entered the market and has not been forced to exit permanently) decides to produce or to be idle in each period. Production is subject to additional per-period fixed operational costs. Firms need to cover these costs by obtaining loans from financial intermediaries. Prices and wages are subject to nominal rigidities.

2.1 Firms

There is a continuum of firms, each producing a different good $\omega \in \Omega$ using labor as the only production factor.[5] Overall firm productivity is given by aggregate productivity A_t and idiosyncratic productivity z, with the latter remaining constant over the entire life cycle of the firm. The production function of a given firm can hence be written as

$$y_t^C(z) = A_t z l_t^C(z), \tag{1}$$

[5]We abstract from physical capital to keep the model as simple as possible. An extended model features qualitatively and quantitatively similar business cycle properties (Bilbiie, Ghironi, and Melitz 2012). An interesting avenue for future research is the interaction of individual productivity and firm-specific physical capital.

where $y_t^C(z)$ denotes consumption output produced by a firm with individual productivity z, and $l_t^C(z)$ is the corresponding amount of labor demand. Aggregate productivity evolves according to an autoregressive AR(1) process in logs.

Labor Demand and Price Setting. Production is subject to fixed operational costs f of effective labor units at the beginning of each period. At this stage, firms do not have funds available and hence obtain loans from financial intermediaries at the nominal gross interest rate R_t to prepare production. This reflects a working capital channel in the spirit of Ravenna and Walsh (2006).[6] Total real costs of production TC_t are given by

$$TC_t(z) = w_t \left(l_t^C(z) + f \frac{R_t}{A_t} \right), \tag{2}$$

where w_t is the real wage. Cost minimization then yields

$$mc_t(z) = \frac{w_t}{A_t z}, \tag{3}$$

which shows that marginal costs differ across firms depending on idiosyncratic productivity. As outlined below, household demand for a specific good is given by

$$y_t^C(z) = \left(\frac{p_t(z)}{P_t} \right)^{-\theta} Y_t^C, \tag{4}$$

where $p_t(z)$ is the nominal individual price, P_t is the aggregate price index, Y_t^C is overall consumption demand, and θ is the constant elasticity of substitution between goods.

The goods market is monopolistically competitive. Each firm chooses its price to maximize the sum of current profits and the firm value (the expected discounted value of the profit stream from $t+1$ onward)[7] subject to its production function, taking the household demand schedule and aggregate variables as given. Firms face

[6]The results are qualitatively and quantitatively similar if all wages have to be paid before production.

[7]The firm value is given by $v_t(z) = E_t \sum_{s=t+1}^{\infty} \Lambda_s d_s(z)$, where Λ_s denotes the household's stochastic discount factor. The pricing problem hence implicitly accounts for the probability to exit production via the expectations operator.

quadratic price adjustment costs following Rotemberg (1982). The costs of adjusting prices in real terms, pac_t, are

$$pac_t(z) = \frac{\tau}{2}\left(\frac{p_t(z)}{p_{t-1}(z)} - 1\right)^2 \rho_t(z) y_t^C(z), \tag{5}$$

where

$$\rho_t(z) = \frac{p_t(z)}{P_t} \tag{6}$$

denotes the real price of firm z. Real profits of a given firm can hence be written as

$$\begin{aligned} d_t(z) &= \rho_t(z) y_t^C(z) - w_t l_t^C(z) \\ &\quad - \frac{\tau}{2}\left(\frac{p_t(z)}{p_{t-1}(z)} - 1\right)^2 \rho_t(z) y_t^C(z) - f\frac{w_t R_t}{A_t}, \end{aligned} \tag{7}$$

where the first term captures revenues, and the remaining terms are different costs (discussed further in the next section). As shown in Appendix A.2, the optimal real price satisfies

$$\rho_t(z) = \mu_t(z) mc_t(z), \tag{8}$$

where the markup over marginal costs is given by

$$\mu_t(z) = \frac{\theta}{(\theta-1)\left[1 - \frac{\tau}{2}\left(\frac{p_t(z)}{p_{t-1}(z)} - 1\right)^2\right] + \tau \Upsilon_t(z)}, \tag{9}$$

where the auxiliary term $\Upsilon_t(z)$ is defined as

$$\begin{aligned} \Upsilon_t(z) &= \frac{p_t(z)}{p_{t-1}(z)}\left(\frac{p_t(z)}{p_{t-1}(z)} - 1\right) \\ &\quad - E_t\left[\Lambda_{t+1}\frac{y_{t+1}^C(z)}{y_t^C(z)}\frac{P_t}{P_{t+1}}\left(\frac{p_{t+1}(z)}{p_t(z)} - 1\right)\left(\frac{p_{t+1}(z)}{p_t(z)}\right)^2\right], \end{aligned} \tag{10}$$

and where Λ_{t+1} denotes the household stochastic discount factor (defined further below). Optimal prices are thus heterogeneous across firms of differing productivity, as both marginal costs and optimal markups differ.[8]

[8]The markup would be identical across firms absent nominal rigidities ($\tau = 0$) and equivalent to the textbook expression $\theta/(\theta - 1)$.

Entry and Exit. Each period, firms enter and exit production depending on their current and expected profitability. There is an unbounded mass of ex ante homogeneous prospective entrants. When entering the market for the first time, each firm draws an idiosyncratic productivity level z from a distribution $G(z)$ with support on $[z_m, \infty)$ and starts to produce in the next period after some time to build. Market entry is subject to entry costs f_E of effective labor units. Following Lewis and Poilly (2012), we assume that some market entries fail.[9] Denoting the total number of new firms entering the market by H_t, the success probability is given by

$$\Psi_t(H_t, H_{t-1}) = 1 - F_{H,t}\left(\frac{H_t}{H_{t-1}}\right), \tag{11}$$

which has the properties $F_H(1) = F'_H(1) = 0, F''_H(1) = \psi > 0$. Potential entrants are forward-looking and decide to enter the market based on the firm value, i.e., the expected value of operation v_t (which is determined via a household asset pricing equation; see below). In equilibrium, firm dynamics yield the following free entry condition:

$$f_E \frac{w_t}{A_t} = v_t(\Psi_t + \Psi'_t H_t) + \beta E_t\left[\left(\frac{C_{t+1}}{C_t}\right)^{-1} v_{t+1}\Psi''_{t+1}H_{t+1}\right]. \tag{12}$$

In Equation (12), the left-hand side represents the costs associated with market entry. These are equated to the expected value of operation on the right-hand side, accounting for changes in the entry success probability induced by the number of entrants.

Turning to firm exit, an incumbent firm produces actively in a given period if its profits are positive, i.e., if $d_t(z) > 0$, and decides to be idle if profits are zero or negative. As such, only a subset of firms $\Omega_t \in \Omega$ are actively producing in any given period. The decision to exit production hence depends on firms' idiosyncratic productivity. The cutoff level of productivity $\bar{z}_t$ is defined by a zero profit condition given by

$$\bar{d}_t \equiv d_t(\bar{z}_t) = 0. \tag{13}$$

[9]This assumption guarantees a gradual response of entry in response to exogenous disturbances. As shown below, this is in line with our empirical findings.

Firms with $z > \bar{z}_t$ make positive profits and thus produce actively, whereas low-productivity firms with $z \leq \bar{z}_t$ decide to be idle. As a result, only relatively more productive firms are active in any period, and some exit from production takes place endogenously. In addition, each firm faces an exogenous exit shock at the end of each period, which occurs with probability δ, and forces firms to close down permanently. The total number of existing firms, N_t, thus evolves according to

$$N_t = (1-\delta)(N_{t-1} + \Psi_{t-1}(H_t, H_{t-1})H_{t-1}), \tag{14}$$

whereas the number of actively producing firms is given by[10]

$$S_t = (1 - G(\bar{z}_t))N_t. \tag{15}$$

2.2 Households

There is a continuum of infinitely lived identical and atomistic households. The representative household maximizes expected utility U_t, given by

$$U_t = E_t \left[\sum_{s=t}^{\infty} \beta^{s-t} \left(log(C_s) - \chi \frac{L_s^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}} \right) \right], \tag{16}$$

where C_s is consumption and L_s denotes labor supply.[11] The discount factor is given by β, and η is the elasticity of labor supply to wages. Consumption is defined as a basket of individual varieties ω over a continuum of goods Ω. Consumption preferences follow Dixit and Stiglitz (1977), such that the elasticity of substitution between individual goods (θ) is constant. This yields the demand schedule for a given variety as shown in Equation (4).

Households can invest in (government) bonds and equity shares in a mutual fund of firms. Bonds yield a safe gross nominal interest rate R_t in the next period. The mutual fund pays out dividends equal

[10]The notation of S_t follows Hamano and Zanetti (2017), who embrace the notion that these firms are "surviving" product destruction. However, firms that decide to remain idle in a given period are also "alive," but are not included in S_t.

[11]The utility function follows King, Plosser, and Rebelo (1988) and ensures the existence of a balanced growth path.

to total firm profits in each period. In period t, the representative household obtains equity shares x_{t+1} at the real share price v_t (the firm value).[12] In addition to interest income and dividend income, the household receives income by selling its existing shareholdings and by supplying labor at the real wage w_t. The budget constraint in real terms hence reads

$$C_t + x_{t+1} v_t (N_t + H_t) + B_{t+1} = w_t L_t + x_t N_t v_t + x_t S_t \widetilde{d}_t + \frac{R_{t-1}}{\pi_t^C} B_t, \tag{17}$$

where B_t are real holdings of bonds, $\widetilde{d}_t$ is the average dividend across active firms, and π_t^C denotes the gross consumption-based inflation rate:

$$\pi_t^C = \frac{P_t}{P_{t-1}}. \tag{18}$$

The household maximizes expected utility by choosing consumption, labor supply, and its portfolio allocation subject to the budget constraint in Equation (17). The first-order condition with respect to bond holdings is a standard Euler equation given by

$$1 = \beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-1} \frac{R_t}{\pi_{t+1}^C} \right]. \tag{19}$$

The optimality condition with respect to shareholdings is given by

$$v_t = E_t \left[\Lambda_{t+1} \left(v_{t+1} + \frac{S_t}{N_t} \widetilde{d}_{t+1} \right) \right], \tag{20}$$

where the stochastic discount factor, Λ_{t+1}, is defined by

$$\Lambda_{t+1} = \beta (1 - \delta) E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-1} \right]. \tag{21}$$

The labor market is monopolistically competitive: households have some market power and set their wages. The differentiated labor supplied by each household is aggregated by a union and hired by firms on a competitive market. The real wage is then given by

[12] By assumption, the household does not know which firms operate in the next period. As a result, it finances all incumbent and new firms during a given period.

$$w_t = \left(\int_0^1 (w_t(j))^{1-\theta_W} dj\right)^{\frac{1}{1-\theta_W}}$$
$$= \left(\lambda_W \left(\frac{w_{t-1}}{\pi_t^C}\right)^{1-\theta_W} + (1-\lambda_W)(w_t^*)^{1-\theta_W}\right)^{\frac{1}{1-\theta_W}}. \qquad (22)$$

2.3 Aggregation

Following Melitz (2003) and Ghironi and Melitz (2005), we specify that individual firm productivity is drawn from a Pareto distribution

$$G(z) = 1 - \left(\frac{z_m}{z}\right)^{\kappa}, \qquad (23)$$

where z_m is the minimum possible productivity level and κ governs the shape and dispersion of the distribution. Since the cutoff level of productivity $\bar{z}_t$ varies over the business cycle, the average productivity across active firms is time-varying as well:

$$\widetilde{z}_t \equiv \left[\frac{1}{1-G(\bar{z}_t)} \int_{\bar{z}_t}^{\infty} z^{\theta-1} dG(z)\right]^{\frac{1}{\theta-1}} = \bar{z}_t \left[\frac{\kappa}{\kappa-(\theta-1)}\right]^{\frac{1}{\theta-1}}. \qquad (24)$$

Variables referring to firms with average productivity are denoted similarly in the following, i.e., $\widetilde{a}_t \equiv a(\widetilde{z}_t)$ for a generic variable a. The average markup is given by

$$\widetilde{\mu}_t = \frac{\theta}{\begin{array}{c}(\theta-1)\left(1-\frac{\tau}{2}(\pi_t-1)^2\right) \\ +\tau\left(\pi_t(\pi_t-1) - E_t\left[\Lambda_{t+1}\frac{Y_{t+1}^C}{Y_t^C}\frac{S_t}{S_{t+1}}(\pi_{t+1}-1)\pi_{t+1}\right]\right)\end{array}}. \qquad (25)$$

Equation (25) is the nonlinear Phillips curve in our model,[13] relating average markups to producer price inflation π, which is linked to consumer price inflation by

[13] One can show that a log-linear version of Equation (25) reduces to an augmented New Keynesian Phillips curve. In contrast to the model by Bilbiie, Ghironi, and Melitz (2008) with exogenous exit, the number of *active* firms (S) determines inflation dynamics, instead of the total number of firms (N). We briefly discuss the implications of endogenous exit for inflation dynamics in Appendix A.4.

$$\pi_t = \frac{\widetilde{\rho}_t}{\widetilde{\rho}_{t-1}} \pi_t^C. \tag{26}$$

The number of active firms can be written as

$$S_t = (1 - \zeta_t) N_t, \tag{27}$$

where the endogenous fraction ζ_t of exits from production due to low productivity is

$$\zeta_t \equiv 1 - G(\bar{z}_t) = 1 - \left(\frac{z_m}{\bar{z}_t} \right)^{\kappa}. \tag{28}$$

Finally, the price index captures a variety effect stemming from consumer preferences:

$$\widetilde{\rho}_t = S_t^{\frac{1}{\theta - 1}}. \tag{29}$$

Market Clearing. Equilibrium on the goods market requires that aggregate consumption output equals the sum of private consumption and price adjustment costs:

$$Y_t^C = C_t + S_t \widetilde{pac}_t = \left(1 - \frac{\tau}{2} (\pi_t - 1)^2 \right)^{-1} C_t. \tag{30}$$

The aggregate accounting identity equates aggregate output to the sum of labor and dividend income:

$$C_t + v_t H_t = w_t L_t + S_t \widetilde{d}_t. \tag{31}$$

Aggregate output is consumption plus investment:

$$Y_t = C_t + I_t, \tag{32}$$

and investment is the creation of new firms:

$$I_t = v_t H_t. \tag{33}$$

The equilibrium on the labor market requires that

$$L_t = S_t \left(\widetilde{l}_t^C + \frac{f}{A_t} \right) + H_t \frac{v_t}{w_t}. \tag{34}$$

To close the model,[14] we assume a central bank interest rate rule given by

$$log\left(\frac{R_t}{R}\right) = \phi_R\, log\left(\frac{R_{t-1}}{R}\right) + (1-\phi_R)\left[\phi_\pi\, log\left(\frac{\pi_t}{\pi}\right) + \phi_y\, log\left(\frac{Y_t}{Y_{t-1}}\right)\right] + \varepsilon_t^M. \quad (35)$$

The central bank thus responds to deviations of producer price inflation from steady state and output growth.[15] ε_t^M is a monetary policy shock, which we analyze in the following.

3. The Theoretical Effect of Monetary Policy

In this section, we analyze how conventional monetary policy affects firm entry and exit in our theoretical model. We show that the resulting productivity effect depends crucially on the reaction of corporate profitability to the monetary shock. We contrast two model variants yielding opposing predictions, which we test empirically in the next section.

3.1 Calibration

The following numerical analysis is based on standard parameter values and estimates for the U.S. economy. We interpret periods as quarters and set $\beta = 0.99$, equivalent to an annualized steady-state real interest rate of 4 percent, and consider a steady-state gross inflation rate $\pi = 1$. Regarding household preferences, we set the elasticity of labor supply $\eta = 2$ and calibrate $\chi = 0.90$ to normalize steady-state labor supply $L = 1$.

With respect to the firm parameters, the entry cost f_E and the minimum productivity level z_m are set to unity, without loss of

[14] Appendix A.1 shows the equilibrium equations and the steady-state computation.

[15] As discussed by Bilbiie, Ghironi, and Melitz (2008), a response to welfare-based consumer price inflation π^C is infeasible in reality due to infrequent updating of the baskets used to measure inflation. Actual consumer price inflation is closer to p_t than P_t. Aghion et al. (2019) discuss how firm dynamics raise difficulties for measuring inflation and growth.

generality. We follow Ghironi and Melitz (2005) and calibrate the elasticity of substitution between goods $\theta = 3.8$ and the shape parameter of the productivity Pareto distribution $\kappa = 3.4$. As in Hamano and Zanetti (2018), we choose the fixed costs f and the exogenous exit rate δ to match annual U.S. entry and exit rates, which were 12.3 percent and 10.6 percent over 1977–2016 according to the Business Dynamics Statistics (BDS). Using this entry rate in Equation (14) implies $\delta = 0.03$. Together with the exit rate, this yields $f = 0.009$ and a steady-state ratio between average and cutoff productivity of $\widetilde{z}/\bar{z} = 1.86$ (see Appendix A.2). Following Lewis and Poilly (2012), we calibrate the firm entry costs parameter $\psi = 8.31$.

Turning to the parameters for nominal rigidities, the elasticity of substitution between differentiated labor is set to $\theta_W = 21$, implying a steady-state wage markup of 1.05 as in Christiano, Eichenbaum, and Evans (2005). We calibrate the fraction of non-adjusting firms as $\lambda_W = 0.75$. The Rotemberg price adjustment parameter τ is set to $\tau = 77$, in line with Bilbiie, Fujiwara, and Ghironi (2014). The monetary policy parameters are calibrated as $\phi_R = 0.8$, $\phi_\phi = 1.5$, $\phi_y = 0.5/4$.

3.2 Monetary Policy Shocks and the Role of Profits

We now aim to understand how conventional monetary policy shocks affect firm dynamics in the model. The framework implies that entry and exit decisions are tightly linked to corporate profits and expectations thereof. On the one hand, the entry condition in Equation (12) stipulates that more firms decide to enter the market if the expected firm value rises. In turn, Equation (20) specifies that the firm value is given by the sum of discounted average profits. On the other hand, entry into and exit from production depends on the zero profit condition in Equation (13). It is thus instructive to consider the different components of profits in closer detail. As outlined in Equation (7), profits of a firm with productivity z are given by

$$d_t(z) = \underbrace{\rho_t(z) y_t^C(z)}_{(1)} - \underbrace{w_t l_t^C(z)}_{(2)} \\ - \underbrace{\frac{\tau}{2}\left(\frac{p_t(z)}{p_{t-1}(z)} - 1\right)^2 \rho_t(z) y_t^C(z)}_{(3)} - \underbrace{f\frac{w_t R_t}{A_t}}_{(4)}. \tag{36}$$

One can thus decompose profits into four components: (1) sales revenues, (2) labor costs, (3) price adjustment costs, and (4) fixed costs. The overall response of profits to changes in monetary conditions thus depends on the relative effects on these components. Inspecting the latter two components directly reveals that their quantitative importance is limited. Price adjustment costs are a squared function of price changes, which makes this term generally small (as also argued by Bilbiie, Fujiwara, and Ghironi 2014). In the fourth term, wages and the interest rate move in opposite directions after monetary policy shocks.

The key question of interest is thus how strongly revenues and labor costs, labeled (1) and (2) above, react to changes in monetary conditions. On the one hand, expansionary monetary policy stimulates aggregate demand from households by decreasing the real interest rate. The additional demand is—ceteris paribus, i.e., before price changes and other general equilibrium effects—distributed proportionally across all firms. As a result, demand for the individual variety increases. This raises sales, profits, and the firm value directly. On the other hand, labor costs rise as well after a monetary expansion. Firms need to hire more workers to expand their production to satisfy the additional demand. As a compensation for the higher labor supply, workers demand a higher wage. To showcase this notion, we contrast two model variants in the following. Variant A features wage rigidities as outlined in the previous section. Variant B assumes perfectly flexible wages ($\lambda_W = 0$).[16]

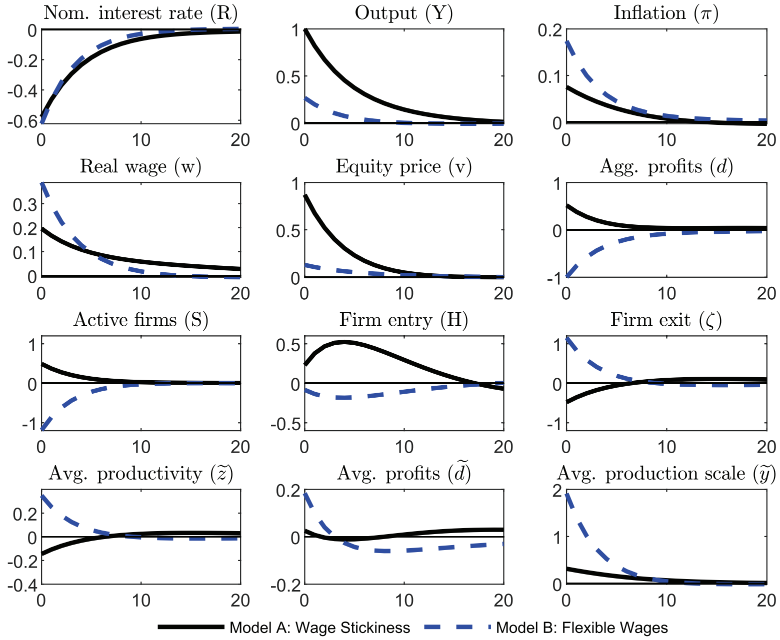
Figure 1 shows the impulse responses to an expansionary monetary policy shock that decreases the nominal interest rate in both model variants.[17] The monetary policy shock increases output and inflation in both cases.[18] As the real interest rate falls, households

[16]Variant A is similar to the frameworks used by Colciago and Silvestrini (2022) and Hamano and Zanetti (2022). Both contributions abstract entirely from price stickiness, such that they are inherently silent about real effects of monetary policy in the absence of wage stickiness (Variant B).

[17]The model's monetary policy variable is the interest rate on one-period (a quarter) bonds. In our empirical analysis, we use the one-year constant-maturity Treasury yield. While not identical, these measures are closely related, such that their reactions to monetary policy shocks are expected to be qualitatively and quantitatively similar.

[18]Note that the graph shows producer price inflation. Within our closed-economy model, this corresponds to GDP deflator inflation, which is the variable employed in our empirical exercise.

Figure 1. Expansionary Monetary Policy Shock in Model Variants



Note: Impulse response functions to an expansionary monetary policy shock. Solid lines refer to Variant A (wage stickiness), dashed lines to Variant B (flexible wages). The shock size is calibrated to yield a 1 percent increase of output in Variant A. All variables are shown in percent deviations from steady state, except for inflation, interest rate, and exit (percentage point deviations).

increase consumption and reduce bond holdings. Firms demand more labor to accommodate the higher demand for consumption goods. The tighter labor market implies higher real wages to compensate for higher labor supply.

While the macroeconomic picture is qualitatively similar across the model variants, they feature completely different views on profits, firm dynamics, and productivity. In Variant A, the economic expansion is accompanied by a procyclical response of the number of active firms (as in Colciago and Silvestrini 2022 and Hamano and Zanetti 2022). This reflects an increase of entry into production (ΔS_t), a rise in the number of firms entering the market (H_t), and a decrease of the exit rate from production (ζ_t). At the same time, aggregate profits increase, indicating that the revenue channel dominates the labor cost channel. As a result, firms become more profitable on impact. This lowers the productivity threshold level that guarantees non-negative profits. Incumbent low-productivity firms thus produce actively, such that average productivity *decreases*. At the same time, the higher corporate profitability increases firms' expected value and thereby renders equity investment more attractive to households. This induces more firms to enter the market. Among these new entrants, low-productivity firms also make positive profits, albeit featuring a lower scale of production. In general equilibrium, average firm profits rise only marginally since actively producing firms charge higher prices, which *lowers* average profits (as the elasticity of substitution is larger than unity), and because they face higher marginal costs (due to a lower average productivity).

The expansionary monetary policy shock thus allows low-productivity incumbents to produce actively and facilitates the entry into production of relatively unproductive firms. As a result, the average productivity of active firms declines. While the favorable monetary conditions prevail, unproductive firms remain profitable and thus continue to produce actively. However, as the monetary stimulus and the associated economic boom fade, the cutoff level of productivity for profitability increases again. As a result, low-productivity firms become unprofitable and decide to become idle, leading to an overshooting of firm exit in the medium run.[19]

Variant B features diametrically opposite predictions on profits, firm dynamics, and productivity: because labor costs rise sharply, firm exit is procyclical and firm entry is countercyclical in this variant. To understand this observation, note that the labor cost channel is tightly linked to the markup decisions (see Equation 36). In the presence of price adjustment costs, optimal markups are inversely related to inflation: as firms raise prices following expansionary monetary policy shocks, markups decrease. The resulting downward pressure on profits makes low-productivity firms unprofitable, such that they decide to become idle and exit increases. At the same time,

[19] Other expansionary shocks such as aggregate productivity shocks yield similar firm dynamics; see Hamano and Zanetti (2017), Rossi (2019), and Appendix A.5.

the rise in real wages implies that entry costs are higher, reducing firm entry (in line with Bilbiie, Ghironi, and Melitz 2008; Lewis 2009).[20] The fewer active firms are on average more productive, more profitable, and larger in terms of their production scale.

The theoretical framework is thus able to generate two opposing views regarding the effect of monetary policy on productivity through firm entry and exit. If expansionary monetary policy raises profitability by stimulating aggregate demand, it allows unproductive firms to be active, thus reducing overall productivity. The converse case that a monetary easing increases productivity requires that the rise in production costs dominates such that profitability decreases. As a consequence, only productive firms are profitable, such that exit increases while entry declines.

4. Empirical Analysis

In this section, we test the theoretical predictions empirically: we analyze the effects of monetary policy on (1) firm dynamics and (2) various measures of productivity.

4.1 Data

Our sample covers U.S. data from 1993:Q2 through 2017:Q4.[21] More recent observations are excluded due to the lack of availability of high-frequency financial surprises (used to identify monetary policy shocks; see below), earlier observations due to the data on firm dynamics. To capture firm entry and exit, we use quarterly data on the number of establishment births and deaths from the Bureau of Labor Statistics (BLS).[22]

We consider a variety of productivity measures. On the one hand, we use aggregate series by Fernald (2014): total factor productivity

[20]The decrease of interest rates implies a fall in the return to bonds. To restore no-arbitrage across different investments, the return to shareholdings also decreases slightly. This happens via a slight increase in the equity prices today relative to tomorrow.

[21]In Appendix B.1, we provide descriptive statistics and data charts.

[22]An establishment is a single physical location; a firm is an establishment or a combination of establishments. Rossi (2019) similarly uses the establishment series to proxy firm entry and exit decisions.

(TFP)—the Solow residual, utilization-adjusted TFP (TFPu)—a cleaner measure of pure technological change, and labor productivity in the business sector (LP).[23] On the other hand, as a closer counterpart to the theoretical productivity variable, we compute average firm-level productivity based on microdata from Compustat. To this end, we consider balance sheet data of all firms in the nonfinancial sectors except utilities, construct a firm-specific measure of the real capital stock using the perpetual inventory method, and estimate firm-level productivity using a fixed-effects regression of sales on production inputs (see Clementi and Palazzo 2019; Ottonello and Winberry 2020; and Appendix B.2).

Our monetary policy variable is the one-year constant-maturity Treasury yield, following Gertler and Karadi (2015) and Jarociński and Karadi (2020). This measure captures the effects of forward guidance and moved sufficiently even during the zero lower bound (ZLB) period.[24,25] The block of macroeconomic variables consists of real GDP and the GDP implicit price deflator. As financial variables, we include the S&P 500 stock price index (deflated by the GDP price deflator) as well as the excess bond premium of Gilchrist and Zakrajšek (2012). Including a measure of financial frictions is crucial to identify the transmission channel of monetary policy (Gertler and Karadi 2015) and the monetary policy rule (Caldara and Herbst 2019). In robustness checks, we consider alternative macrofinancial variables (see Section 4.4 and Appendix B.5).

[23]The aggregate productivity series are based on growth accounting techniques proposed by Basu, Fernald, and Kimball (2006). TFP growth is output growth not explained by (observed) input growth $\Delta TFP = \Delta Y - \alpha\Delta K - (1-\alpha)\Delta L$, where ΔY is real output growth, ΔK is capital growth, ΔL is labor growth, and α is the capital share on output. Utilization-adjusted TFP growth is TFP not explained by capital and labor utilization growth $\Delta TFPu = \Delta TFP - \Delta Util$. Labor productivity growth is defined as growth in output per hour $\Delta LP = \Delta Y - \Delta H$, where ΔH is hours worked in business sector.

[24]Forward guidance became important for U.S. monetary policy after the FOMC started issuing press releases in February 1994 (Gürkaynak, Sack, and Swanson 2005), which almost coincides with the start of our sample.

[25]Ikeda et al. (2024) show that the ZLB is empirically relevant when identifying the transmission of a monetary policy shock and find that the shadow short rate appropriately captures unconventional monetary policy. We consider the shadow short rate in a robustness exercise.

The theoretical model suggests that wages and profits constitute further variables of interest. We construct per capita wages by dividing aggregate wages and salaries by the total number of employees. Aggregate profits are measured by corporate profits after taxes with inventory valuation and capital consumption adjustment from the Bureau of Economic Analysis (BEA). We deflate both series using the GDP implicit price deflator.

4.2 Methodology

Our baseline empirical model is a VAR with high-frequency surprises along the lines of Jarociński and Karadi (2020). The high-frequency surprises are yield and stock price changes around monetary policy announcements by the Federal Open Market Committee (FOMC), which we use to identify monetary policy shocks (see further below). Let m_t be a vector of surprises in quarter t[26] and y_t be a vector of macroeconomic and financial variables. We add further variables of interest (e.g., firm exit) one by one to adopt a parsimonious estimation approach. The baseline VAR model is given by

$$\begin{pmatrix} m_t \\ y_t \end{pmatrix} = \begin{pmatrix} 0 \\ c_Y \end{pmatrix} + \sum_{p=1}^{4} \begin{pmatrix} 0 & 0 \\ A_{p,YM} & A_{p,YY} \end{pmatrix} \begin{pmatrix} m_{t-p} \\ y_{t-p} \end{pmatrix} + \begin{pmatrix} u_t^m \\ u_t^y \end{pmatrix}, \begin{pmatrix} u_t^m \\ u_t^y \end{pmatrix} \sim \mathcal{N}(0, \Sigma), \tag{37}$$

where $\mathcal{N}$ denotes the normal distribution. The zero restrictions for m_t imply a zero mean and independence from lags of m_t and y_t; these restrictions are plausible if high-frequency financial surprises are unpredictable. We estimate this VAR using Bayesian methods in log-levels for all variables except interest rates, spreads, and high-frequency surprises, set the maximum lag length to four, and use a flat prior for our benchmark results.

To identify monetary policy shocks, we adopt a sign-restriction approach in the spirit of Jarociński and Karadi (2020). We use changes in the three-month federal funds future and the S&P

[26] m_t is the sum of intraday surprises on the days with FOMC announcements occurring in quarter t.

500 index within a tight window around FOMC announcements.[27] Changes in the three-month federal funds future reflect both surprises about actual rate-setting and near-term forward guidance and therefore constitute a broad measure of conventional monetary policy. Our identification procedure imposes opposite sign restrictions on both high-frequency surprises and their low-frequency counterparts (the interest rate and the stock price). While not the focus of our analysis, we also identify central bank information shocks to avoid confounding effects.[28,29] Table 1 shows our set of identification restrictions.

Our sign restrictions are more stringent than the approach of Jarociński and Karadi (2020), which remains agnostic about low-frequency variables. In our application, these additional restrictions are necessary to ensure a proper identification. As outlined above, the lack of data availability restricts our sample start to 1993:Q2. For this sample, sign restrictions on high-frequency variables only yield implausible interest rate dynamics after monetary policy shocks (see Figure B.6 in Appendix B.4).[30] We hence add low-frequency sign restrictions in line with our theoretical framework, standard DSGE models (e.g., Smets and Wouters 2007), and the empirical literature (e.g., Liu et al. 2019).

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[27]We use an updated version of the data set by Gürkaynak, Sack, and Swanson (2005). The window starts 10 minutes before the announcement and ends 20 minutes after. Gürkaynak, Sack, and Swanson (2005) show that these changes are not driven by confounding factors like macroeconomic releases on that day.

[28]High-frequency interest rate surprises may not only reflect monetary policy shocks, but also contain information about the state of the economy (Miranda-Agrippino and Ricco 2021). It is hence essential to control for this information channel (Romer and Romer 2000; Melosi 2017; Nakamura and Steinsson 2018) when identifying monetary policy shocks, as it may bias impulse responses. Figure B.4 in Appendix B shows that an identification procedure that does not account for central bank information shocks yields a decline of real GDP and stock prices following a monetary easing.

[29]We enlarge the rotation space of orthonormal matrices to include the interest rate and the stock price to increase the set of structural models that potentially exhibit a strong link between high-frequency surprises and their low-frequency counterparts.

[30]The data from 1990:M2 through 1993:M3 (as used in Jarociński and Karadi 2020) are particularly informative about monetary policy shocks. This period coincides with the U.S. savings and loan crisis, which featured large and surprising interest rate cuts by the FOMC and associated positive stock surprises.

Table 1. Sign Restrictions

Variable	Shock: Monetary Policy (Negative Comovement)	Shock: CB Information (Positive Comovement)	Shock: Other
m_t, High Frequency			
Interest Rate Surprise	+	+	0
Stock Price Surprise	−	+	0
y_t, Low Frequency			
Interest Rate	+	+	0
Stock Price Index	−	+	0

Note: Sign restrictions imposed on the respective variable's impact response to shocks. Empty fields denote an unrestricted response.

Aside from the VAR, we use panel local projections (PLPs) à la Jordà (2005) and Jordà, Schularick, and Taylor (2015) to exploit the cross-sectional information of the firm-level data. The PLP model is given by

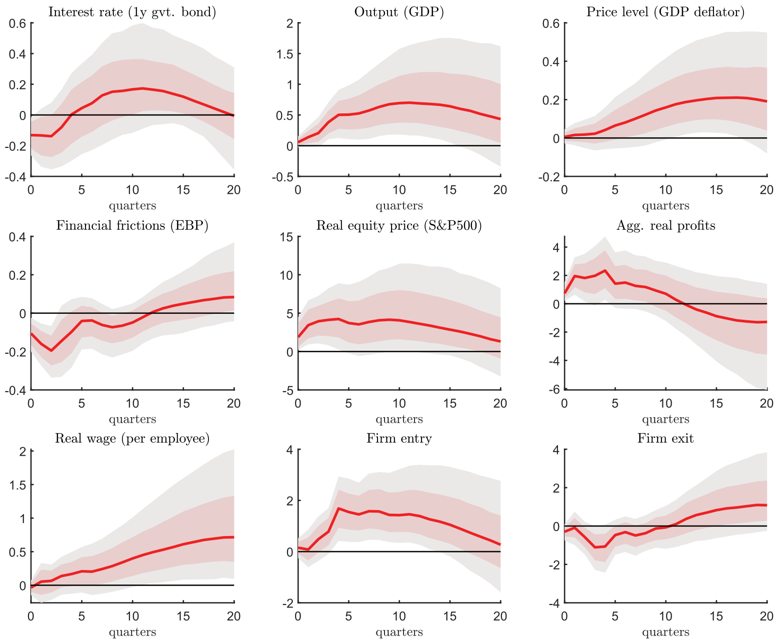
$$y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + D_t\eta_h + x_t\beta_h + \sum_{j=1}^{2} \Delta y_{i,t-j}\theta_{j,h} + \sum_{j=1}^{2} w_{t-j}\gamma_{j,h} + u_{i,t+h}, \tag{38}$$

where $y_{i,t}$ is productivity of firm i, D_t is a dummy vector to control for seasonal patterns, x_t is a monetary policy shock, and w_t is a vector of additional controls. To match the information set of the VAR, we consider the same macrofinancial controls (interest rate, output, price level, stock price, and the excess bond premium). β_h is the coefficient of interest and measures the response of firm productivity at time $t+h$ to a shock at time t. The lags of the dependent variables in first differences control for autoregressive dynamics. Standard errors are clustered two-way at the firm level and the time level.

4.3 Results

Figure 2 shows our empirical results regarding the effect of an expansionary monetary policy shock on macrofinancial variables and firm

Figure 2. Expansionary Monetary Policy and Firm Dynamics



Note: Impulse response functions to a monetary policy shock identified in a VAR with FOMC announcement surprises using sign restrictions on the comovement between high- and low-frequency variables. The thick lines are the median estimates; the shaded areas depict the 68 percent and 90 percent credible intervals. Responses are shown in percent deviations, except for the interest rate and the measure of financial frictions (percentage point deviations).

dynamics based on the VAR. On impact, the one-year Treasury yield decreases by roughly 10 basis points. This interest rate response to the shock is very short-lived. Output and the aggregate price level increase in response to the monetary stimulus with a delay of a couple of quarters, consistent with standard theory. Stock prices increase over a prolonged period, while financial frictions decline on impact, in line with the credit channel of monetary policy. Albeit somewhat smoother, these macrofinancial impulse responses are very similar to the monthly estimates reported in recent contributions (Gertler and Karadi 2015; Caldara and Herbst 2019; Jarociński and Karadi 2020; Miranda-Agrippino and Ricco 2021).

With respect to firm dynamics, our results show that a monetary policy shock significantly affects the firm-extensive margin. Firm entry is procyclical and increases following a monetary easing. The peak effect occurs after one year at close to 2 percent. The rise in firm entry is persistent and lasts around three years. At the same time, firm exit is countercyclical and decreases following more favorable monetary conditions.[31] The number of active production units (sometimes labeled net business formation, i.e., entry minus exit) peaks one year after the monetary shock. After around two years, firm exit overshoots its long-run level and gradually reverts afterward, while the expansion of economic activity fades. These empirical results are qualitatively in line with the theoretical predictions of Variant A (see Figure 1). This empirical support for Variant A regarding firm entry and exit is corroborated by the impulse responses of wages and profits: corporate profits increase persistently after the monetary easing (in line with Lewis and Poilly 2012), while wages rise sluggishly over the medium run, likely reflecting nominal rigidities. The first set of empirical results regarding firm entry and exit thus supports the notion invoked by Variant A (with sticky wages), while contradicting Variant B (with flexible wages).

Our result regarding firm entry is consistent with Lewis (2009), Lewis and Poilly (2012), and Bergin, Feng, and Lin (2018), while Hamano and Zanetti (2022) document similar results for entry and exit. All of these studies are based on pre-2000 data to proxy entry and exit. As such, our analysis provides new empirical evidence that an expansionary monetary policy shock induces a rise in firm entry in more recent times, shows that both sides of the firm-extensive margin are affected, and documents an overshooting of firm exit.[32] Our

[31]Firm exit is also unconditionally countercyclical in our sample; see Appendix B.1, in line with earlier findings by Campbell (1998) and Jaimovich and Floetotto (2008).

[32]These studies use short-run restrictions on output and prices for identification. In our more recent sample characterized by forward guidance, such restrictions are insufficient for identification, as they do not fully capture the central bank information set (Gürkaynak, Sack, and Swanson 2005). Short-run restrictions are also problematic when including financial variables, as these may

results share similarities with earlier findings for productivity shocks by Rossi (2019), who documents that firm exit falls initially after a positive aggregate productivity shock, but overshoots its long-run level after approximately two years. She rationalizes these findings in a model similar to our Variant A.

Turning to the empirical response of productivity, Figure 3 shows the effects of an expansionary monetary policy shock on various productivity measures. The upper panels (A) are based on the VAR, whereas the lower panels (B) originate from PLPs using the sign-identified monetary policy shocks from the VAR.

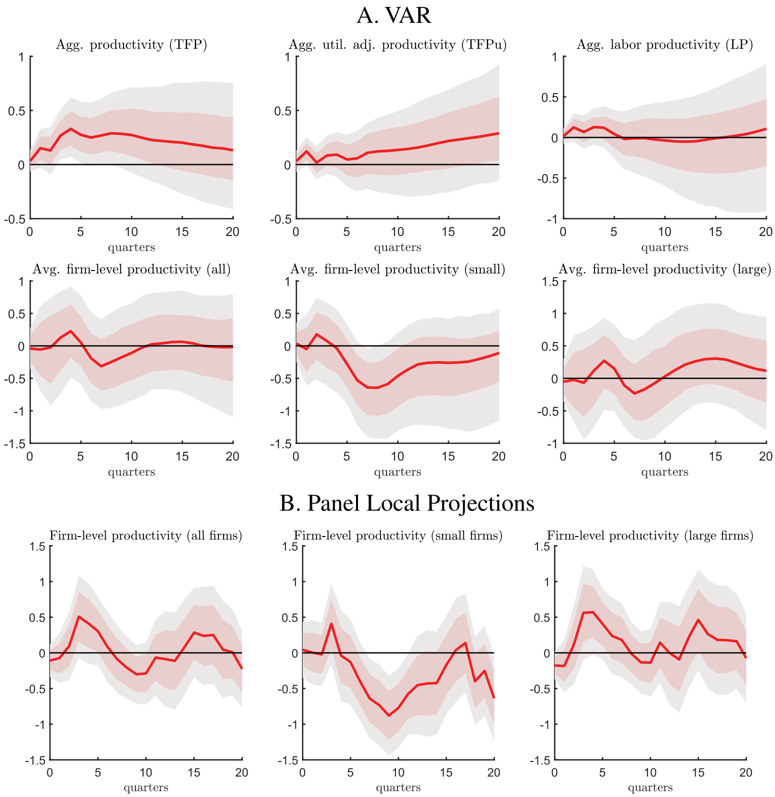
Overall, the empirical results regarding productivity differ across measures and methods. Among the aggregate measures (shown in the first row), TFP rises persistently and significantly following more favorable monetary conditions. In contrast, the responses of utilization-adjusted TFP and labor productivity are largely insignificant, which suggests that the rise of TFP is driven by (nontechnological) variable input utilization.[33] The response of average firm-level productivity is also insignificant at conventional levels in the VAR (second row, left panel). However, a closer inspection (second row, middle and right panels) reveals that the productivity response depends on firm size: productivity declines somewhat for comparably small firms (classified as having sales below $10 million).

The PLP impulse responses are qualitatively and quantitatively highly similar to the VAR responses. However, exploiting the rich cross-sectional variation by using PLPs sharpens the identification of the impulse response functions considerably. In particular, the decline of average productivity across small firms is both substantial—about 1 percent after two years—and statistically

respond simultaneously with policy (Gertler and Karadi 2015). Figure B.5 in Appendix B illustrates this issue.

[33]These results stand in contrast to those of Christiano, Eichenbaum, and Evans (2005), Moran and Queralto (2018), and Meier and Reinelt (2022), who document that aggregate productivity rises after a monetary easing. Christiano, Eichenbaum, and Evans (2005) and Moran and Queralto (2018) identify monetary policy shocks using short-run restrictions in a sample in which forward guidance became important, which is problematic (see Footnote 32). Meier and Reinelt (2022) employ local projections without macrofinancial controls. Figure B.17 in Appendix B highlights the importance of including such control variables.

Figure 3. Expansionary Monetary Policy and Productivity



Note: Panel A shows impulse response functions to the sign-identified monetary policy shock in a VAR with FOMC announcement surprises. Panel B shows impulse response functions to the sign-identified monetary policy shock in PLPs using a full set of macrofinancial controls. The thick lines are the median estimates; the shaded areas depict the 68 percent and 90 percent credible (confidence) intervals for the VAR (PLPs). Responses are shown in percent deviations.

highly significant (third row, middle panel). In contrast, the response of average productivity across all firms is nonsystematic and not significant at the 10 percent level (third row, left panel). This largely resembles the behavior of average productivity of large firms (third row, right panel).

Our empirical findings hence suggest that expansionary monetary policy facilitates the entry and profitability of small, unproductive firms. The simple view of firm heterogeneity in the theoretical framework, in particular in Variant A, thus appears to be an appropriate representation for smaller firms. Intuitively, small firms are particularly likely to be the "marginal" firms, i.e., the ones entering or exiting production. This notion is also embedded in the theoretical framework: the firm-level production scale is proportional to productivity, such that low-productivity firms are smaller than productive firms (see Appendix A.1). In contrast, new firms are naturally rarely large in reality, and large firms tend to be more successful and thus less likely to exit production.

However, the empirical results regarding *aggregate* productivity are clearly not in line with either variant of the model. While the responses of entry and exit in the data are consistent with Variant A, one would accordingly expect a significant decline of aggregate productivity after a monetary easing. Contrary to this theoretical prediction, we do not find compelling evidence of a systematic effect of monetary policy on aggregate productivity. This finding suggests that entry and exit of unproductive firms are of limited quantitative importance for the overall productivity effect of monetary policy: since smaller firms are primarily affected, they hardly have an impact on the aggregate.

The empirical exercise also indicates that a key dimension of reality is not included in the theoretical framework, i.e., that the model is incomplete and misses an important feature. A model in line with the empirical results could, for example, combine an endogenous firm-extensive margin with firm-specific productivity evolving endogenously over the life cycle. Such a unifying framework hence constitutes an interesting avenue for future research with a view to examining the relative importance of the different productivity channels.

4.4 Robustness

We verify the robustness of our empirical results along several dimensions, reported in Appendix B.5. Figure B.8 shows that the low-frequency sign restrictions guarantee a proper identification of monetary policy shocks in our setup. Figure B.9 highlights that an alternative identification, the so-called poor man's proxy by Jarociński and Karadi (2020), yields results similar to our baseline. The same is true when using surprises from scheduled FOMC meetings only or assuming that surprises are predictable by macrofinancial factors (Figures B.10 and B.11). Our VAR results are also robust when considering a monthly frequency (B.12), to different monetary policy indicators (B.13), to alternative measures for output and financial frictions (B.14), and in a sample up to or excluding the Great Recession (B.15 and B.16). Figure B.17 confirms our VAR results by using local projections and highlights the importance of macrofinancial controls. We hence explore the PLP results' sensitivity to alternative sets of controls in Figure B.18, which reveals considerable robustness of the significantly negative response of average productivity in the subset of small firms. In Figure B.19, we show that controlling for sectoral heterogeneity yields results broadly in line with our baseline findings. Finally, we confirm that the baseline VAR results are robust to different procedures to construct the firm-level productivity series, in particular alternative sector compositions (B.20) and estimation approaches (B.21).

5. Conclusion

There exists a notion that accommodative monetary conditions may allow unproductive firms to remain active or start production. We explore this effect of monetary policy on productivity through firm entry and exit in the context of conventional policy measures. In a general equilibrium model of heterogeneous firms, we show that an exogenous decrease of nominal interest rates allows low-productivity incumbents to remain active and unproductive firms to enter production if the looser monetary conditions stimulate corporate profitability. Empirically, we find that a monetary easing indeed raises profits, reduces firm exit, and increases entry. However, we find compelling evidence for a negative productivity effect only for small firms, whereas the response of aggregate productivity is insignificant and nonsystematic. These results imply that a negative impact of expansionary monetary policy on productivity through entry and exit is primarily a concern for small firms, and hence quantitatively less important for aggregate productivity than suggested by the theory.

Appendix A. Theoretical Analysis

A.1 Equilibrium Equations

The equilibrium is characterized by 33 endogenous and 3 exogenous variables, $(A_t, \varepsilon_t^C, \varepsilon_t^M)$. See Table A.1.

A.2 Steady State

We first normalize technology, labor, and inflation in the steady state to 1:

$$A = 1, \tag{A.1}$$

$$L = 1, \tag{A.2}$$

$$\pi = \pi^C = 1. \tag{A.3}$$

From the household bond Euler equation (19), we get

$$R = \beta^{-1}\pi, \tag{A.4}$$

and from the definition of the stochastic discount factor (21),

$$\Lambda = \beta(1 - \delta). \tag{A.5}$$

Average markup and markups at the cutoff then follow from (9) and (25) as

$$\widetilde{\mu} = \bar{\mu} = \frac{\theta}{(\theta - 1)\left(1 - \frac{\tau}{2}(\pi - 1)^2\right) + \tau(1 - \Lambda)\pi(\pi - 1)}. \tag{A.6}$$

We now want to obtain an expression for the total number of products N. Starting from the average profit in (28), inserting (31) and (36) and using (A.1) yields

$$\widetilde{d} = \frac{1 - \widetilde{\mu}^{-1} - \frac{\tau}{2}(\pi - 1)^2}{1 - \frac{\tau}{2}(\pi - 1)^2}\frac{C}{S} - fwR. \tag{A.7}$$

The aggregate resource constraint, obtained by combining (32) and (A.2), is given by

$$C + vH = w + \widetilde{d}S. \tag{A.8}$$

Table A.1. Equilibrium Equations

Firms		
Average Pricing	(E1)	$\widetilde{\rho}_t = \widetilde{\mu}_t \widetilde{mc}_t$
Average Markup	(E2)	$\widetilde{\mu}_t = \frac{\theta}{(\theta-1)\left(1-\frac{\tau}{2}(\pi_t-1)^2\right)+\tau\left(\pi_t(\pi_t-1)-E_t\left[\Lambda_{t+1}\frac{Y^C_{t+1}}{Y^C_t}\frac{S_t}{S_{t+1}}(\pi_{t+1}-1)\pi_{t+1}\right]\right)}$
Average Marginal Costs	(E3)	$\widetilde{mc}_t = \frac{w_t}{A_t \widetilde{z}_t}$
Real Price	(E4)	$\widetilde{\rho}_t = S_t^{\frac{1}{\theta-1}}$
Average Profit	(E5)	$\widetilde{d}_t = \left(1-\widetilde{\mu}_t^{-1}-\frac{\tau}{2}(\pi_t-1)^2\right)\frac{Y^C_t}{S_t} - f\frac{w_t R_t}{A_t}$
Entry Condition	(E6)	$f_e\frac{w_t}{A_t} = v_t(\Psi_t+\Psi'_t H_t) + \beta E_t\left[\left(\frac{C_{t+1}}{C_t}\right)^{-1} v_{t+1}\Psi''_{t+1}H_{t+1}\right]$
Entry Success Probability	(E7)	$\Psi_t = 1 - g_3\left(exp\left(g_1\left(\frac{H_t}{H_{t-1}}-1\right)\right)+\frac{g_1}{g_2}exp\left(-g_2\left(\frac{H_t}{H_{t-1}}-1\right)\right)-2\right)$
1st Derivative Entry Success Prob.	(E8)	$\Psi'_t = -g_1 g_3\left(exp\left(g_1\left(\frac{H_t}{H_{t-1}}-1\right)\right)-exp\left(-g_2 \quad \frac{H_t}{H_{t-1}}-1\right)\right)\frac{1}{H_{t-1}}$
2nd Derivative Entry Success Prob.	(E9)	$\Psi''_t = g_1 g_3\left(exp\left(g_1\left(\frac{H_t}{H_{t-1}}-1\right)\right)-exp\left(-g_2 \quad \frac{H_t}{H_{t-1}}-1\right)\right)\frac{H_t}{(H_{t-1})^2}$
Profit at Cutoff	(E10)	$\bar{d}_t = \left(1-\bar{\mu}_t^{-1}-\frac{\tau}{2}\left(\frac{\bar{\rho}_t}{\bar{\rho}_{t-1}}\pi^C_t-1\right)^2\right)\bar{\rho}_t\bar{y}_t - f\frac{w_t R_t}{A_t}$
Exit Condition	(E11)	$\bar{d}_t = 0$
Price at Cutoff	(E12)	$\bar{\rho}_t = \bar{\mu}_t \bar{mc}_t$
Markup at Cutoff	(E13)	$\bar{\mu}_t = \frac{\theta}{(\theta-1)\left(1-\frac{\tau}{2}\left(\frac{\bar{\rho}_t}{\bar{\rho}_{t-1}}\pi^C_t-1\right)^2\right)+\tau\left(\frac{\bar{\rho}_t}{\bar{\rho}_{t-1}}\pi^C_t\left(\frac{\bar{\rho}_t}{\bar{\rho}_{t-1}}\pi^C_t-1\right) - E_t\left[\Lambda_{t+1}\frac{\bar{y}_{t+1}}{\bar{y}_t}\left(\frac{\bar{\rho}_{t+1}}{\bar{\rho}_t}\pi^C_{t+1}-1\right)\left(\frac{\bar{\rho}_{t+1}}{\bar{\rho}_t}\right)^2\pi^C_{t+1}\right]\right)}$
Marginal Costs at Cutoff	(E14)	$\bar{mc}_t = \frac{w_t}{A_t \bar{z}_t}$
Exit Rate	(E15)	$\zeta_t = 1 - \left(\frac{z_m}{\bar{z}_t}\right)^\kappa$
Average Productivity	(E16)	$\widetilde{z}_t = \bar{z}_t\left(\frac{\kappa}{\kappa-(\theta-1)}\right)^{\frac{1}{\theta-1}}$
Active Firms	(E17)	$S_t = (1-\zeta_t)N_t$
Evolution of Firms	(E18)	$N_t = (1-\delta)(N_{t-1}+\Psi_{t-1}H_{t-1})$
Average Output	(E19)	$\widetilde{y}_t = \frac{Y^C_t}{\widetilde{\rho}_t S_t}$
Output at the Cutoff	(E20)	$\bar{y}_t = \widetilde{y}_t\left(\frac{\bar{z}_t}{\widetilde{z}_t}\right)^\theta$

(continued)

Table A.1. (Continued)

Households		
Wage Setting 1st FOC	(E21)	$g_t = \frac{\theta_W - 1}{\theta_W} (w_t^*)^{1-\theta_W} w_t^{\theta_W} \varepsilon_t^C C_t^{-1} L_t + \beta \lambda_W E_t \left[\left(\pi_{t+1}^C \frac{w_{t+1}^*}{w_t^*} \right)^{\theta_W - 1} g_{t+1} \right]$
Wage Setting 2nd FOC	(E22)	$g_t = \chi \left(\frac{w_t}{w_t^*} \right)^{\theta_w \left(1+\frac{1}{\eta}\right)} L_t^{1+\frac{1}{\eta}} + \beta \lambda_W E_t \left[\left(\pi_{t+1}^C \frac{w_{t+1}^*}{w_t^*} \right)^{\theta_W \left(1+\frac{1}{\eta}\right)} g_{t+1} \right]$
Real Wage	(E23)	$w_t = \left(\lambda_W \left(\frac{w_{t-1}}{\pi_t^C} \right)^{1-\theta_W} + (1-\lambda_W)(w_t^*)^{1-\theta_W} \right)^{\frac{1}{1-\theta_W}}$
Euler Equation Shares	(E24)	$v_t = E_t \left[\Lambda_{t+1} (v_{t+1} + \frac{S_t}{N_t} \widetilde{d}_{t+1}) \right]$
Euler Equation for Bonds	(E25)	$1 = \beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-1} \frac{R_t}{\pi_{t+1}^C} \right]$
Stochastic Discount Factor	(E26)	$\Lambda_{t+1} = \beta(1-\delta) E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-1} \right]$
CPI Inflation	(E27)	$\pi_t^C = \frac{\widetilde{\rho}_{t-1}}{\widetilde{\rho}_t} \pi_t$
Aggregation and Monetary Policy		
Market Clearing	(E28)	$Y_t = C_t + v_t H_t$
Accounting	(E29)	$Y_t = w_t L_t + \widetilde{d}_t S_t$
Aggregate Consumption Output	(E30)	$Y_t^C = \left(1 - \frac{\tau}{2}(\pi_t - 1)^2\right)^{-1} C_t$
Investment	(E31)	$I_t = v_t H_t$
Aggregate Profits	(E32)	$d_t = \widetilde{d}_t S_t$
Taylor Rule	(E33)	$log\left(\frac{R_t}{R}\right) = \phi_R \, log\left(\frac{R_{t-1}}{R}\right) + (1-\phi_R)\left[\phi_\pi \, log\left(\frac{\pi_t}{\pi}\right) + \phi_y \, log\left(\frac{Y_t}{Y_{t-1}}\right)\right] + \varepsilon_t^M$

Rearranging (A.7) for C and inserting this expression in (A.8) gives

$$\frac{1-\frac{\tau}{2}(\pi-1)^2}{1-\widetilde{\mu}^{-1}-\frac{\tau}{2}(\pi-1)^2}\left(\widetilde{d}+fwR\right)S+vH=w+\widetilde{d}S. \tag{A.9}$$

In steady state, the entry condition (12) implies under the normalization $f_E=1$, (A.1) and the steady-state properties of the success probability (11):

$$v=w. \tag{A.10}$$

Inserting this in (A.9) and rearranging yields

$$1=\left(\frac{\widetilde{\mu}^{-1}}{1-\widetilde{\mu}^{-1}-\frac{\tau}{2}(\pi-1)^2}\frac{\widetilde{d}}{w}+\frac{1-\frac{\tau}{2}(\pi-1)^2}{1-\widetilde{\mu}^{-1}-\frac{\tau}{2}(\pi-1)^2}fR\right)S+H. \tag{A.11}$$

Now, we want to replace the term $\frac{\widetilde{d}}{w}$. Combining (7) at the cutoff and (13) gives

$$\left(1-\bar{\mu}^{-1}-\frac{\tau}{2}\left(\pi-1\right)^2\right)\bar{\rho}^{1-\theta}Y^C=fwR. \tag{A.12}$$

Using (3) and (8) at the cutoff while inserting (24) and (A.6) gives

$$\left(1-\widetilde{\mu}^{-1}-\frac{\tau}{2}\left(\pi-1\right)^2\right)\widetilde{\rho}^{1-\theta}Y^C=f\frac{\kappa}{\kappa-(\theta-1)}wR. \tag{A.13}$$

Note that the left-hand side is the first term in the average profit in (27). We can use this to rewrite (A.13) as

$$\frac{\widetilde{d}}{w}=f\frac{\theta-1}{\kappa-(\theta-1)}R. \tag{A.14}$$

This is the term we wanted to replace in (A.11), which we can now write as

$$\begin{aligned}1=f&\left(\frac{\widetilde{\mu}^{-1}}{1-\widetilde{\mu}^{-1}-\frac{\tau}{2}(\pi-1)^2}\frac{\theta-1}{\kappa-(\theta-1)}\right.\\&\left.+\frac{1-\frac{\tau}{2}(\pi-1)^2}{1-\widetilde{\mu}^{-1}-\frac{\tau}{2}(\pi-1)^2}\right)RS+H.\end{aligned} \tag{A.15}$$

Inserting (14) and rearranging yields

$$N^{-1} = f\left(\frac{\widetilde{\mu}^{-1}}{1-\widetilde{\mu}^{-1}-\frac{\tau}{2}(\pi-1)^2}\frac{\theta-1}{\kappa-(\theta-1)} + \frac{1-\frac{\tau}{2}(\pi-1)^2}{1-\widetilde{\mu}^{-1}-\frac{\tau}{2}(\pi-1)^2}\right)R\frac{S}{N} + \frac{\delta}{1-\delta}. \tag{A.16}$$

This provides the steady state of the number of firms N, given the endogenous destruction rate S/N. From the Euler equation in (20), we have

$$1 = \Lambda\left(1 + \frac{S}{N}\frac{\widetilde{d}}{v}\right). \tag{A.17}$$

Again using $v = w$ from (A.10) and inserting (A.16) yields

$$1 = \Lambda\left(1 + f\frac{\theta-1}{\kappa-(\theta-1)}R\frac{S}{N}\right). \tag{A.18}$$

Rearranging yields

$$\frac{S}{N} = \frac{1}{fR}\frac{\kappa-(\theta-1)}{\theta-1}\frac{1-\Lambda}{\Lambda}. \tag{A.19}$$

Inserting this into (A.16) yields the steady state for the total number of firms:

$$N = \left(\frac{\widetilde{\mu}^{-1} + \left(1-\frac{\tau}{2}(\pi-1)^2\right)\frac{\kappa-(\theta-1)}{\theta-1}}{1-\widetilde{\mu}^{-1}-\frac{\tau}{2}(\pi-1)^2}\frac{1-\Lambda}{\Lambda} + \frac{\delta}{1-\delta}\right)^{-1}. \tag{A.20}$$

The number of active firms follows directly from (A.19). The steady-state values of all other variables can be solved recursively.

A.3 Firms' Pricing Decision

This section derives the expression for the firm markup in Equation (9) of the main text. Firms choose prices, $p_t(z)$, and labor, $l_t^C(z)$, to maximize the sum of current profits, $d_t(z)$, and the firm value, $v_t(z)$ (the expected discounted value of the profit stream from $t+1$ onward) in period t subject to its production function, taking the household demand schedule and aggregate variables as given. The Lagrangian of this problem is given by

$$\mathcal{L}_t(z) = d_t(z) + v_t(z) + \Xi_t(z)[A_t z l_t^C(z) - y_t(z)], \tag{A.21}$$

where $\Xi_t(z)$ denotes the Lagrange multiplier on the production constraint (the term in square brackets). Firm profits in real terms are given by

$$d_t(z) = \frac{p_t(z)}{P_t} y_t(z) - w_t l_t^C(z) - pac_t(z) - f\frac{w_t R_t}{A_t}, \tag{A.22}$$

with price adjustment costs, $pac_t(z)$, being defined as

$$pac_t(z) = \frac{\tau}{2}\left(\frac{p_t(z)}{p_{t-1}(z)} - 1\right)^2 \frac{p_t(z)}{P_t} y_t^C(z). \tag{A.23}$$

The first-order condition of the Lagrangian with respect to labor is

$$-w_t + \Xi_t(z)A_t z = 0, \tag{A.24}$$

which implies that

$$\Xi_t(z) = \frac{w_t}{A_t z}. \tag{A.25}$$

The Lagrange multiplier is hence equivalent to real marginal costs, $mc_t(z)$, at the optimum.

The first-order condition with respect to the product price is

$$\frac{\partial d_t(z)}{\partial p_t(z)} + \frac{\partial v_t(z)}{\partial p_t(z)} - mc_t(z)\frac{\partial y_t(z)}{\partial p_t(z)} = 0. \tag{A.26}$$

We now derive these three expressions one by one. First, the derivative of firm profits with respect to the product price is

$$\begin{aligned}\frac{\partial d_t(z)}{\partial p_t(z)} = &(1-\theta)\frac{y_t(z)}{P_t}\left[1 - \frac{\tau}{2}\left(\frac{p_t(z)}{p_{t-1}(z)} - 1\right)^2\right] \\ &- \tau\frac{p_t(z)}{p_{t-1}(z)}\left(\frac{p_t(z)}{p_{t-1}(z)} - 1\right)\frac{y_t(z)}{P_t},\end{aligned} \tag{A.27}$$

which uses the insight that the elasticity of firm output with respect to the firm price is equal to $-\theta$, the negative constant elasticity of substitution.

Going to the second expression, the firm value at time t equals the expected discounted value of the profit stream from $t + 1$ to infinity,

$$v_t(z) = E_t \sum_{s=t+1}^{\infty} \Lambda_s d_s(z), \tag{A.28}$$

where the representative household's discount factor is given by

$$\Lambda_s = [\beta(1-\delta)]^{s-t} \left(\frac{C_s}{C_t}\right)^{-1}. \tag{A.29}$$

The firm value at time t implicitly accounts for the probability of exiting production in any given period via the expectations operator. The only term in the infinite sum that depends on $p_t(z)$ is $d_{t+1}(z)$ through $pac_{t+1}(z)$. The second expression we are searching for is hence given by

$$\frac{\partial v_t(z)}{\partial p_t(z)} = \frac{\partial E_t[\Lambda_{t+1} d_{t+1}(z)]}{\partial p_t(z)} \tag{A.30}$$

$$= -\frac{\partial E_t[\Lambda_{t+1} pac_{t+1}(z)]}{\partial p_t(z)} \tag{A.31}$$

$$= \tau E_t \left[\Lambda_{t+1} \left(\frac{p_{t+1}(z)}{p_t(z)}\right)^2 \left(\frac{p_{t+1}(z)}{p_t(z)} - 1\right) \frac{y_{t+1}(z)}{P_{t+1}}\right]. \tag{A.32}$$

The third expression can be rewritten as follows:

$$-mc_t(z)\frac{\partial y_t(z)}{\partial p_t(z)} = -mc_t(z)\frac{\partial y_t(z)}{\partial p_t(z)}\frac{p_t(z)}{y_t(z)}\frac{y_t(z)}{p_t(z)} = \theta mc_t(z)\frac{y_t(z)}{p_t(z)}. \tag{A.33}$$

The first-order condition hence becomes

$$(1-\theta)\frac{y_t(z)}{P_t}\left[1-\frac{\tau}{2}\left(\frac{p_t(z)}{p_{t-1}(z)}-1\right)^2\right]$$

$$-\tau\frac{p_t(z)}{p_{t-1}(z)}\left(\frac{p_t(z)}{p_{t-1}(z)}-1\right)\frac{y_t(z)}{P_t} \tag{A.34}$$

$$+\tau E_t\left[\Lambda_{t+1}\left(\frac{p_{t+1}(z)}{p_t(z)}\right)^2\left(\frac{p_{t+1}(z)}{p_t(z)}-1\right)\frac{y_{t+1}(z)}{P_{t+1}}\right] \tag{A.35}$$

$$+\theta mc_t\frac{y_t(z)}{p_t(z)}=0. \tag{A.36}$$

Dividing both sides by $\frac{y_t(z)}{P_t}$ yields

$$(1-\theta)\left[1-\frac{\tau}{2}\left(\frac{p_t(z)}{p_{t-1}(z)}-1\right)^2\right]-\tau\Upsilon_t(z)+\theta mc_t\frac{P_t}{p_t(z)}=0, \tag{A.37}$$

where

$$\Upsilon_t(z)=\frac{p_t(z)}{p_{t-1}(z)}\left(\frac{p_t(z)}{p_{t-1}(z)}-1\right)$$

$$-E_t\left[\Lambda_{t+1}\frac{y^C_{t+1}(z)}{y^C_t(z)}\frac{P_t}{P_{t+1}}\left(\frac{p_{t+1}(z)}{p_t(z)}-1\right)\left(\frac{p_{t+1}(z)}{p_t(z)}\right)^2\right]. \tag{A.38}$$

Rearranging yields

$$p_t(z)=mc_tP_t\frac{\theta}{(\theta-1)\left[1-\frac{\tau}{2}\left(\frac{p_t(z)}{p_{t-1}(z)}-1\right)^2\right]+\tau\Upsilon_t(z)}, \tag{A.39}$$

which can be used to define the markup $\mu_t(z)$ over real marginal costs as in Equation (9) of the main text as

$$\mu_t(z)=\frac{\theta}{(\theta-1)\left[1-\frac{\tau}{2}\left(\frac{p_t(z)}{p_{t-1}(z)}-1\right)^2\right]+\tau\Upsilon_t(z)}. \tag{A.40}$$

A.4 Endogenous Exit and Inflation

In this section, we briefly analyze the implications of endogenous firm exit for inflation dynamics. Log-linearizing Equation (25) yields

$$\widehat{\pi}_t = -\frac{\theta - 1}{\tau}\widehat{\widetilde{\mu}}_t + \beta(1-\delta)E_t[\widehat{\pi}_{t+1}], \tag{A.41}$$

where variables with a hat denote log-deviations from steady state. This is the familiar linearized New Keynesian Phillips curve, relating inflation to variations in the (average) firm markup. Using the optimal pricing condition (8) with the definitions of marginal costs (3) and the variety effect (36), we can substitute the markup and write

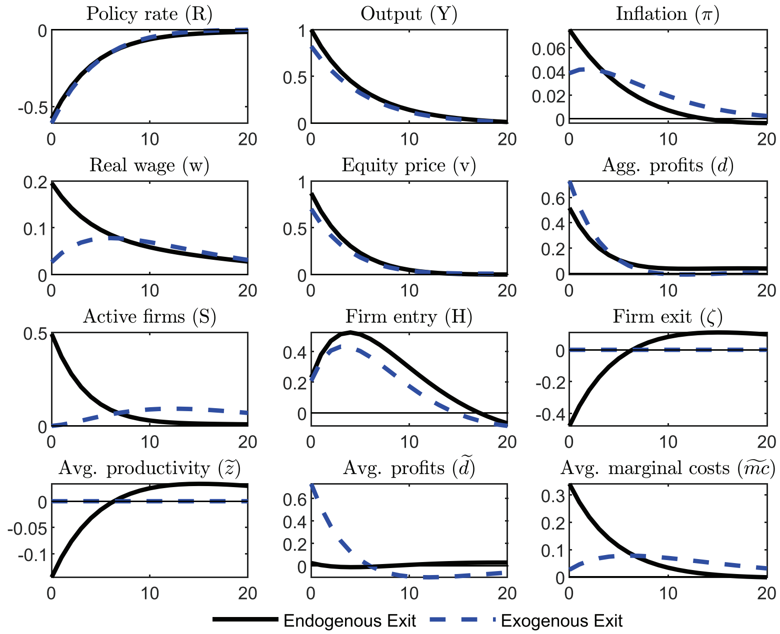
$$\widehat{\pi}_t = \frac{\theta - 1}{\tau}(\widehat{w}_t - \widehat{A}_t - \widehat{\widetilde{z}}_t) - \frac{1}{\tau}\widehat{S}_t + \beta(1-\delta)E_t[\widehat{\pi}_{t+1}]. \tag{A.42}$$

Equation (A.42) is a New Keynesian Phillips curve relating producer price inflation to marginal costs and the number of active firms in the economy. Intuitively, firms' price setting crucially depends on their marginal costs. As such, changes in aggregate (A) or firm-specific ($\widetilde{z}$) productivity affect effective marginal costs and thus inflation. Furthermore, the number of active firms influences relative prices (the price of each good relative to the consumption basket) and thus markups, which translates into an effect on inflation. This may be interpreted as representing the effect of heightened competition.

As an illustration, we compare Variant A to an economy where all firms are homogeneous and exit occurs only exogenously. We set idiosyncratic firm productivity $z = 1$ for all firms and abstract from fixed costs of production by setting $f = 0$. This model variant is essentially the one considered by Bilbiie, Ghironi, and Melitz (2008) and Bilbiie, Fujiwara, and Ghironi (2014), but additionally includes entry frictions and wage rigidities. Figure A.1 compares the transmission of an expansionary monetary policy shock across the two models.

In Variant A, expansionary monetary policy shocks increase firm profits and allow unproductive firms to be active. As a consequence, average productivity declines, and average marginal costs increase sharply on impact of the shock. The decline in average productivity yields an initially stronger inflation response in the first year

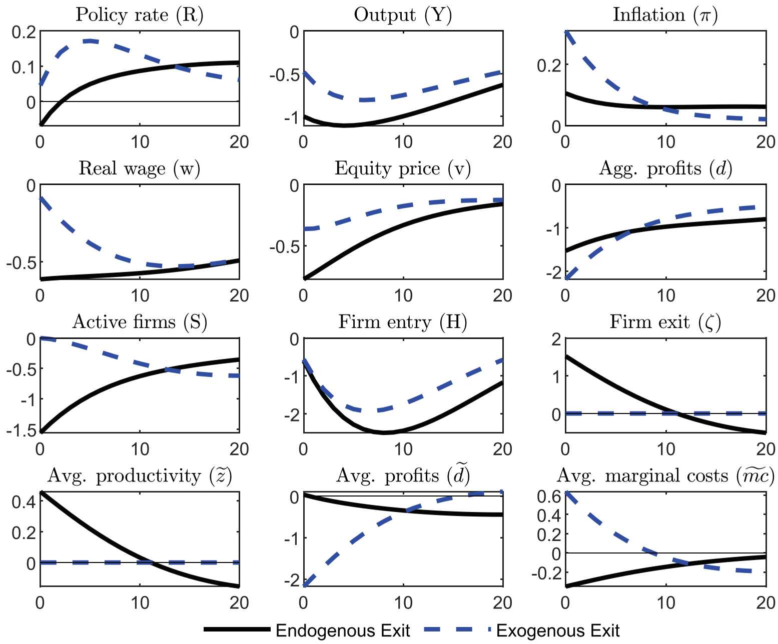
Figure A.1. Monetary Policy Shock and the Role of Endogenous Exit



Note: Impulse response functions to an expansionary monetary policy shock in Variant A (with endogenous exit, solid lines) and a variant with exogenous exit (dashed lines). The shock size is calibrated to yield a 1 percent increase of output in Variant A. Inflation, interest rate, and exit are shown in percentage point deviations from steady state, all other variables in percentage deviations.

(compared with the model with exogenous exit). At the same time, the overall number of firms increases and exit rates decline. Via the competition effect, this translates into lower markups and thus lower inflation. After the first year, the competition effect dominates the productivity effect such that the overall inflation response is lower in the case of endogenous exit. Interestingly, this shares similarities with the microeconometric findings by Acharya et al. (2020), who document that a rise in lending to "zombie firms" is associated with disinflation. In this respect, the demand-side and preference-based variety effect in our framework may be interpreted as operating similarly to a supply-side competition effect, whereby excess capacity creates downward pressure on prices.

Figure A.2. Technology Shock



Note: Impulse response functions to a contractionary technology shock with an autoregressive coefficient of 0.9 in Variant A (with wage stickiness and endogenous exit, solid lines) and a variant with exogenous exit (dashed lines). The shock size is calibrated to yield a 1 percent increase of output in Variant A. Inflation, interest rate, and exit are shown in percentage point deviations from steady state, all other variables in percentage deviations.

The amplification of the output response via endogenous exit is largely due to higher investment in new firms. Intuitively, entering production becomes profitable for firms with relatively low productivity. As a result, investment in new firms and firm entry respond more strongly to monetary policy shocks. Over the medium term, lower inflation and real interest rates also contribute to slightly higher consumption relative to the model with exogenous exit.

A.5 Technology Shock

Figure A.2 shows the transmission of a contractionary technology shock, comparing Variant A (with wage stickiness) to a model where firm exit is entirely exogenous and constant. As also described by Hamano and Zanetti (2017) and Rossi (2019), negative technology shocks increase real marginal costs and thus lower expectations of future profits in Variant A, thereby disincentivizing the entry of new firms. The firm-specific productivity cutoff required for profitability increases, such that more firms exit production. As a result, the contraction is more pronounced relative to a model with exogenous exit. Only relatively more productive firms are able to remain active, causing average productivity to increase initially. As the economy reverts to the initial equilibrium, firm exit drops below baseline, reflecting a decreasing cutoff level of productivity.

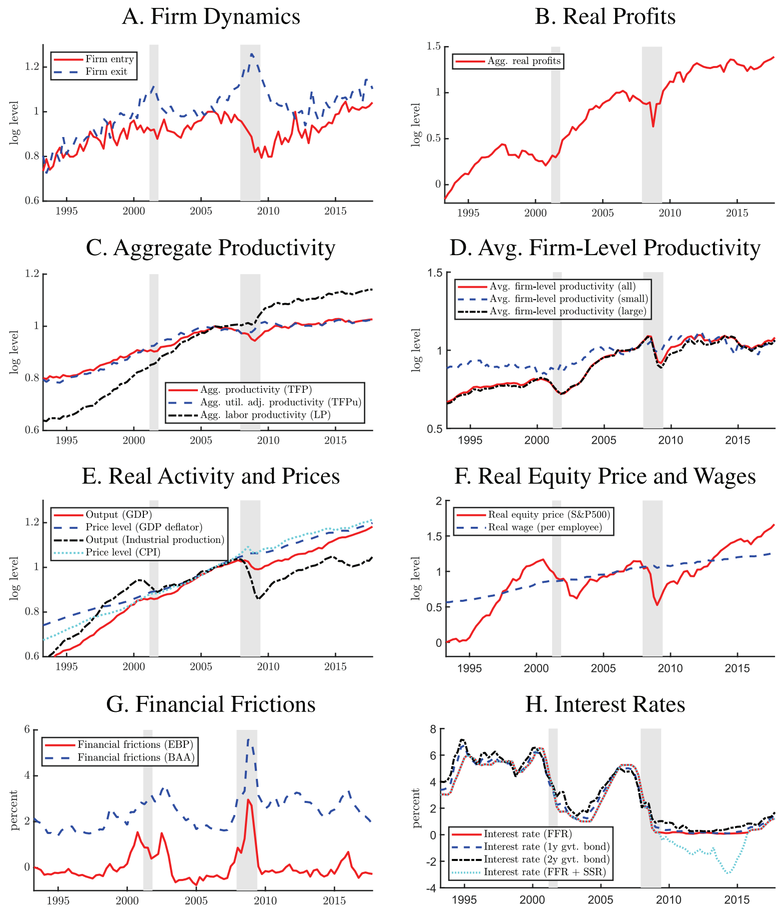
Appendix B. Empirical Analysis

B.1 Data

Figure B.1 shows time-series plots of the data. Firm entry is procyclical and exit countercyclical around recessions. Profits show some procyclical patterns. Aggregate TFP displays some mild signs of procylicality, while utilization-adjusted TFP and labor productivity evolve rather independently of the cycle. The comovement of average firm-level productivity depends on the firm size (see definition in Section B.2): it is procyclical for all firms and the subset of large firms, but hardly reacts to the cycle for small firms.

Table B.1 presents descriptive statistics on business cycle fluctuations as measured by the cyclical component of all variables in log-levels using the regression-based filter of Hamilton (2018). Panel A reports volatility, relative volatility to the cyclical component of real GDP, persistence, and contemporaneous comovement. Firm entry and exit dynamics are almost three times more volatile than fluctuations in output and profits are about seven times more volatile. Aggregate productivity measures are less volatile than output, whereas average firm-level productivity is more volatile—at a similar level to firm dynamics. Firm entry and exit dynamics are the least persistent series. Profits and productivity measures are slightly less persistent than output. Firm entry is procyclical, while exit is countercyclical, in line with the evidence presented by Campbell (1998) and Jaimovich and Floetotto (2008), who consider a different data set and study an earlier period. Interestingly, aggregate TFP

Figure B.1. Data



Note: Time-series plot of the data. All variables are in log-levels and normalized to 1 in 2006:Q1, except for the proxies of financial frictions and the interest rates. Measures of financial frictions and interest rates are in percent. Shaded gray areas indicate National Bureau of Economic Research (NBER) recession dates.

is strongly procyclical while profits, utilization-adjusted TFP, and labor productivity hardly comove with the cycle. In fact, the estimated correlations are insignificant and thus, these series may be considered as acyclical. Average firm-level productivity is procyclical for the overall aggregate and even more so for large firms, while it is countercyclical for small firms.

Table B.1. Business Cycle Statistics for the U.S. Economy

A. Business Cycle Moments				
	$\sigma(Y_{i,t})$	$\frac{\sigma(Y_{i,t})}{\sigma(X_t)}$	$\rho(Y_{i,t}, Y_{i,t-1})$	$\rho(Y_{i,t}, X_t)$
(1) Output (GDP)	2.29	1.00	0.89	1.00
(2) Price Level (GDP Deflator)	1.02	0.45	0.86	0.30
(3) Firm Entry	5.54	2.42	0.75	0.70
(4) Firm Exit	6.71	2.93	0.79	−0.24
(5) Agg. Real Profits	15.32	6.69	0.86	0.00
(6) Agg. Productivity (TFP)	1.82	0.79	0.87	0.64
(7) Agg. Util. Adj. Productivity (TFPu)	1.60	0.70	0.83	−0.13
(8) Agg. Labor Productivity (LP)	1.81	0.79	0.82	−0.09
(9) Avg. Firm-Level Productivity (all)	6.40	2.80	0.90	0.45
(10) Avg. Firm-Level Productivity (small)	4.58	2.00	0.77	−0.18
(11) Avg. Firm-Level Productivity (large)	6.52	2.85	0.90	0.54
(12) Real Wage (per Employee)	1.77	0.77	0.79	0.62
(13) Real Equity Price (S&P 500)	21.57	9.43	0.88	0.81
(14) Interest Rate (1y Gvt. Bond)	2.18	0.95	0.97	0.28
(15) Financial Frictions (EBP)	0.67	0.29	0.83	−0.48

(*continued*)

Table B.1. (Continued)

B. Contemporaneous Correlations															
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**	**(15)**
(1)	1.00														
(2)	0.30	1.00													
(3)	0.70	0.35	1.00												
(4)	−0.24	0.10	−0.01	1.00											
(5)	0.00	0.08	0.03	−0.60	1.00										
(6)	0.64	0.22	0.36	−0.67	0.58	1.00									
(7)	−0.13	−0.17	−0.11	−0.20	0.26	0.36	1.00								
(8)	−0.09	−0.21	−0.29	−0.47	0.51	0.59	0.78	1.00							
(9)	0.45	0.61	0.32	−0.18	0.35	0.48	−0.25	−0.01	1.00						
(10)	−0.18	0.20	−0.07	−0.23	0.51	0.22	0.09	0.27	0.57	1.00					
(11)	0.54	0.68	0.40	−0.17	0.28	0.49	−0.26	−0.08	0.97	0.43	1.00				
(12)	0.62	0.34	0.46	0.25	−0.57	0.14	−0.29	−0.29	0.26	−0.29	0.34	1.00			
(13)	0.81	0.10	0.55	−0.14	−0.05	0.45	−0.26	−0.15	0.36	−0.16	0.43	0.57	1.00		
(14)	0.28	0.20	0.09	0.04	−0.40	0.01	−0.14	−0.11	−0.03	−0.40	0.02	0.49	0.06	1.00	
(15)	−0.48	−0.14	−0.28	0.55	−0.49	−0.63	0.01	−0.18	−0.44	−0.20	−0.44	−0.03	−0.54	−0.03	1.00

Note: All variables are in log-levels. The cyclical component is estimated using the regression-based filter of Hamilton (2018), except for the interest rate and the excess bond premium. Panel A reports business cycle moments for each variable: (1) standard deviation, (2) relative standard deviation to output, (3) first-order autocorrelation, and (4) contemporaneous correlation with output. Panel B depicts the contemporaneous correlation matrix of all variables.

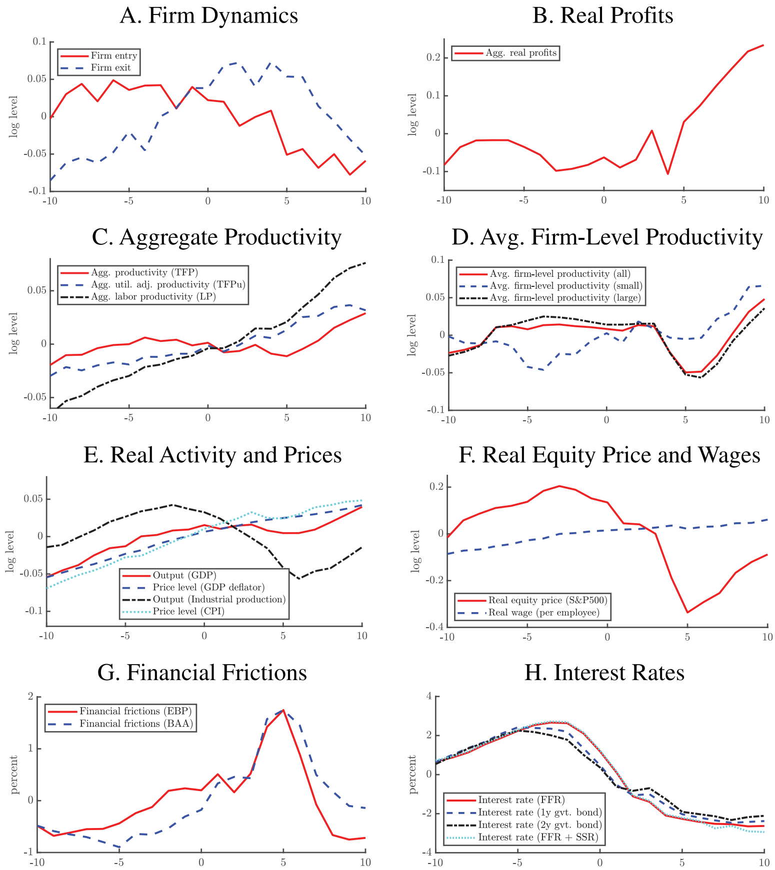
Panel B provides more details on contemporaneous correlations between real GDP, firm dynamics, profits, and various productivity measures. While there is no comovement between firm entry and exit, firm dynamics are strongly correlated with aggregate TFP. A cyclical upswing of firm entry is associated with higher aggregate productivity, while firm exit and productivity tend to move in opposite directions, in line with VAR estimates of Rossi (2019). Moreover, profits show negative comovement with firm exit and positive comovement with productivity measures, while they are unrelated to entry.

Firm dynamics are contemporaneously hardly related to pure technological progress. Because of the growth accounting definitions in Basu, Fernald, and Kimball (2006), this implies that the covariation of firm dynamics with aggregate TFP is driven by variable capital and labor utilization. Moreover, both firm entry and exit are countercyclical to labor productivity. Roughly speaking, labor productivity rises if workers have more capital or better skills, or if aggregate TFP rises (Fernald 2015). Thus, the negative correlation of firm entry suggests that variations in capital and labor quality dominate the positive effects of aggregate TFP. For firm exit, these effects only slightly affect the negative correlation.

The comovement between average firm-level productivity and firm dynamics depends on the size of the firm. An increase in the rate of firm entry is associated with an increase of average productivity for large firms, while for small firms it is associated with a decline. Firm exit, on the other hand, is mildly negatively correlated with all average firm-level productivity measures.

Turning from unconditional to conditional comovements, Figure B.2 shows Burns-Mitchell diagrams; these diagrams depict the average behavior of selected time series around the start of U.S. recessions. Chart A shows the average behavior of firm dynamics. Firm entry remains high during the expansion, but drops substantially after the turning point of the cycle. Firm exit, on the other hand, starts to increase prior to the start of the recession and peaks after four quarters. During the recovery, firm exit starts to diminish while firm entry remains subdued for a prolonged period. Chart B shows that profits are acyclical to real activity but start to decline prior to a recession. After the economy reaches its trough after four to six quarters and the economy starts to recover, profits increase strongly.

Figure B.2. Burns-Mitchell Diagrams



Note: Average behavior of variables around cyclical peaks, as measured by the start of a U.S. recession. $x_t = \frac{1}{M}\sum_{i=1}^{M}\left(y_{i,t} - \frac{1}{21}\sum_{t=-10}^{10} y_{i,t}\right)$, where $y_{i,-10}, y_{i,-9}, \ldots, y_{i,0}, y_{i,1}, \ldots, y_{i,10}$, $i = 1, 2, \ldots, M$, and $y_{i,0}$ is quarter of business cycle peak. All variables enter in log-levels, except interest rates, the excess bond premium, and corporate BAA spread, which are in percent.

Charts C and D show the average conditional behavior of productivity measures. Aggregate TFP is procyclical and leading, peaking several quarters before the turning point, while utilization-adjusted TFP and labor productivity show no strong cyclical patterns. Their average growth is uninterrupted during recessions. Average firm-level productivity of all and large firms behave similarly during a recession. They hardly react prior to the recession but eventually decline after the turning point. Average productivity of small firms, in contrast, declines somewhat prior to the recession but increases continuously throughout this period.

The remaining charts present the average behavior of key macroeconomic and financial variables. Real activity and prices, Chart E, move as expected. Real activity contracts while prices react rather sluggishly. The sluggish behavior of prices is a common feature of more recent recessions; see Figure B.1. Equity peaks prior to the turning point in real GDP and substantially declines in the downturn, while real wages show hardly any reaction; see Chart F. Financial frictions, Chart G, are low prior to a recession but increase substantially when the economy dips further into the recession. Chart H shows that the policy rate and longer-term interest rates decline in response to subdued economic activity.

B.2 Construction of Firm-Level Productivity

We combine annual and quarterly Compustat data on U.S. public firms—incorporated in the U.S. and doing business in U.S. dollars—from 1990:Q1 to 2019:Q4 to estimate TFP at the firm level. We exclude financial firms (due to their special balance sheets) and utilities (due to their dependence on commodity prices) from our data set.

For each firm, we construct the capital stock using the perpetual inventory method. First, we initialize the capital stock with the first available entry of PPEGT (total gross property, plant, and equipment). Second, we iterate using the initial value of the firms' capital stock using the accumulation equation

$$k_{i,t} = k_{i,t}(1 - \delta) + i_{i,t},$$

where we use PPENT (total net property, plant, and equipment) as our measure of net investment ($i_{i,t} - \delta k_{i,t}$). In case of missing values for PPENT, we replace them using a log-linear interpolation. Moreover, we deflate our constructed measure of firm-level capital stock by the investment goods deflator from the Bureau of Economic Analysis (BEA).

We construct a quarterly measure of employment by merging annual and quarterly Compustat series using the firm identifier

(GVKEY) and time (DATADATE). We use a log-linear interpolation for the missing observations. Further, we construct a real measure of sales by deflating the nominal series by the GDP deflator from the BEA. Last, we exclude observations with negative sales, capital stock or employment (measurement error) and winsorize sales, capital, and employment at the 1st and 99th percentile (outliers).

We then estimate a standard growth accounting equation using panel ordinary least squares (OLS):

$$\log(y_{i,t}) = \mu_i + \mu_t + \alpha \log(k_{i,t-1}) + \beta \log(n_{i,t}) + \epsilon_{i,t}, \qquad \text{(B.1)}$$

where $y_{i,t}$ is real sales, $k_{i,t-1}$ is the constructed capital stock (Compustat capital is recorded at the end of the period), $n_{i,t}$ is employment, μ_i is a firm fixed effect, and μ_t is a time fixed effect. Then, TFP at the firm level is given by

$$\log(\hat{\nu}_{i,t}) = \log(y_{i,t}) - \hat{\alpha}\log(k_{i,t-1}) - \hat{\beta}\log(n_{i,t}) = \hat{\mu}_i + \hat{\mu}_t + \hat{\epsilon}_{i,t},$$

which we use to compute average firm-level productivity as

$$\hat{\nu}_t = N_t^{-1} \sum_{i}^{N_t} \hat{\nu}_{i,t},$$

with N_t being the number of firms in time t. We winsorize estimated firm-level productivity at the 1st and 99th percentile to control for the effect of potentially very large outliers.[34] We adjust the average firm-level productivity series for seasonality using the x13 program of the U.S. Census Bureau.

Table B.2 reports the number of firms for each sector and by firm size. We classify a firm to be small (large) if it has sales below (above) \$10 million. The manufacturing and services sectors make up 70 percent of the firms in the Compustat universe. Moreover, panel A in Figure B.3 shows that average productivity dynamics of nonfinancial ex utilities firms (Chart (I)) are primarily driven by manufacturing and services sector firms (Chart (II)).

[34]Without winsorization, average firm-level productivity exhibits somewhat distinct dynamics and occasional breaks relative to the median and other percentiles of firm-level productivity.

Table B.2. Number of Firms

Sector	All Firms	Small Firms	Large Firms
Agriculture*	69	43	26
Construction	205	61	144
Manufacturing	6,866	3,334	3,532
Mining	831	491	340
Retail Trade	1,128	274	854
Services	3,918	1,979	1,939
Transportation*	1,054	362	692
Wholesale Trade	676	230	446
Total	14,747	6,774	7,973

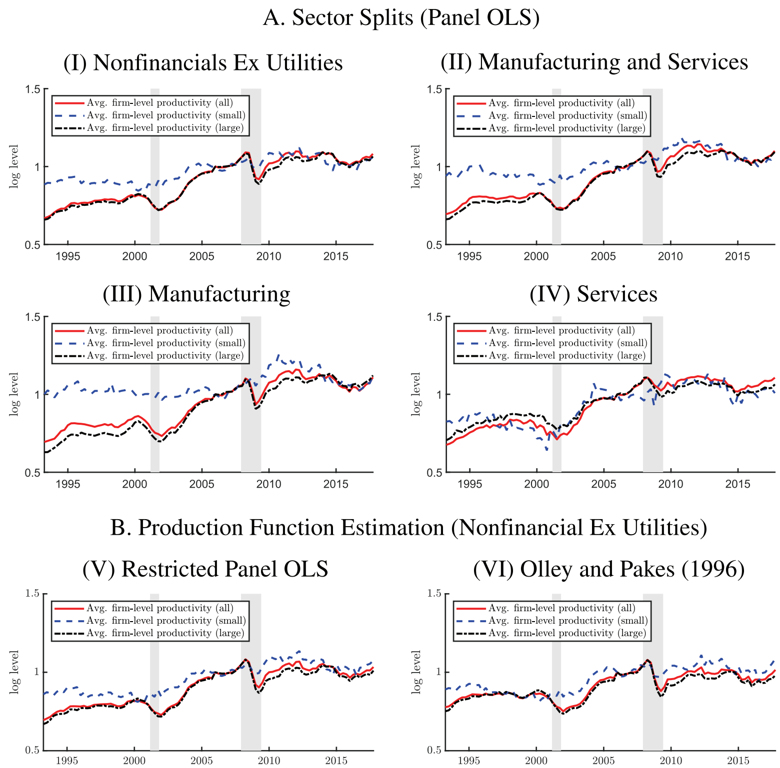
Note: Number of firms per sector and firm size. Agriculture* denotes the sector agriculture, fishing, and forestry, and Transportation* denotes the sector transportation, communications, electricity, and sanitary services except utilities.

Table B.3 reports cross-sectional moments of firm-level productivity based on the period 1990:Q2–2019:Q4. Our overall sample consists of 559,796 observations. Small firms make up about one-third and large firms two-thirds of the observations.[35] Average firm-level productivity depends positively on the firm size, i.e., larger firms tend to be more productive. The productivity distribution has a very long right tail due to some extremely large companies (measured by sales). The distribution is less dispersed for small firms. On average, the most productive firms are in the construction and wholesale trade sector.

As a robustness check, we consider two alternative estimation methods: (1) imposing constant returns to scale in production, i.e., $\alpha = 1 - \beta$, estimated via restricted panel OLS, and (2) using the Olley and Pakes (1996) method, which controls for input factor endogeneity. Table B.4 shows that these alternative estimation methods affect the estimated share in production factors. Specifically, they lead to an increase in the share of capital and labor as compared with the baseline panel regression with fixed effects. Nevertheless, the resulting firm-level productivity averages (and other moments of

[35]We lose 14,919 observations as $k_{i,t}$ enters with a lag in (B.1).

Figure B.3. Alternative Estimates of Average Firm-Level Productivity



Note: Time-series plot of average firm-level productivity for different sector splits (panel A) and alternative production function estimation approaches (panel B). All variables are in log-levels and normalized to 1 in 2006:Q1. Shaded gray areas indicate NBER recession dates.

the distribution) exhibit similar cyclical variation as compared with the baseline estimates; see panel B in Figure B.3.

B.3 Importance of the Central Bank Information Effect

Figure B.4 shows impulse response functions to a monetary policy shock identified by short-run zero restrictions on the interest rate surprises ordered first in the VAR (blue dashed) and those of a central bank information shock (black dashed-dotted).

Table B.3. Cross-Sectional Moments of Firm-Level Productivtiy

Sector	Total				Small Firms				Large Firms			
	N	**Mean**	**Median**	**Std.**	**N**	**Mean**	**Median**	**Std.**	**N**	**Mean**	**Median**	**Std.**
Agriculture*	2,649	20.2	12.1	33.8	1,161	9.5	5.7	21.4	1,488	28.6	18.6	38.9
Construction	8,116	76.0	40.6	73.9	1,603	27.0	14.4	37.8	6,513	88.1	52.0	75.6
Manufacturing	283,060	28.7	22.7	29.2	101,069	15.5	11.0	21.2	181,991	36.1	28.4	30.5
Mining	31,235	32.9	21.0	40.1	14,477	13.8	8.2	20.6	16,758	49.5	34.9	45.2
Retail Trade	43,955	28.5	19.9	33.0	5,154	18.3	8.1	34.2	38,801	29.9	21.2	32.6
Services	128,133	25.7	19.1	28.9	45,954	16.6	11.6	25.0	82,179	30.7	23.9	29.8
Transportation*	37,438	31.6	22.5	33.9	6,782	19.1	10.6	31.1	30,655	34.3	24.6	33.9
Wholesale Trade	25,210	73.5	51.7	65.9	5,831	28.9	18.5	38.2	19,378	86.9	63.3	66.6
Total	559,796	31.1	22.1	35.7	182,031	16.3	11.0	24.1	377,763	38.2	27.4	38.2

Note: The table reports, for each sector, the total number of observations, and the mean, median, and standard deviation of firm-level productivity over the sample period 1990:Q1–2019:Q4. Agriculture* denotes the sectors agriculture, fishing, and forestry, and Transportation* denotes the sectors transportation, communications, electricity, and sanitary services except utilities.

Table B.4. Firm-Level Productivity Regressions

Sale	**Panel OLS (1)**	**Rest. Panel OLS (2)**	**Olley and Pakes (3)**
Capital	0.23***	0.27***	0.34***
	(0.01)	(0.01)	(0.00)
Employment	0.68***	0.73***	0.73***
	(0.02)	(0.01)	(0.01)
Fixed Effects	Firm, Quarter	Firm, Quarter	Firm, Quarter
Observations	559,796	559,796	558,500

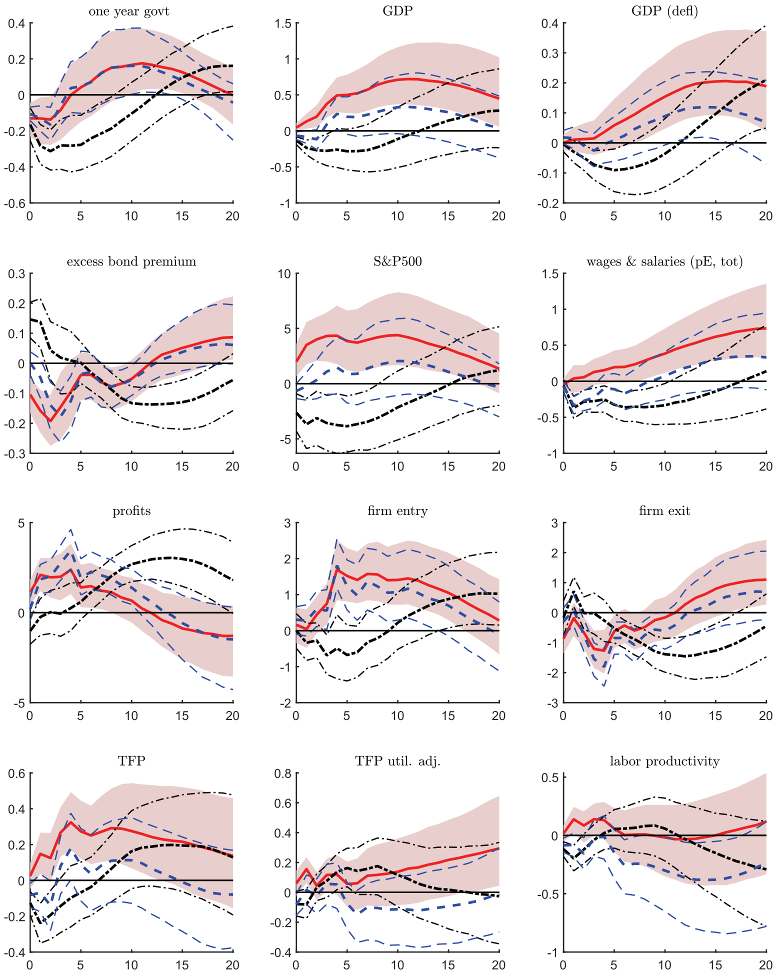
Note: The table reports the estimated share of capital and labor from (1) our baseline panel regression in (B.1), (2) a restricted panel regression with constant returns to scale, and (3) the Olley and Pakes (1996) production function approach. Standard errors are clustered two-way at the firm level and time level for (1) and (2) and bootstrapped in (3). *, **, *** indicate that the coefficient is significant at the 10 percent, 5 percent, and 1 percent level.

Figure B.5 shows impulse response functions to a monetary policy shock identified by short-run zero restrictions on real GDP and prices (blue dashed) and those of a central bank information shock (black dashed-dotted).

B.4 Additional Information on the Identification

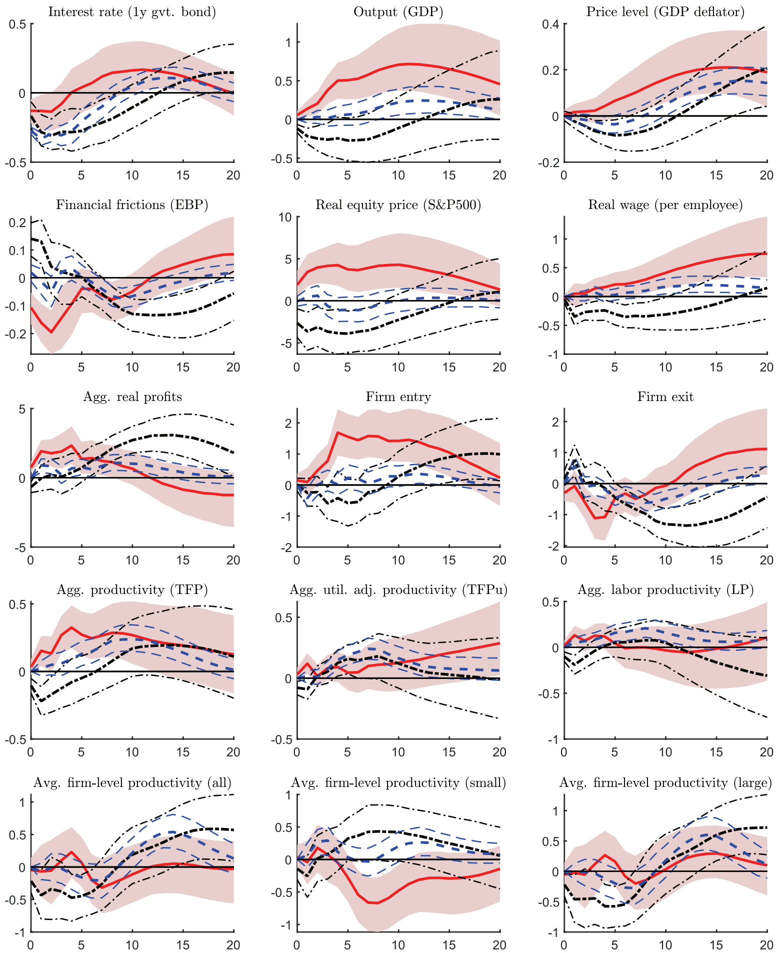
In this section, we investigate how the results are affected by the different data frequency, the different sample size, and the additional sign restrictions on the low-frequency variables (coupled with the enlargement of the rotation space) as compared with Jarociński and Karadi (2020). Figure B.6 shows estimates based on monthly data in panel A and based on quarterly data in panel B. We exclude our main variables of interest due to the slightly longer sample. Each panel shows the estimates for our considered sample starting in 1993:M4 and the slightly longer sample starting in 1990:M2, as well as for the different identification schemes. The red solid lines and the black dashed-dotted lines correspond to sign restriction on both high-frequency and low-frequency variables, while the blue dashed lines and the cyan dotted lines correspond to sign restrictions on high-frequency variables only, as in Jarociński and Karadi (2020).

Figure B.4. VAR Short-Run Restrictions on Interest Rate Surprises



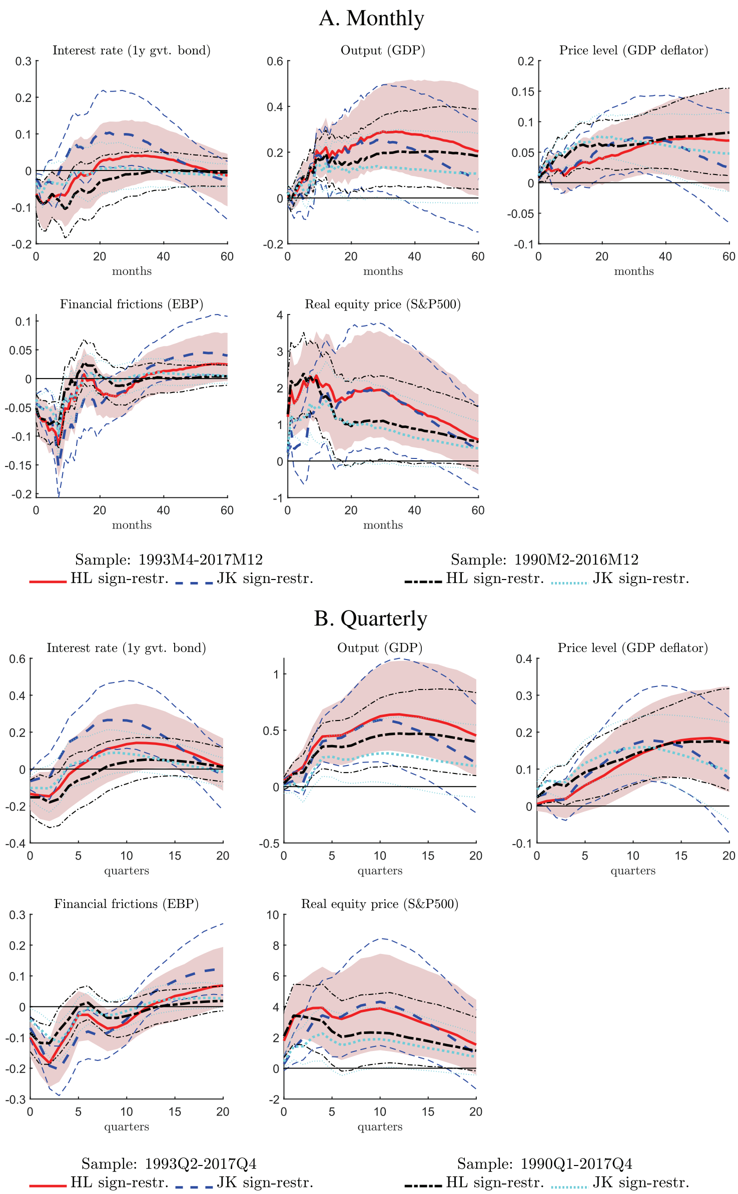
Note: Impulse response functions to a monetary policy shock according to the baseline identification (solid lines), a shock identified by zero restrictions on the interest rate surprises ordered first (dashed), and a central bank information shock identified by sign restrictions (dashed-dotted). The thick lines are the median estimates; the shaded areas and thin lines are the 68 percent credible intervals. Responses are shown in percent deviations, except for the interest rate and the measure of financial frictions (percentage point deviations).

Figure B.5. VAR Short-Run Restrictions on Interest Rate



Note: Impulse response functions to a monetary policy shock according to the baseline identification (solid lines), a shock identified by zero restrictions on the contemporaneous comovement of GDP and prices for the interest rate (dashed), and a central bank information shock identified by sign restrictions (dashed-dotted). The thick lines are the median estimates; the shaded areas and thin lines are the 68 percent credible intervals. Responses are shown in percent deviations, except for the interest rate and the measure of financial frictions (percentage point deviations).

Figure B.6. Monetary Transmission at Different Frequency and Sample Size



Note: Impulse response functions to a monetary policy shock identified by alternative sign restrictions, for different sample sizes and different data frequencies. HL corresponds to the baseline sign restrictions and JK to the sign restrictions used by Jarociński and Karadi (2020). The thick lines are the median estimates; the shaded areas and thin lines are the 68 percent credible intervals. Responses are shown in percent deviations, except for the interest rate and the measure of financial frictions (percentage point deviations).

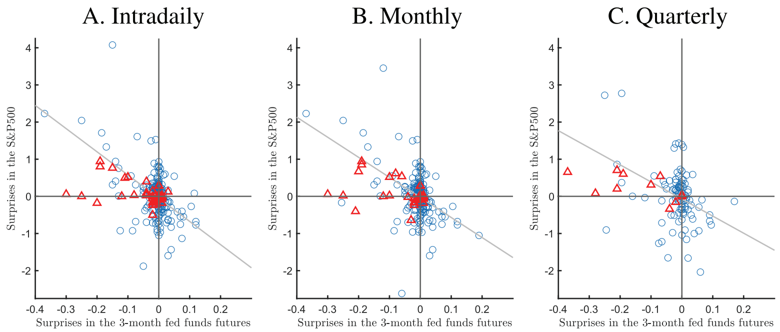
Panel A shows that the estimated impulse response functions at the monthly frequency are affected by the different sample size and by the alternative identification restrictions. The monetary impulse identified by sign restrictions on high-frequency variables only and for the sample starting in 1993:M4 (blue dashed) differs substantially from the other median estimates. Particularly, the initial impulse to the interest rate is rather small and disproportionally compensated in the medium term. Notable, furthermore, is the insignificant response of the stock market under this specification.

In contrast, the median estimate of the interest rate response based on the longer sample starting in 1990:M2 (cyan dotted) is more comparable to the median estimates obtained under our identification restrictions, which are qualitatively similar in both samples. Note that for the longer sample the response of the interest rate and the stock price index are significant and last over several months when using sign restrictions only on high-frequency variables. Apart from that, it should be noted that both identification schemes yield qualitatively similar estimates of the responses of macroeconomic and financial variables to a monetary policy shock.

Turning to panel B, the chart shows that median estimates of the interest rate response also differ across different sample size and identification restrictions at the quarterly frequency. However, the estimated impulse response functions for a specific sample size and identification scheme are very similar at different data frequencies. In particular, the quarterly estimates can be interpreted as a smoothed version of the monthly estimates. Nevertheless, it should be noted that the stock market response is only very marginally significant when sign restrictions are imposed on high-frequency variables only.

Based on these considerations, we conclude that excluding the sample from 1990:M2 to 1993:M3 from the estimation may obscure the relationship between high-frequency and low-frequency variables. The lack of these data in our sample makes it more difficult to identify a plausible monetary transmission channel when structural parameters are identified using sign restriction on high-frequency variables only. By imposing additional restrictions on the low-frequency variables (coupled with the enlarged rotation space), we are able to identify a plausible monetary transmission channel.

Figure B.7. Interest Rate and Stock Price Surprises



Note: Changes in the three-month federal funds futures and the S&P 500 stock index around FOMC announcements, in percent. For plot A, each dot represents one FOMC announcement. For plots B and C, each dot represents the sum of intradaily surprises of FOMC announcements in the current month and quarter, respectively. The gray line is the fitted least-squares prediction. Red triangles correspond to the period 1990:M2–1993:M3 and blue circles correspond to 1993:M4 through 2017:M12.

To further investigate the effects of a different sample size on the relationship between high-frequency surprises and their low-frequency counterparts, Figure B.7 depicts scatter plots of interest rate and stock price surprises across (A) intradaily frequency, (B) monthly frequency, and (C) quarterly frequency for the sample 1993:M4–2017:M12 in blue dots and the pre-sample 1990:M2–1993:M3 in red triangles.

Two notable features stand out. First, the pre-sample period from 1990:M2 through 1993:M3 features relatively large negative interest rate surprises as well as positive stock market surprises. Thus, the pre-sample is dominated by surprises that classify as a monetary policy shock according to the comovement restrictions. The Federal Reserve lowered the interest rate during several intermeeting moves to cushion the effects of the savings and loan crisis on the U.S. economy during this time. Therefore, the absence of this relatively important episode may be the reason why the sign-restriction approach on high-frequency variables only lacks the power to identify a reasonably sized monetary impulse for the sample starting in 1993:M4.

Second, there are fewer large interest rate and stock price surprises at the quarterly frequency as compared with the monthly and the intradaily frequency. The similarity between monthly and intradaily frequency can be rationalized by the fact that there is rarely more than one FOMC announcement per month.[36] However, there are several surprises within a given quarter that might potentially offset each other, thus leading to smaller surprises in the aggregate. This loss in variability might make it more difficult to identify a relationship between high-frequency and low-frequency variables.

B.5 Robustness

This section presents a series of robustness checks regarding our baseline empirical strategy.

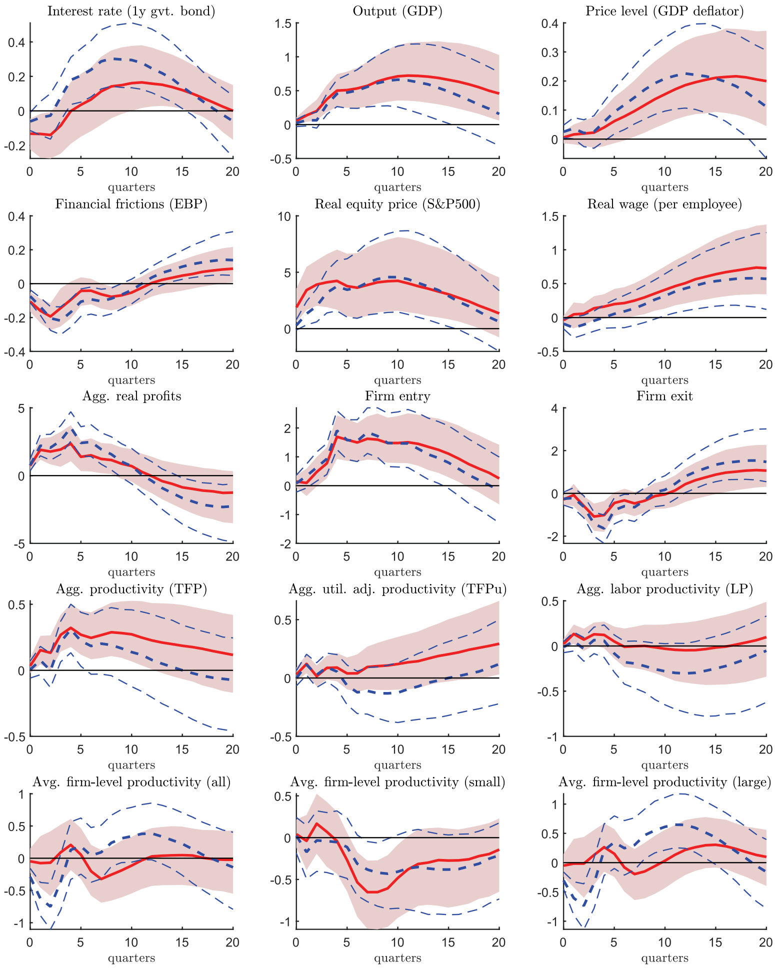
B.5.1 Specifications Exploiting the Aggregate Time-Series Dimension

Sign Restrictions on Low-Frequency Variables. To explore whether our VAR results are driven by the low-frequency sign restrictions, we analyze the sensitivity of our results by using the identification strategy of Jarociński and Karadi (2020), which imposes sign restrictions on the comovement of high-frequency surprises only. Figure B.8 shows that this identification yields a rather implausible interest rate impulse response in our sample (as also discussed above in Section 4.2). In particular, the initial impulse is small and disproportionally compensated in the medium term. However, our main results on the firms' extensive margin are robust. While the responses of aggregate productivity measures are closer to zero, average productivity now declines significantly in the short run.

Poor Man's Proxy. Jarociński and Karadi (2020) also propose a simpler identification of monetary policy shocks based on sign restrictions on the comovement of surprises in a given month. We follow their approach and construct the so-called poor man's proxy at quarterly frequency: we impose sign restrictions on the sum of daily surprises in a quarter. The implicit assumption is that each

[36]Since 1994, most FOMC announcements are regularly scheduled meetings and take place monthly or every six weeks. The remaining FOMC announcements are unscheduled meetings and conference calls, which are, however, rare in the sample we consider.

Figure B.8. VAR with Sign Restrictions on High-Frequency Variables Only



Note: Impulse response functions to a monetary policy shock according to the baseline identification (solid lines) and a shock identified by using sign restrictions on high-frequency variables only (dashed). The thick lines are the median estimates; the shaded areas and thin lines are the 68 percent credible intervals. Responses are shown in percent deviations, except for the interest rate and the measure of financial frictions (percentage point deviations).

quarter features a monetary policy shock or a central bank information shock.[37] We incorporate the poor man's proxy of monetary policy shock into a VAR with zero restrictions, ordering the shock first while imposing short-run restrictions. Figure B.9 shows that the qualitative impulse response patterns for all variables remain roughly unchanged.

Surprises from Scheduled FOMC Announcements Only. FOMC decisions at unscheduled meetings and conference calls often occur when economic conditions deteriorate abruptly, i.e., may constitute an endogenous response of monetary policy to contemporaneous shocks (Nakamura and Steinsson 2018). This raises concerns with respect to the proper identification of monetary policy shocks. Figure B.10 shows that excluding the unscheduled decisions particularly affects the interest rate response. The qualitative response pattern of all other variables is roughly unchanged.

Are Surprises Unpredictable? Miranda-Agrippino and Ricco (2021) show that the three-month federal funds future surprises are serially correlated and predictable by macrofinancial factors. We thus explore the sensitivity of our results by abandoning the zero restrictions of the VAR in Equation (37) and estimate a fully parameterized VAR. Figure B.11 shows that our main results are broadly unchanged when relaxing the restrictions.

Monthly Frequency. Our empirical specification uses quarterly data, while several other contributions use monthly data. We hence build a monthly data set by interpolating our baseline quarterly variables using monthly proxies (if available) or by cubic splines.[38] Figure B.12 shows that our results are robust to the

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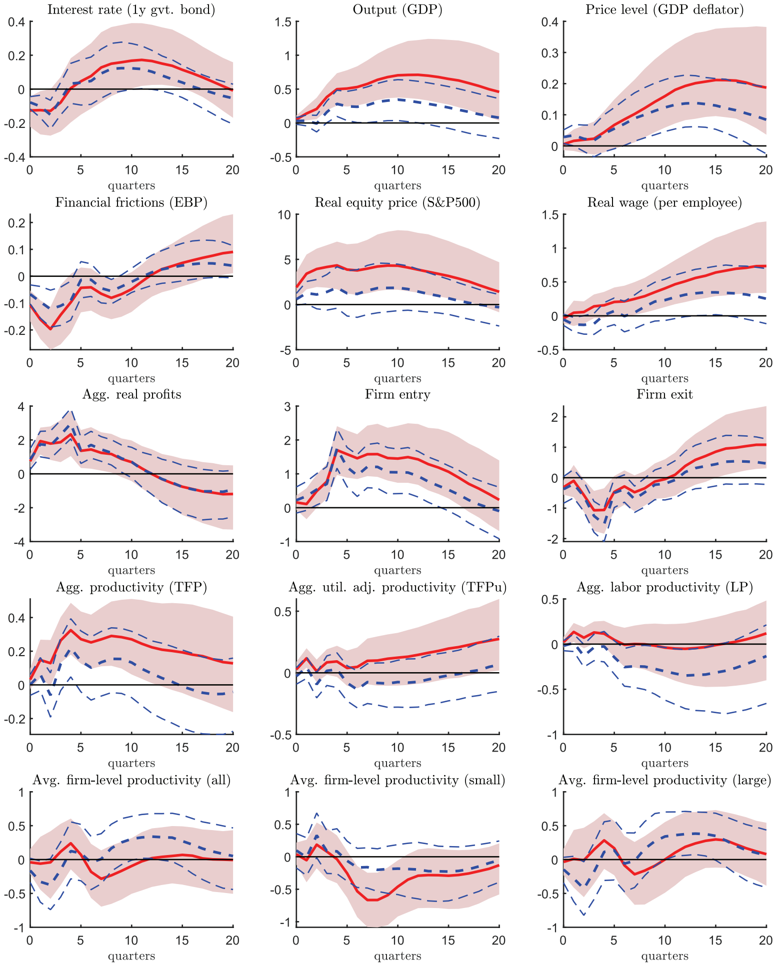
[37]In practice, monetary policy and information shocks occur simultaneously in a month (Jarociński and Karadi 2020). We obtain similar results when we impose a weaker version of the poor man's sign restriction that allows monetary policy shocks and information to occur simultaneously in a quarter. This procedure involves sign restrictions on (1) daily and (2) monthly surprises to identify pure monetary policy and information shocks. These shocks are converted to quarterly frequency by summation.

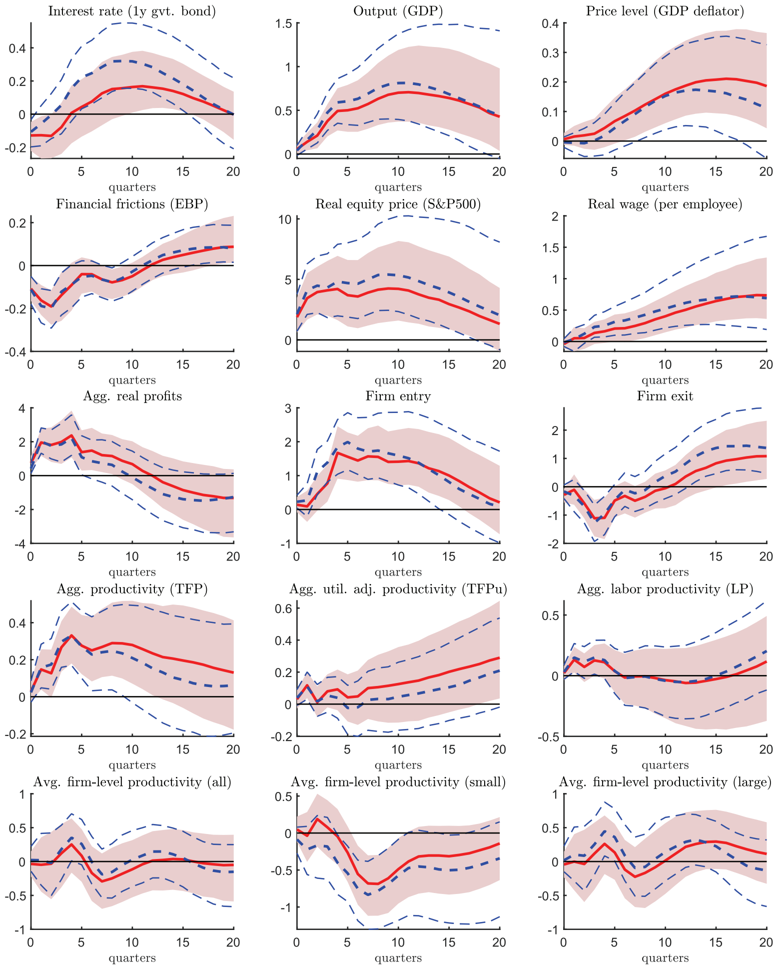
[38]Specifically, we include the core variables from the Jarociński and Karadi (2020) data set, i.e., surprises, interest rate, activity, prices, excess bond premium, and the stock price, in our data set and interpolate profits, wages, measures of firm dynamics, and productivity by cubic splines. Real GDP and GDP deflator are each interpolated by industrial production and consumer prices.

Figure B.9. VAR with Poor Man's Proxy



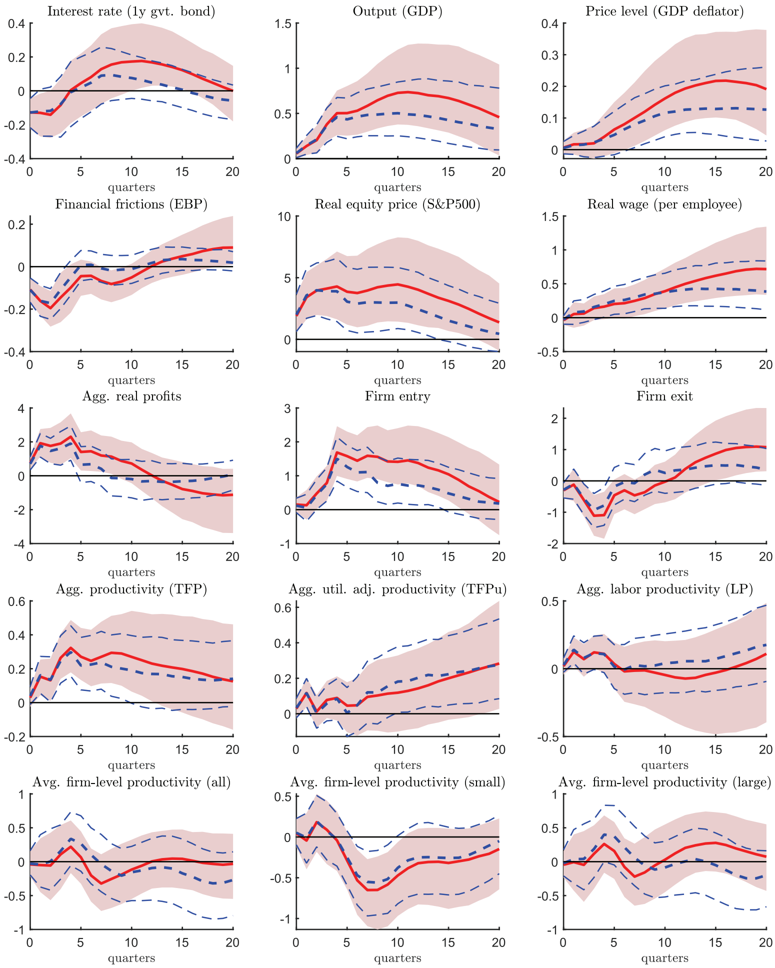
Note: Impulse response functions to a monetary policy shock according to the baseline identification (solid lines) and a shock identified using the poor man's proxy of a monetary policy shock in a VAR with zero restrictions (dashed). The thick lines are the median estimates; the shaded areas and thin lines are the 68 percent credible intervals. Responses are shown in percent deviations, except for the interest rate and the measure of financial frictions (percentage point deviations).

Figure B.10. Surprises from Scheduled FOMC Meetings Only



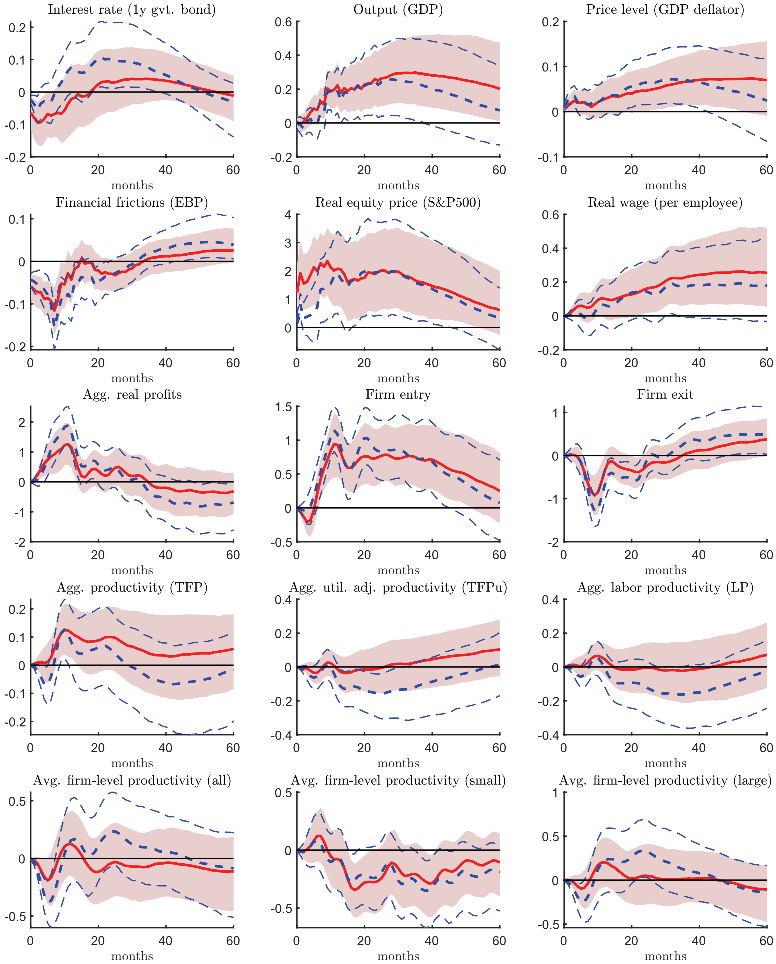
Note: Impulse response functions to a monetary policy shock according to the baseline using all FOMC announcements (solid lines) and when using only surprises from scheduled FOMC announcements (dashed). The thick lines are the median estimates; the shaded areas and thin lines are the 68 percent credible intervals. Responses are shown in percent deviations, except for the interest rate and the measure of financial frictions (percentage point deviations).

Figure B.11. Unrestricted VAR



Note: Impulse response functions to a monetary policy shock according to the baseline using a restricted VAR (solid lines) and an unrestricted VAR (dashed). The thick lines are the median estimates; the shaded areas and thin lines are the 68 percent credible intervals. Responses are shown in percent deviations, except for the interest rate and the measure of financial frictions (percentage point deviations).

Figure B.12. VAR with Monthly Interpolated Time Series



Note: Impulse response functions to a monetary policy shock according to the baseline identification (solid lines) and a shock identified by using sign restriction on high-frequency variables only (dashed) for the data set at monthly frequency. The thick lines are the median estimates; the shaded areas and thin lines are the 68 percent credible intervals. Responses are shown in percent deviations, except for the interest rate and the measure of financial frictions (percentage point deviations).

alternative data frequency for both our baseline identification procedure and that of Jarociński and Karadi (2020).

Alternative Measures and Sample Splits. Identifying monetary policy shocks at the ZLB is associated with potential issues (Ikeda et al. 2024). This suggests using measures of the interest rate that specifically account for the ZLB and nonstandard measures. Figure B.13 shows that our baseline results are robust when using the Wu and Xia (2016) shadow rate, the simple federal funds rate or the two-year government bond yield. Our results are also unaffected by alternative measures for output (industrial production), the price level (consumer price index), and financial frictions (spread of BAA-rated corporate bonds relative to 10-year Treasury yield); see Figure B.14. They are furthermore robust to different sample splits, i.e., when considering a sample up to the Great Recession only or excluding the Great Recession, as shown in Figures B.15 and B.16.

Local Projections. Estimated VAR impulse responses may be biased for more distant lags if the selected lag order is too small. We hence use the local projection method by Jordà (2005), which is more flexible and imposes weaker dynamic restrictions.[39] The local projection (LP) model is given by

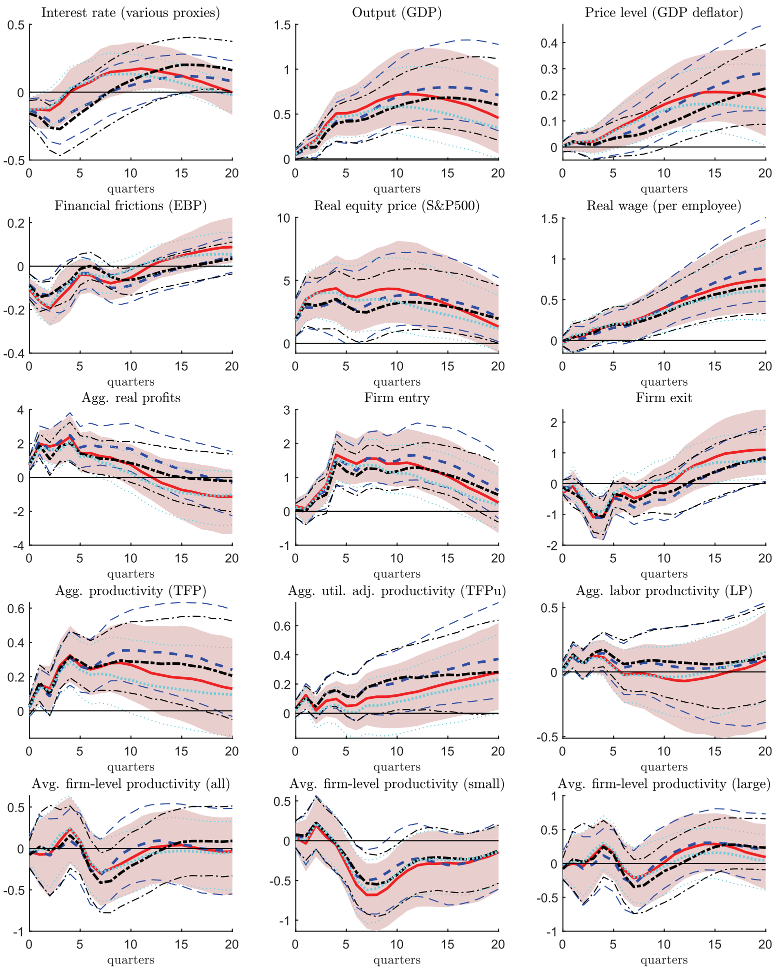
$$y_{t+h} = \alpha_h + x_t \beta_h + \sum_{j=1}^{2} y_{t-j} \theta_{j,h} + \sum_{j=1}^{2} w_{t-j} \gamma_{j,h} + u_{t+h}, \qquad \text{(B.2)}$$

where y_t is the dependent variable, x_t is a monetary policy shock and w_t is a vector of controls. Figure B.17 shows the estimates of the VAR with the poor man's proxy, the LP estimates with macrofinancial controls, and LP estimates without additional controls. Overall, the estimated LP impulse responses with controls are qualitatively similar, though somewhat more erratic.[40] This confirms our main

[39]LPs and VARs estimate the same impulse responses in a recursive VAR with unrestricted lag structure (Plagborg-Møller and Wolf 2021). As we use a flat prior in the VAR, the estimates are directly comparable for $h \leq 2$.

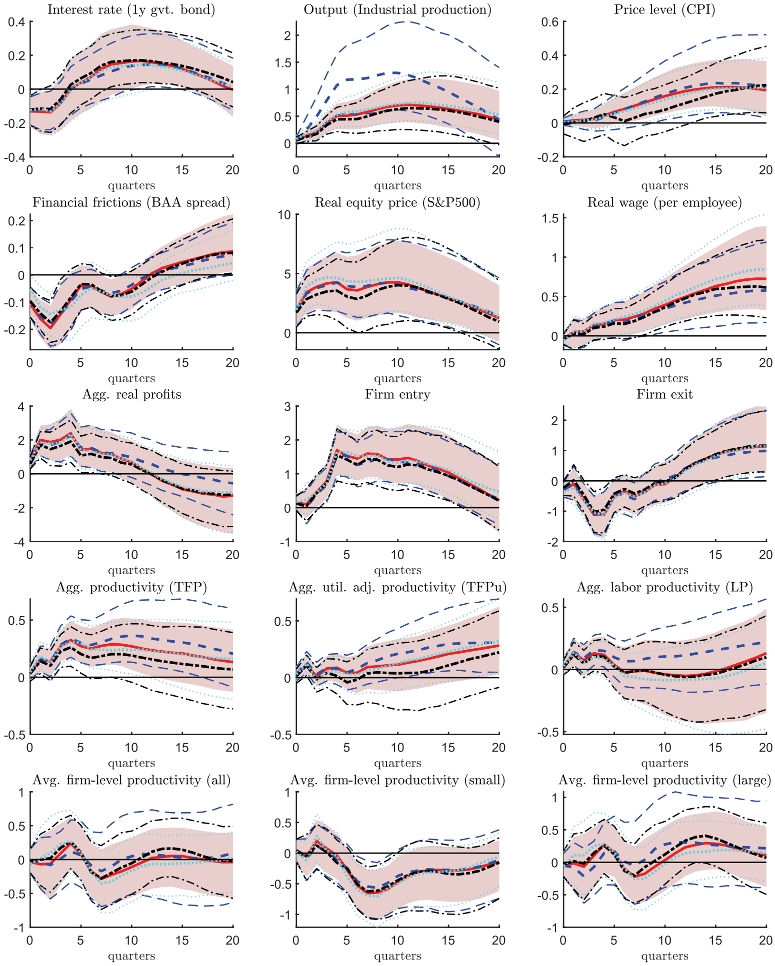
[40]The erratic pattern of LP impulse response functions as compared with a VAR is due to a loss in efficiency in the estimation and fewer dynamic restrictions (Barnichon and Brownlees 2019).

Figure B.13. VAR with Various Interest Rate Measures



Note: Impulse response functions to a monetary policy shock according to the baseline using the one-year government bond yield (solid lines) and using alternative measures of monetary policy: the federal funds rate (dashed), the federal funds rate extended by the shadow short rate of Wu and Xia (2016) (dashed-dotted), and the two-year government bond yield (dotted). The thick lines are the median estimates; the shaded areas and thin lines are the 68 percent credible intervals. Responses are shown in percent deviations, except for the interest rate and the measure of financial frictions (percentage point deviations).

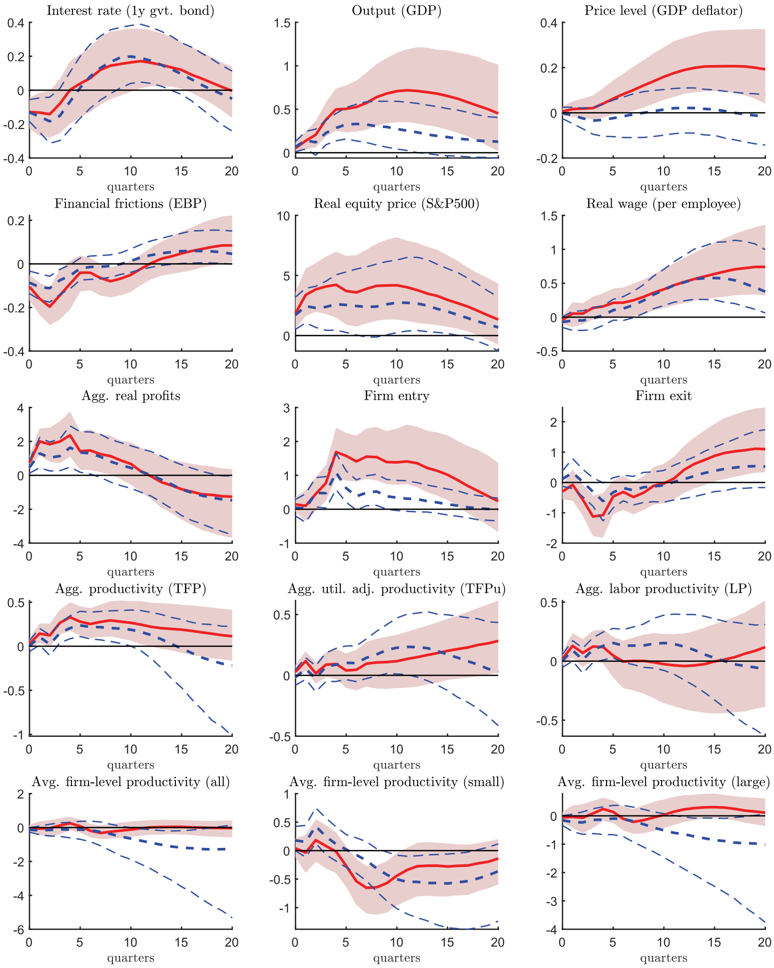
Figure B.14. VAR with IP, CPI, BAA



Note: Impulse response functions to a monetary policy shock using the baseline measures (solid lines) and when using alternative measures of activity (dashed), prices (dashed-dotted), and financial frictions (dotted). The thick lines are the median estimates; the shaded areas and thin lines are the 68 percent credible intervals. Responses are shown in percent deviations, except for the interest rate and the measure of financial frictions (percentage point deviations).

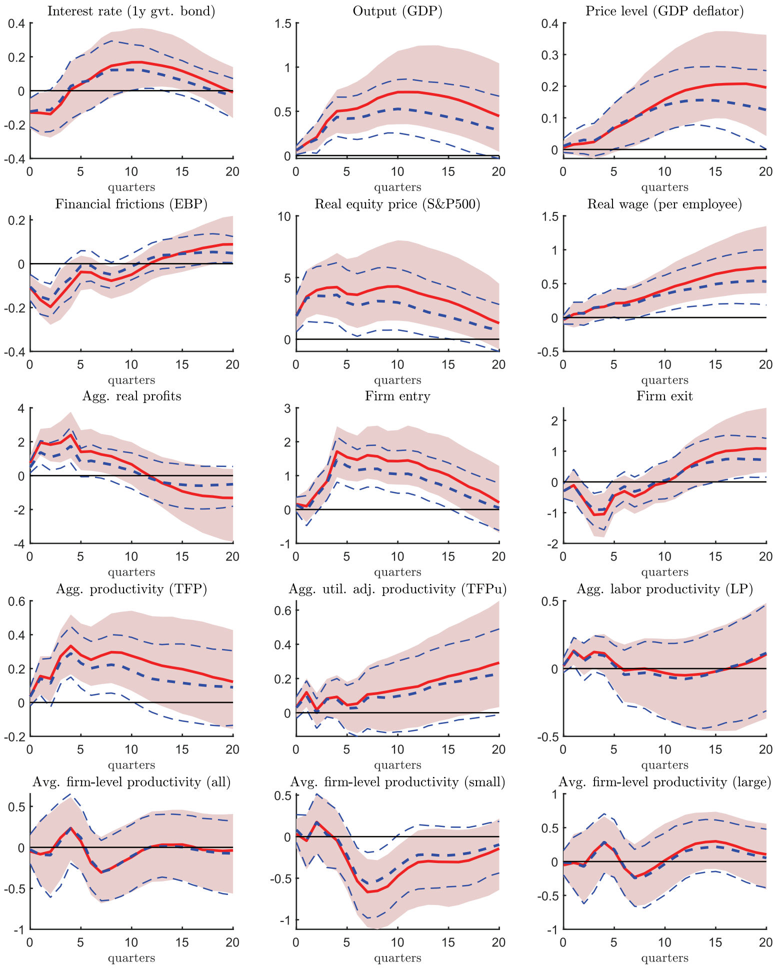
results. In contrast, the estimates without controls exhibit substantial output and price puzzles and may hence be regarded as implausible. This highlights the importance of including macrofinancial

Figure B.15. VAR Pre–Great Recession



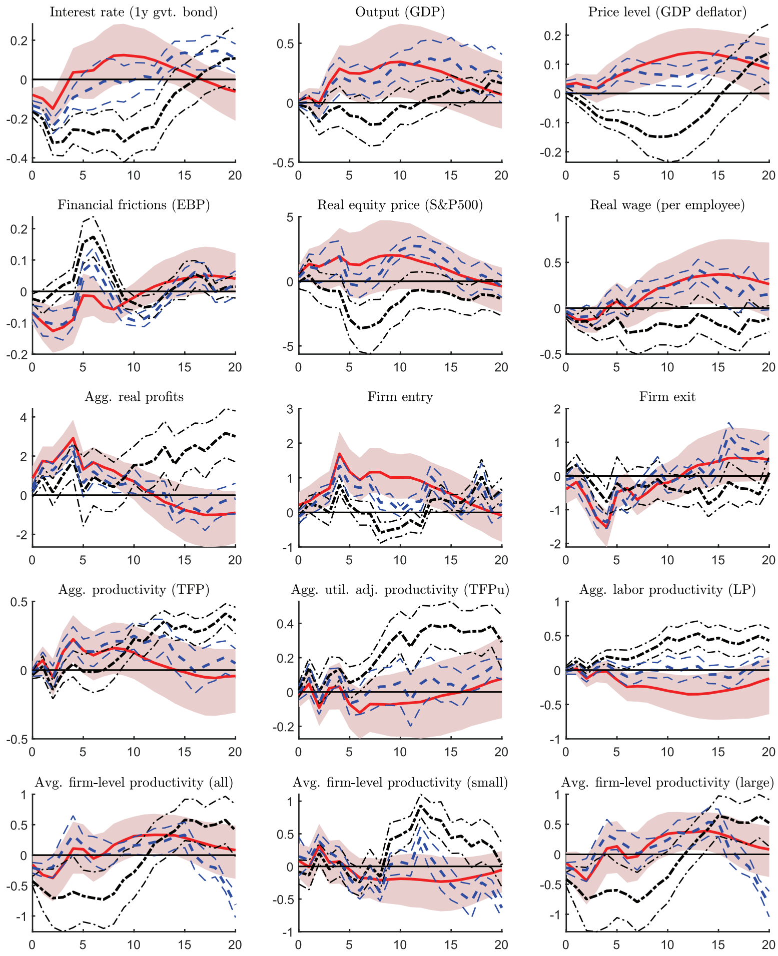
Note: Impulse response functions to a monetary policy shock using the baseline sample (solid lines) and when using a sample until 2008:Q2 (dashed). For the pre–Great Recession sample, a moderately loose Minnesota prior is used with overall tightness of $\lambda = 0.7$ and the federal funds rate is used as the policy indicator. The thick lines are the median estimates; the shaded areas and thin lines are the 68 percent credible intervals. Responses are shown in percent deviations, except for the interest rate and the measure of financial frictions (percentage point deviations).

Figure B.16. VAR Excluding Surprises from Apex of Great Recession



Note: Impulse response functions to a monetary policy shock according to the baseline using the full sample (solid lines) and a sample excluding the apex of the Great Recession, i.e., ex 2008:Q3–2009:Q2 (dashed). The thick lines are the median estimates; the shaded areas and thin lines are the 68 percent credible intervals. Responses are shown in percent deviations, except for the interest rate and the measure of financial frictions (percentage point deviations).

Figure B.17. Poor Man's Proxy: VAR and Local Projections



Note: Impulse response functions to a monetary policy shock identified using the poor man's proxy in a VAR with zero restrictions (solid lines), in a local projection with a set of macroeconomic and financial controls (dashed), and in a local projection without additional controls (dashed-dotted). The thick lines are the median (point) estimates; the shaded areas (thin lines) are the 68 percent credible intervals (confidence intervals) of the VAR (local projection). Responses are shown in percent deviations, except for the interest rate and the measure of financial frictions (percentage point deviations).

controls when estimating the effects of a monetary policy shock via local projections. Further below, we hence also discuss the impact of alternative controls on our PLP results.

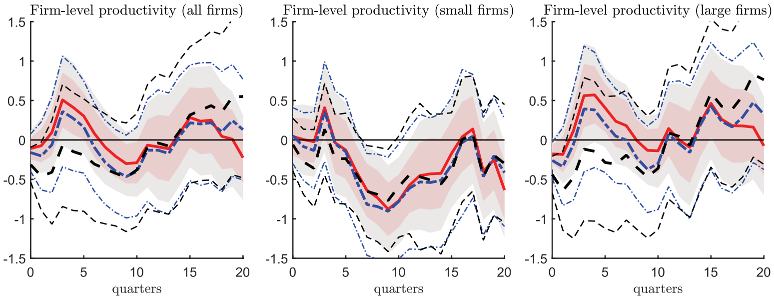
B.5.2 Specifications Exploiting the Panel Dimension

Alternative Sets of Controls. As discussed above, the set of controls may have a decisive impact on the estimated impulse responses in local projections. We hence explore how our PLP results change when including only macro controls (i.e., excluding stock price and financial frictions from the set of controls) and when including no macrofinancial controls. Figure B.18 shows that the qualitative patterns and the confidence intervals indeed hinge on the set of control variables. Most importantly, the response of firm-level productivity across small firms is robust to the set of controls and remains significant throughout. In contrast, the responses for all firms and large firms change considerably. We view this as further evidence that expansionary monetary policy decreases average productivity of small firms. At the same time, this exercise highlights the importance of accounting for the macrofinancial state when estimating the effects of monetary policy using PLPs to avoid misguided inference.

Heterogeneous Effects by Firm Size. The sample split by firm size in the baseline PLP does not account for potentially heterogeneous responses of different sectors to monetary policy, and that such sectoral heterogeneity could be correlated with firm size. To investigate whether small and large firms respond differently to monetary policy, we interact our sign-identified monetary policy shock with a firm-size dummy in a PLP while including various time-by-sector fixed effects to control for sectoral heterogeneity following Anderson and Cesa-Bianchi (2020) and Ottonello and Winberry (2020). We estimate the following model:

$$y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + D_t\eta_h + \Psi + (x_t \cdot size_{i,t})\beta_h + \sum_{j=1}^{2} \Delta y_{i,t-j}\theta_{h,j} + \sum_{j=1}^{2} size_{i,t-j}\delta_{h,j} + \sum_{j=1}^{2} w_{t-j}\gamma_{h,j} + u_{i,t+h}, \tag{B.3}$$

Figure B.18. Alternative Set of Controls in PLPs

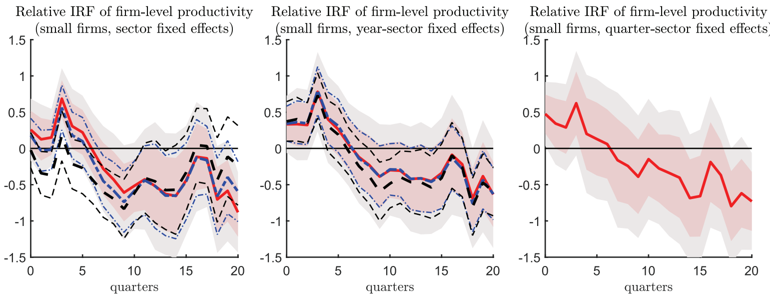


Note: Impulse response functions to the sign-identified monetary policy shock for different specifications of the PLP, using a full set of macrofinancial controls as a baseline (solid lines), macro controls only (dashed), and no additional controls (dashed-dotted). Shaded areas depict the 68 percent and 90 percent confidence intervals for the baseline; the thin lines show 68 percent confidence intervals for the alternative specifications. Responses are shown in percent deviations.

where $size_{i,t}$ is a dummy variable that is 1 for firms with sales lower than \$10 million and $\Psi \in \{\Xi_s, \Xi_{y,s}, \Xi_{t,s}\}$ is a time-by-sector fixed effect for all t (Ξ_s), by year ($\Xi_{y,s}$), and by quarter ($\Xi_{t,s}$). Note that Ξ_s is simply a sector fixed effect and thus identical to $\alpha_{i,h}$ since firms do not switch sectors. Following Ottonello and Winberry (2020) and Anderson and Cesa-Bianchi (2020), we include the lagged firm size dummy as an additional control.

Figure B.19 shows the corresponding relative impulse response functions of firm-level productivity for three different time-by-sector fixed-effects specifications (sector only, year-by-sector, quarter-by-sector). In all cases, the relative responses are first positive and turn negative after around six quarters. This suggests that the productivity of small firms is initially less responsive and becomes subsequently more responsive to monetary policy compared with that of large firms. This result is broadly in line with our baseline findings using a sample split by firm size (Figure 3, third row, middle and right panel). However, the relative responses are largely not significant at conventional levels. In interpreting these results, one needs to keep in mind that the year-by-sector fixed effects absorb a substantial amount of information contained in the macro and financial controls (middle panel); the quarter-by-sector fixed effects even

Figure B.19. Relative Impulse Response Functions of Small Firms



Note: Relative impulse response functions to the sign-identified monetary policy shock for different specifications of the PLP, using a full set of macrofinancial controls as a baseline (solid lines), macro controls only (dashed), and no additional controls (dashed-dotted), and various degrees of time-by-sector fixed effects. Shaded areas depict the 68 percent and 90 percent confidence intervals for the baseline; the thin dashed and dashed-dotted lines show 68 percent confidence intervals for the alternative specifications. Responses are shown in percent deviations.

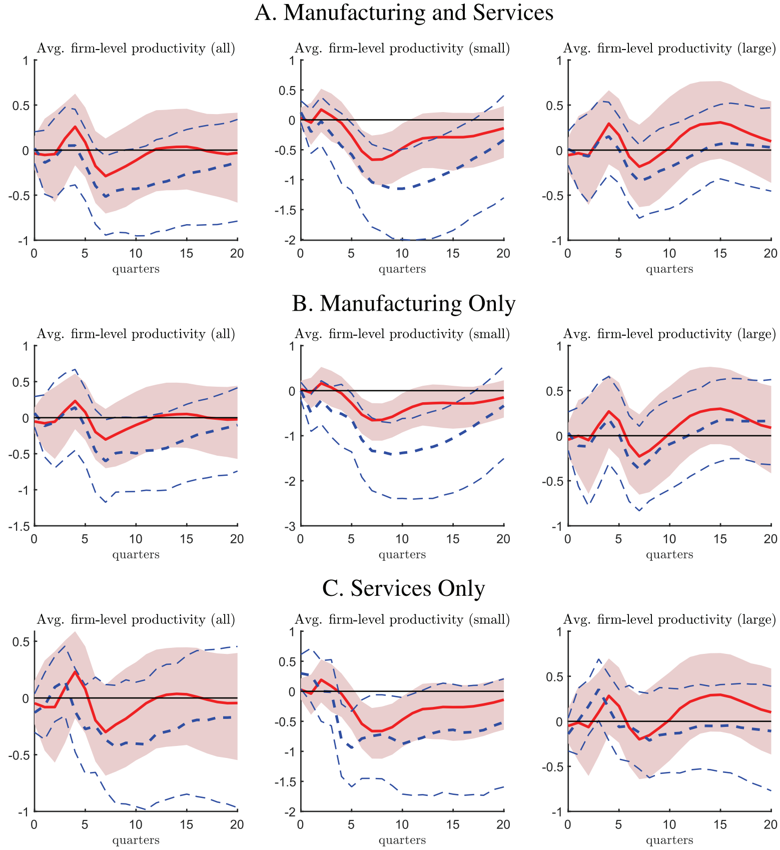
absorb it completely (right panel). In addition, small firms make up only one-third of our sample. Therefore, we view the evidence from this exercise to be somewhat mixed and inconclusive, which also guides our interpretation of the results in Section 4.3.

B.5.3 Construction of Firm-Level Productivity Series

Sector Composition. Firms in the manufacturing and services sectors are the closest counterparts to the theoretical goods-producing firms and constitute more than 70 percent of the firms in the Compustat sample (see Table B.2).[41] We hence investigate how average firm-level productivity in these sectors responds to monetary policy. Figure B.20 shows the effects of a monetary policy shock using the baseline VAR with all nonfinancial firms ex utilities and alternative sectoral splits: (A) manufacturing and services, (B) manufacturing

[41]The productivity dynamics for nonfinancial firms excluding utilities are mainly driven by these sectors (see Panel A in Figure B.3 and the related discussion in Section B.2).

Figure B.20. Sector Splits and Firm-Level Productivity

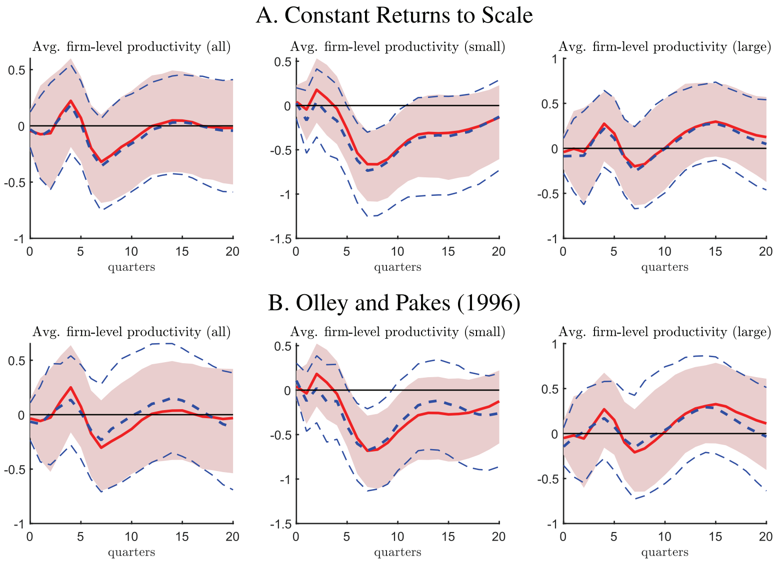


Note: Impulse response functions to a monetary policy shock according to the baseline using all nonfinancial sectors ex utilities (solid lines) and alternative sector splits (dashed). The thick lines are the median estimates; the shaded areas and thin lines are the 68 percent credible intervals. Responses are shown in percent deviations.

only, and (C) services only. The responses of average productivity for these three sector splits are somewhat shifted downward compared with the benchmark, but are still barely significant. However, the previously documented decline for small firms is even more pronounced for the manufacturing and service sectors.

Production Function Estimation. Our micro productivity measures are based on estimations of firm-level production functions.

Figure B.21. Production Function and Firm-Level Productivity



Note: Impulse response functions to a monetary policy shock according to the baseline using a panel OLS regression to estimate firm-level productivity (solid lines) and alternative production function estimations (dashed). The thick lines are the median estimates; the shaded areas and thin lines are the 68 percent credible intervals. Responses are shown in percent deviations.

We explore the robustness of our baseline—a panel OLS regression with fixed effects—by considering two alternative methods. First, we impose constant returns to scale for the share of capital α and labor β, i.e., $\alpha = 1 - \beta$, using a restricted panel OLS regression with fixed effects. Second, we use the semiparametric estimation approach of Olley and Pakes (1996) to control for input factor endogeneity. Table B.4 shows that these alternative methods lead to an increase in the estimated shares of capital and labor as compared with the baseline. Nevertheless, the resulting productivity time series are highly similar to the baseline estimate; see panel B in Figure B.3. Figure B.21 confirms that these alternative productivity measures do not respond to monetary policy shocks differently than the baseline series.

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