Chapter 1

Monetary policy with oligopolistic competition, firm heterogeneity and entry

Abstract

The standard textbook New Keynesian model relies on counter-cyclical profits for monetary policy to have an effect as recently pointed out by Broer et al. (2020). This paper first tests this hypothesis by adding oligopolistic competition and static free entry to an otherwise standard NK model. Including search and matching frictions to the labour market, breaks the result of money neutrality despite free entry of firms. Beyond that, the model is further augmented to accommodate firm heterogeneity and dynamic entry to investigate how the market structure affects the propagation of monetary policy shocks. The findings are threefold: First, through the channel of oligopolistic competition, heterogeneity in firms' productivity leads to pro-cyclical profits for lower levels of wage rigidity compared to the homogeneous case. Second, firm heterogeneity increases the response in aggregate output which is in line with Mongey (2017). Third, dynamic entry is further enhancing this effect, yet the strengthening of competition has a negative impact on firms' profits. Local projections using Compustat firm-level data and Romer & Romer (2004) monetary policy shocks support the predictions of the theoretical model.

Keywords: Monetary policy, oligopolistic competition, heterogeneous firms, firm entry.
JEL Codes: E62, E22, E23

1.1 Introduction

The standard framework to study the monetary transmission mechanism, which describes how interest rate changes affect the rest of the economy, has been the New Keynesian (NK) model. Counter-cyclical fluctuations in the firms' profits play a crucial role in this process: A decrease in dividends received by households raises labour supply through a wealth effect and the mere presence of profits reduces the offsetting negative income effect of the wage rise. This ultimately leads to an increase in hours worked and subsequently aggregate output. Muting the channel of firms' profits received by households as done in Broer et al. (2020) by introducing capitalists into a two-agent version of the NK model or by allowing for free entry of firms via a zero-profit condition as done in Bilbiie (2017) completely restores the frictionless equilibrium of money neutrality. Hence, profits seem to be an under-appreciated feature of the transmission mechanism of monetary policy. Profits are influenced by the market structure, which in turn is a function of the type of firm competition, concentration and potential entry and exit of firms. Yet, the standard NK framework usually restricts itself to the assumption of static monopolistic competition. This paper contributes to the question of how market structure affects the transmission of monetary policy and vice versa, since monetary policy shocks might alter the endogenous market structure. More specifically, I examine how the different determinants of market structure – competition, market concentration and firm entry – contribute to shaping the aggregate effect of monetary policy.

This paper relaxes the assumption of monopolistic competition in an otherwise standard NK model with nominal rigidities by introducing oligopolistic competition as in Atkeson & Burstein (2008) and entry of firms. The finding of Bilbiie (2017) that free entry leads to money neutrality even under sticky prices is replicated for the oligopolistic case. As a remedy to restore monetary non-neutrality, I include search and matching frictions into the labour market following Christiano et al. (2016). There, households supply labour inelastically, hence acyclical profits imposed by a zero profit condition do not neutralize the transmission of monetary policy. Search and matching frictions guarantee changes in employment despite households supplying labour inelastically. Beyond that, building on the labour market setup proposed by Christiano et al. (2016), I introduce firm heterogeneity and dynamic entry of firms to the oligopolistic framework in order to investigate the effect of market structure on the propagation of monetary policy shocks. I show that larger firms, the ones with higher productivity levels, respond less to changes in marginal cost relative to smaller, less efficient firms. Hence, the propagation of monetary policy shocks becomes a function of the endogenous market structure, characterised by the amount of competing firms and concentration within the market. This mechanism gives rise to several findings. The main findings are threefold: First, through the channel of oligopolistic competition, heterogeneity in firms' productivity leads to pro-cyclical profits for lower levels of wage rigidity compared to the homogeneous case. Second, firm heterogeneity increases the response in aggregate output which is in line with Mongey (2017). Third, dynamic and pro-cyclical entry is further enhancing this effect, yet the strengthening of competition has a negative impact on firms' profits.

Empirically, the motivation to include multiple strategically interacting firms into the framework is straightforward, as the majority of product markets are not made up by a sole monopolist. Furthermore, most markets are highly concentrated. As Mongey (2017) points out, the median effective number of firms is only 3.7[1]. Moreover, entry is a non-negligible aspect of most product markets and an important feature to explain business cycle fluctuations as shown in recent studies. Broda & Weinstein (2010) for instance provide evidence that 35% of an increase in aggregate sales stems from newly introduced products. Also Bilbiie et al. (2012) emphasize the importance of new products, including those produced by existing firms, as source of aggregate output fluctuations.

Literature. While the monetary policy literature usually abstracts from firm dynamics, thus relying on monopolistic competition with static product varieties, research on business cycles and on trade occasionally accounts for oligopolistic market structures and entry, yet mostly separated. The underlying project hence combines several strands of literature to investigate the effects of firm dynamics on the transmission mechanism of monetary policy.

Pioneered by Hopenhayn (1992)'s model of industry dynamics, many papers incorporated firms' entry and exit in macroeconomics models to study their effects on real business cycles. Contributions that endogenized firms' entry are for instance Jaimovich & Floetotto (2008), Lewis (2009) and Bilbiie et al. (2012) among others. Bilbiie et al. (2012) showed that variation in the number of producers and products through entry and exit can be an important propagation mechanism for fluctuations. Within their setup they are able explain stylized facts such as the pro-cyclical behaviour of entry and profits[2]. In his seminal paper, Melitz (2003) extended the model of Hopenhayn (1992) to accommodate heterogeneity in firms' productivity. His model captures the difference in firms'

[1] A measure of market concentration computed as the inverse of the Herfindahl index

[2] Specifically, their assumption of translog preferences results in counter-cyclical markups with pro-cyclical profits.

responses to being exposed to trade. Trade induces only the more productive firms to export while simultaneously forcing the least productive firms to exit the market. Hence, market shares and profits are reallocated to the more productive firms. This project aims to capture potentially different responses of firms to shocks in the nominal interest rate. Papers studying the effect of entry in the context of monetary policy include Bergin & Corsetti (2008), Bilbiie et al. (2014) and Bilbiie (2017). The latter points out that free entry of firms restores the frictionless equilibrium of money neutrality even under sticky prices. However, all of them rely on the standard assumption of monopolistic competition.

Effects of strategically competing firms have been mainly studied within real business cycle models being agnostic about any effects on the transmission of monetary policy as in Etro & Colciago (2010), Colciago & Etro (2010) and Colciago & Rossi (2015) among others. Etro & Colciago (2010) show in a real business cycle model with endogenous market structures that a temporary positive productivity shock fosters entry and consequently strengthens competition which in turn reduces markups temporarily and increases real wages. They argue that oligopolistic competition creates an intertemporal substitution effect which boosts consumption and employment. Oligopolistic competition in trade models was introduced by Brander (1981) and extended with free-entry by Brander & Krugman (1983). Atkeson & Burstein (2008) renewed the interest in oligopolistic market structures to explain some trade features and more recent contributions in that area include Impullitti et al. (2017) and Impullitti & Licandro (2018) who combine oligopolistic competition and free entry of firms to study the gains from trade.

The first applications in the NK framework have been developed by Faia (2012) and Lewis & Poilly (2012). The most recent study in an NK framework capturing oligopolistic competition and entry stems from Etro & Rossi (2015) who derive a New Keynesian Phillips curve under Calvo staggered pricing and endogenous market structures with Bertrand competition. They find that both strategic interactions and endogenous business creation strengthen nominal rigidities. This reduces the slope of the Phillips curve and consequently amplifies the real effects of monetary policy shocks.

Moreover, the monetary policy literature has traditionally focused on the aggregate effect of policy shocks. Questions on how micro-level heterogeneity and distributional effects change the transmission of monetary policy are of quite recent interest (see e.g. Sterk & Tenreyro (2015), Cloyne et al. (2016), Auclert (2017), Kaplan et al. (2018)). However, these papers have mainly focused on heterogeneity in households not across firms. Among the first to introduce heterogeneity between firms in a NK model are Ottonello & Winberry (2018) who study the role of heterogeneity in firms' financial positions in determining the investment channel of monetary policy. In a heterogeneous firm NK model they show that firms with high default risk are less responsive to monetary shocks because their marginal cost of external finance is high. Probably closest related to this project is the paper by Mongey (2017) who proposes an equilibrium menu cost model with a continuum of sectors, each consisting of two strategically engaged firms competing in prices and facing heterogeneity in product demand. He shows that compared to a model with monopolistically competitive sectors, the duopoly model features a smaller inflation response to a monetary shock and an output response which is more than twice as large. This project departs from Mongey (2017) in allowing for endogenous entry and selection and a different form of oligopolistic competition.

Outlook. The paper is structured as follows: First, section 1.2 introduces the reader to the baseline model for symmetric firms, followed by a note on static free entry and money non-neutrality in section 1.3. Section 1.4 lays out the extended model to accommodate heterogeneity in firms' productivity and introduces dynamic entry. The calibration of the theoretical model is explained in detail in section 1.5. Section 1.6 analyses the effect of oligopolistic competition, firm heterogeneity and entry on the propagation of monetary policy shocks. Empirical evidence for heterogeneous responses to monetary policy is presented in section 1.7. Finally, section 1.8 concludes.

1.2 Baseline Model

The baseline model is augmenting the standard NK model by oligopolistic competition and search and matching frictions in the labour market as this forms the basis for the monetary policy analysis later on. At first, this model will be compared to a model with oligopolistic competition but with a simplistic competitive labour market[3] for the case of static free entry of firms.

Time is discrete and infinite. The model environment consists of a representative household obtaining utility from consuming the final good, a final good producer using the intermediate goods as input and firms producing the intermediate good. Intermediate producers face nominal rigidities which are modelled as a quadratic adjustment cost following Rotemberg (1982). Within intermediate sectors, firms compete strategically à la Cournot and are symmetric in their marginal cost for now. The labour market is modelled separately and exhibits search and matching frictions following the framework

[3] Described in detail in the appendix in section A.1.

of Mortensen & Pissarides (1994). The bargaining process follows the alternating offer bargaining as proposed in Christiano et al. (2016) in order to introduce endogenous wage inertia. A monetary authority sets nominal interest rates and monetary policy shocks are the only disturbance in the model economy.

1.2.1 Households

There is a continuum of infinitely lived identical households. The representative household has a unit measure of labour which it supplies inelastically to the Diamond-Mortensen-Pissarides labour market. A fraction of L_t of the household is employed and receives a real wage w_t. The residual fraction $1 - L_t$ is unemployed receiving unemployment benefits D_t from the government.[4] There is perfect consumption insurance within each household so that each member is provided with the same level of consumption. The household's preferences are consequently the equally weighted average of the preferences of its members. The representative household maximizes the following lifetime utility:

$$\max_{C_t, B_{t+1}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(C_t), \tag{1.1}$$

subject to the nominal budget flow equation of the household

$$C_t P_t + B_{t+1} = B_t(1 + i_t) + w_t P_t L_t + (1 - L_t) P_t D_t + \pi_t, \tag{1.2}$$

where C_t and B_{t+1} denote the consumption choice and risk-free bond purchases by the household in period t. The household takes equilibrium real wages w_t and the equilibrium gross interest rate of $1 + i_t$ as given. Furthermore, π_t denotes nominal firm profits after taxes, P_t denotes the price level of the final good. The first order condition yields the Euler equation of the household:

$$u'(C_t) = \beta \mathbb{E}_t \Big[(1 + i_t) \frac{P_t}{P_{t+1}} u'(C_{t+1}) \Big]. \tag{1.3}$$

1.2.2 Production

Production is modelled according to the oligopolistic competition framework proposed by Atkeson & Burstein (2008). There is a representative competitive final goods firm which

[4]Unemployment benefits are financed by a lump-sum tax which is deducted from the firms' profits before the household receives the residual.

aggregates intermediate goods according to a constant-elasticity of substitution (CES) technology as in Dixit & Stiglitz (1977). Furthermore, there is a continuum of sectors producing an intermediate good. The market structure of each such sector is an oligopoly made up of n identical firms (for now). Within each sector, firms are competing à la Cournot and produce output using labour only. Prices are sticky, as firms have to pay a quadratic adjustment cost when changing prices.

Final Good Producer. The final good Y_t is produced by a competitive firm with a CES production function, taking a continuum of measure one of intermediate goods as input,

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}}, \quad i \in [0,1], \tag{1.4}$$

where $Y_t(i)$ denotes output of sector i and σ is the elasticity of substitution across intermediate goods. Intermediate goods are imperfect substitutes (i.e. $\sigma < \infty$). The final good producer buys the intermediate goods and maximizes profits according to

$$\max_{Y_t(i)} P_t \left(\int_0^1 Y_t(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} - \int_0^1 P_t(i) Y_t(i) di, \tag{1.5}$$

where $P_t(i)$ denotes the price for the intermediate good i. Maximizing profits yields the demand function for each intermediate good i

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\sigma} Y_t, \tag{1.6}$$

The relative demand for intermediate i is hence a function of its relative price. The price index can be derived using nominal output as

$$P_t Y_t = \left(\int_0^1 P_t(i) Y_t(i) di \right).$$

Plugging in the demand for each variety, we get

$$P_t Y_t = \left(\int_0^1 P_t(i)^{1-\sigma} P_t^{\sigma} Y_t di \right),$$

which boils down to the following expression for the aggregate price level

$$P_t = \left(\int_0^1 P_t(i)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}. \tag{1.7}$$

Intermediate Producers. There are $n_t(i)$ intermediate producers $j \in [1, n_t(i)]$ in each sector i at time t. Sector output is the CES aggregate of all intermediate goods in that sector:

$$Y_t(i) = n_t(i)^{\frac{1}{1-\zeta}} \left(\sum_{j=1}^{n_t(i)} Y_t(i,j)^{\frac{\zeta-1}{\zeta}} \right)^{\frac{\zeta}{\zeta-1}}, \tag{1.8}$$

where $Y_t(i,j)$ is the amount produced by firm j in industry i at time t. We assume that goods within a sector are more substitutable than goods across sectors, hence $1 < \sigma < \zeta$. Following Jaimovich & Floetotto (2008), I abstract from a variety effect by multiplying with $n_t(i)^{\frac{1}{1-\zeta}}$. Again, analogous to above, the sectoral price index $P_t(i)$ is given by:

$$P_t(i) = n_t(i)^{\frac{\zeta}{1-\zeta}} \left(\sum_{j=1}^{n_t(i)} P_t(i,j)^{1-\zeta} \right)^{\frac{1}{1-\zeta}},$$

and the inverse demand function for goods within a sector is given by:

$$Y_t(i,j) = \left(\frac{P_t(i,j)}{P_t(i)} \right)^{-\zeta} Y_t(i).$$

Furthermore, each firm produces according to a constant returns to scale production function with hired labour, $h_t(i,j)$, as the sole input elevated by total factor productivity A_t

$$Y_t(i,j) = A_t h_t(i,j). \tag{1.9}$$

Intermediate oligopolists face a common price for hiring workers. As prices set by the intermediate producers are sticky (see below) oligopolists cannot freely adjust prices to maximize profits but they will minimize cost. The minimization problem is subject to the constraint of producing enough to meet the demand for the intermediate good

$$\min_{h_t(i,j)} P_t^h h_t(i,j),$$

subject to

$$A_t h_t(i,j) \geq Y_t(i,j),$$

where P_t^h is the price for hiring one unit of labour $h_t(i,j)$. Taking first order conditions we get that marginal cost, mc_t, equals the cost to hire one unit of labour divided by its productivity

$$mc_t = \frac{P_t^h}{A_t} = \frac{\vartheta_t}{A_t} P_t, \tag{1.10}$$

where ϑ_t is the relative price of hiring one unit of labour to the price of the homogeneous final product ($\vartheta_t = \frac{P_t^h}{P_t}$). Marginal cost is identical across all sectors and firms as we abstract from any heterogeneity in productivity for now.

Intermediate firms' optimization problem. Since firms are finite and not atomistic, they take their impact in sectoral output into account. More specifically, as they compete à la Cournot they internalize the quantities produced by their competitors when optimizing their production plan. Moreover, as changing prices comes with a quadratic adjustment cost in the spirit of Rotemberg (1982), the firms' optimization problem is intertemporal and each firm consequently discounts future profits when optimizing quantities according to a stochastic discount factor $m_{t,t+\tau}$. The profit maximization problem for firm j in sector i can be written as follows

$$\max_{Y_{t+\tau}(i,j)} \mathbb{E}_t \sum_{s=0}^{\infty} m_{t,t+\tau} \left(P_{t+\tau}(i,j) Y_{t+\tau}(i,j) - \frac{\vartheta_{t+\tau}}{A_{t+\tau}} P_{t+\tau} Y_{t+\tau}(i,j) - \frac{\theta_p}{2} \left(\frac{P_{t+\tau}(i,j)}{P_{t+\tau-1}(i,j)} - 1 \right)^2 P_{t+\tau}(i,j) Y_{t+\tau}(i,j) \right),$$

$$s.t. \qquad P_t(i,j) = \left(\frac{Y_t(i,j)}{Y_t(i)} \right)^{-1/\zeta} P_t(i), \tag{1.11}$$

where θ_p is the Rotemberg coefficient for quadratic price adjustment cost.
The first order condition implies that the optimal sectoral price (firms are symmetric) is a markup over marginal cost[5]

$$P_t(i,j) = \mu_t(i,j) \frac{\vartheta_t}{A_t} P_t, \tag{1.12}$$

where

$$\begin{aligned}
\mu_t(i,j) &= \frac{\Theta_t(i,j)}{(\Theta_t(i,j)-1)\left[1 - \frac{\theta_p}{2}(\pi_t(i)-1)^2\right] + \theta_p \pi_t(i)(\pi_t(i)-1) - \Gamma_t(i)} \\
\Theta_t(i,j) &= \left[\frac{1}{\zeta} + \left(\frac{1}{\sigma} - \frac{1}{\zeta} \right) s_t(i,j) \right]^{-1} \\
\Gamma_t(i) &= \theta_p \mathbb{E}_t \left[m_{t,t+1} \pi_{t+1}(i)^2 (\pi_{t+1}(i) - 1) \frac{Y_{t+1}(i) n_t}{Y_t(i) n_{t+1}} \right]
\end{aligned} \tag{1.13}$$

with $s_t(i,j)$ denoting the market share of firm j in sector i defined as $\left(\frac{P_t(i,j)}{P_t(i)}\right)^{1-\zeta}$. For symmetric firms, the firm specific index j can be omitted and the market share is simply $\frac{1}{n_t(i)}$ with $n_t(i)$ being the number of firms in industry i. $\pi_t(i)$ is the inflation of the sectoral

[5] For a detailed derivation please see appendix A.2.

price. For flexible prices ($\theta_p = 0$) and symmetric firms the markup reduces to

$$\mu_t(i) = \frac{\Theta_t(i)}{\Theta_t(i) - 1}, \tag{1.14}$$

with

$$\Theta_t(i) = \left[\frac{1}{\zeta} + \left(\frac{1}{\sigma} - \frac{1}{\zeta}\right)\frac{1}{n_t(i)}\right]^{-1}. \tag{1.15}$$

For an increasing number of firms $n_t(i)$ in a sector, the sectoral market structure becomes monopolistic with a markup of $\frac{\zeta}{\zeta-1}$ as products are imperfect substitutes also within each sector. Furthermore, the monopolistic case is also nested if both elasticities of substitution are equal, i.e. $\sigma = \zeta$. If there is a single firm per sector, the markup equals $\frac{\sigma}{\sigma-1}$.

1.2.3 Personnel agency, workers and the labour market

The labour market is modelled separately to the intermediate producers' problem as in Christiano et al. (2016). They adjust the workhorse search and matching framework by Mortensen & Pissarides (1994) to resolve the Shimer (2005) puzzle. Shimer (2005) shows that a standard DMP labour market does not produce realistic volatility of labour market variables following a technological shock. However, Christiano et al. (2016) show that adding hiring cost (Pissarides, 2009) and a bargaining process known as alternating offer bargaining (AOB)[6] produces realistic responses of employment and posted vacancies with respect to what is observed in the data. The reasons to employ this labour market setup are twofold: First, it induces wage rigidity endogenously and solves the Shimer (2005) puzzle making it preferable to a standard Calvo model of wage rigidity. Secondly, it allows us to investigate in more detail how labour market variables react to firm dynamics compared to a simplistic competitive labour market. The following section lays out the DMP labour market model with hiring cost and alternating offer bargaining as in Christiano et al. (2016).

Personnel agencies post vacancies and workers search for employment. The law of aggregate employment, L_t, is given by

$$L_t = (\rho + x_t)L_{t-1}, \tag{1.16}$$

where ρ is the probability that a match between a personnel agency and a worker continues to be productive in the next period. Hence, ρL_{t-1} denotes the number of workers who

[6] First adoption in this context by Hall & Milgrom (2008).

have been employed in $t-1$ and remain employed in t. Furthermore, $x_t L_{t-1}$ denotes the number of new meetings between firms and workers at the start of period t. Following Christiano et al. (2016) meetings always result in employment, hence x_t can be interpreted as the hiring rate. The number of workers searching for work at the start of each period is the sum of workers who were unemployed in period $t-1$, which is given by $1-L_{t-1}$, and the number of workers who separate from firms at the end of $t-1$, which is given by $(1-\rho)L_{t-1}$. Hence, the probability of finding a job f_t is given by

$$f_t = \frac{x_t L_{t-1}}{1-\rho L_{t-1}}. \tag{1.17}$$

Personnel agencies earn revenues by renting out workers to intermediate goods producers. If a firm wishes to meet a worker in period t it must post a vacancy which costs s in real terms. The vacancy is filled with probability Q_t. In case the vacancy is filled, the agency must pay a fixed cost of κ before being able to bargain with the new worker. The fixed cost of meeting a worker delivers more volatility in the job finding rate and hence a more volatile response of unemployment to cyclical productivity shocks. Interpretations for the fixed cost component can be one-off negotiation costs, administrative costs or training costs (Pissarides, 2009). The value to the firm of each worker match can be expressed as follows

$$J_t = \vartheta_t^p - w_t^p, \tag{1.18}$$

where ϑ_t^p denotes the expected present value of the flow of revenues from hiring out the employees over the duration of the match, given the real price of renting a worker $\vartheta_t = \frac{P_t^h}{P_t}$. Analogously, w_t^p denotes the present value of the real wage, $w_t = \frac{W_t}{P_t}$. Hence, in recursive form the present values can be written as follows

$$\vartheta_t^p = \vartheta_t + \rho E_t m_{t+1} \vartheta_{t+1}^p, \qquad w_t^p = w_t + \rho E_t m_{t+1} w_{t+1}^p, \tag{1.19}$$

where $m_{t,t+1}$ is the stochastic discount factor as discussed above. Free entry of personnel agencies guarantees that in equilibrium, the expected value of a match has to equal its cost

$$Q_t(J_t - \kappa_t) = s_t, \tag{1.20}$$

where κ_t denotes the cost of hiring a worker and s_t denotes the cost of search in form of posting vacancies. The left hand side expresses the expected value of hiring a worker which has to equal the cost to find a match. Let furthermore V_t denote the value of an employed worker which can be expressed as the sum of the expected present value of wages earned while the match endures and the continuation value when worker and firm separate

$$V_t = w_t^p + A_t, \tag{1.21}$$

and

$$A_t = (1-\rho)E_t m_{t+1}\left[f_{t+1}V_{t+1} + (1-f_{t+1})U_{t+1}\right] + \rho E_t m_{t+1} A_{t+1}. \tag{1.22}$$

The variable U_t denotes the value of an unemployed worker, which is simply the sum of unemployment benefits and the continuation value of unemployment

$$U_t = D_t + \tilde{U}_t, \tag{1.23}$$

where again $\tilde{U}_t$ denotes the continuation value of unemployment

$$\tilde{U}_t = E_t m_{t+1}\left[f_{t+1}V_{t+1} + (1-f_{t+1})U_{t+1}\right]. \tag{1.24}$$

Defining labour market tightness as the number of vacancies posted by firms $v_t L_{t-1}$ relative to all workers looking for jobs

$$\Xi_t = \frac{v_t L_{t-1}}{1-\rho L_{t-1}}. \tag{1.25}$$

We can write the vacancy filling rate and the job finding rate as follows assuming that they are related to market tightness

$$f_t = \eta_m \Xi_t, \qquad Q_t = \eta_m \Xi_t^{-\eta}, \qquad \eta_m > 0, 0 < \eta < 1. \tag{1.26}$$

where η_m is the level parameter in the matching function and η the matching function parameter.

1.2.4 Alternating Offer Bargaining

Instead of using a simple Nash bargaining rule where both agents, firms and workers, share the surplus according to their bargaining power, we use a version of the alternating offer bargaining game between firms and workers adopted by Christiano et al. (2016) and initially proposed by Hall & Milgrom (2008). The advantage of AOB is that it creates endogenous inertia in wages without the need to impose it in a Calvo fashion exogenously. As Hall & Milgrom (2008) point out, the alternating offer bargaining process is detaching the real wage from general labour market conditions making it less sensitive. Consequently, AOB is a further remedy to the Shimer (2005) puzzle as it allows firms to enjoy a larger share of the rent when an expansionary shock hits, therefore increasing their incentive to expand employment and vice versa for a negative shock.

This section describes the process of bargaining and the resulting wage arrangement between firms and workers following the model described in Christiano et al. (2016). After all productive matches L_t have been initialised, each worker engages in bilateral bargaining of the wage rate with the personnel agency. Each worker-firm pair takes the outcome of all other wage discussions that period as given. Furthermore, conditional on remaining matched, each pair has beliefs about future wage arrangements. Specifically, they assume that future wages do not depend on the outcome in the current period.

The model frequency is assumed to be quarterly, yet the bargaining game proceeds across M subperiods within each quarter, where M is even. The firm is the first to make a wage offer at the start of the first subperiod. Optimally, the firm would target a wage as low as possible subject to the worker not rejecting it. Immediately after having received the offer, the other party can either accept or reject it. If the worker rejects he can make an counter-offer in the next period which is an even subperiod. This goes on as long as firm and worker reject their offers, respectively, until the last subperiod M when the worker makes a take-it or leave-it offer. There is also a probability δ that one party leaves the negotiations after having rejected an offer and bargaining breaks down.

More formally, a firm is offering exactly the wage $w_{j,t}$ in subperiod $j < M$ and j being odd which satisfies the following indifference condition:

$$V_{j,t} = \max\{U_{j,t}, \delta U_{j,t} + (1-\delta)[D_t/M + V_{j+1,t}]\}. \tag{1.27}$$

It is assumed that if the agent is indifferent between accepting and rejecting the offer, he accepts it. The left hand side of equation (24) denotes the value of an agent being employed and receiving the offered wage $w_{j,t}$:

$$V_{j,t} = w_{j,t} + \rho E_t m_{t+1} w_{t+1} + A_t,$$

which is simply the sum of current wage and the present discounted value of future wage earnings conditional on the worker-firm match remaining productive. The right hand side of the indifference equation is the maximum over the worker's options if he chooses to reject the wage offer, namely an outside option $U_{j,t}$ and the worker's disagreement payoff. The latter denotes the value of a worker who rejects the offer but intends to male a counter-offer. The outside option is defined as the share of unemployment benefits in period t after j subperiods and the continuation value of unemployment as defines above:

$$U_{j,t} = \frac{M-j+1}{M} D_t + \tilde{U}_t.$$

Hence the term $\delta U_{j,t}$ reflects the case that talks break down and the worker remains unemployed and receives proportionate benefits. The second term of the disagreement payoff reflects the case that the worker receives unemployment benefits for the subperiod and then makes a counter-offer. The worker offers the highest possible wage subject to the firm not rejecting it. Hence, the offer satisfies the following indifference condition:

$$J_{j,t} = \max\{0, (1-\delta)[-\phi_t + J_{j+1,t}]\}, \tag{1.28}$$

where the left hand side is the value of a firm which accepts the offer:

$$J_{j,t} = \frac{M-j+1}{M} \vartheta_t + \rho E_t m_{t+1} \vartheta_{t+1} - (w_{j,t} + \rho E_t m_{t+1} w_{t+1}), \tag{1.29}$$

where again, it is assumed that a worker produces $1/M$ intermediate goods each subperiod following employment. As before, the right hand side reflects the trade off between the firm's outside option (i.e. zero) and it's disagreement payoff. In contrast to the worker, the firm incurs a real cost ϕ_t in order to make a counter-offer. Hence, if the firm intends to disagree, yet to prepare a counter-offer, it faces the cost ϕ_t and the potential gain $J_{j+1,t}$ of accepting $w_{j+1,t}$.

Under the assumption that each bargaining party prefers a disagreement and subsequent counter-offer to their outside option we can solve the bargaining game backwards. Starting with the last subperiod M, the worker offers the highest wage possible as a take-it-or leave it offer subject to the firm not rejecting it. Hence, the firm will be indifferent between accepting and taking the outside option. Therefore we have that:

$$J_{M,t} = 0.$$

Using that and equation 1.29, we can derive the present value of wage flows $w^P_{j,t}$ which are defined above as the sum of current wage and discounted future wages:

$$w^P_{M,t} = \vartheta/M + \tilde{\vartheta}^P_t.$$

Knowing the present value at subperiod M we can the proceed to calculate the present value at $M-1$ using the worker's indifference condition as it's the firm's turn to make an offer. Analogously, w^P_{M-2} can be derived using 1.28 and so on. The final solution to the bargaining problem is simply $w^P_{1,t}$, the wage a firm would offer in the first stage of the game. Christiano et al. (2016) show that the linear indifference curves lead to the following closed-form solution for w^P_t:

$$w^P_t = \frac{1}{\alpha_1 + \alpha_2}[\alpha_1 \vartheta^P_t + \alpha_2(U_t - A_t) + \alpha_3 \phi_t - \alpha_4(\vartheta_t - D_t)],$$

where

$$\alpha_1 = 1 - \delta + (1-\delta)^M,$$
$$\alpha_2 = 1 - (1-\delta)^M,$$
$$\alpha_3 = \alpha_2 \frac{1-\delta}{\delta} - \alpha_1,$$
$$\alpha_4 = \frac{1-\delta}{2-\delta}\frac{\alpha_2}{M} + 1 - \alpha_2,$$

which are strictly positive. Rearranging the terms above gives us the alternating offer bargaining rule:

$$J_t = \beta_1(V_t - U_t) - \beta_2 \phi_t + \beta_3(\vartheta_t - D_t), \tag{1.30}$$

with $\beta_i = \alpha_{i+1}/\alpha_i$ for $i \in 1,2,3$.

1.2.5 Monetary authority

Lastly, there is a central bank setting the nominal interest rate following a Taylor rule. The central bank takes into account the deviation from price stability as captured by inflation and the deviation of output from its potential as captured by its steady-state measure:

$$\log(R_t/R_{ss}) = \rho_R \log(R_{t-1}/R_{ss}) + (1-\rho_R)\left[\theta_\pi \log(\pi_t/\pi_{ss}) + \theta_Y \log(Y_t/Y_{ss}) + \upsilon_t\right], \tag{1.31}$$

where π_t is gross inflation of the final good price, θ_π is the weight on inflation in the reaction function. Analogously, θ_Y is the weight on the output gap, measured as deviation from steady state output, Y_{ss}. ρ_R is a smoothing parameter and the policy shock υ_t is the only aggregate disturbance in the model. The monetary policy shock has unit variance and zero mean. The shock is a one time shock and not autocorrelated.

1.2.6 Aggregation and market clearing

Imposing price stickiness following Rotemberg (1982) has the advantage that there is no price dispersion between firms or sectors and aggregation is straightforward as outputs and consequently prices are identical for the case of symmetric firms. Hence, we have that $\forall (i,j) \in [0,1] \times [1,n_t] : y_t(i,j) = y_t, n_t(i) = n_t, p_t(i,j) = p_t$. Aggregate hired labour is then given by $H_t = n_t h_t$. Aggregate output is obtained by combining the definition of final good and intermediate CES aggregators and the linear production function of the intermediate good

$$Y_t = \left(\int_0^1 \left(n_t^{\frac{1}{1-\zeta}} \left(\sum_{j=1}^{n_t} y_t^{\frac{\zeta-1}{\zeta}} \right)^{\frac{\zeta}{\zeta-1}} \right)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} = \left(\int_0^1 (n_t y_t)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}},$$

$$= \left(\int_0^1 (n_t A_t h_t)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} = A_t H_t. \tag{1.32}$$

Analogously the price level equals the individual firm's price

$$P_t = \left(\int_0^1 \left(n_t^{\frac{\zeta}{1-\zeta}} \left(\sum_{j=1}^{n_t} p_t^{1-\zeta} \right)^{\frac{1}{1-\zeta}} \right)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}} = p_t.$$

Consequently, from equation 1.13 we get that marginal cost is equal to the inverse of the markup

$$\vartheta_t / A_t = \frac{1}{\mu_t}. \tag{1.33}$$

Furthermore, the labour market needs to clear, hence hired labour by the intermediate goods sector H_t has to equal the labour employed through the DMP wholesalers L_t,

$$H_t = L_t. \tag{1.34}$$

Finally, market clearing demands that the goods market clears and the real adjustment cost as well as the real costs of searching and meeting employees is paid. Hence, it has to hold that

$$Y_t = C_t + \frac{\theta_p}{2} (\pi_t - 1)^2 Y_t + (s/Q_t + \kappa) x_t L_{t-1}. \tag{1.35}$$

1.3 Static free entry and monetary non-neutrality

In a very recent paper, Broer et al. (2020) emphasize an under-appreciated feature of the standard textbook NK model. Namely, that both the counter-cyclical response of profits and their steady-state size play a key role for the response of employment and output to monetary policy shocks. With elastic labour supply and preferences in the King-Plosser-Rebelo class, the deviation of total income from labour income is decisive for the response of labour supply. More specifically, as households receive profits lump-sum such a deviation occurs as profits fall following an increase in goods demand and wages. As this leaves households poorer, it triggers the required increase in labour supply to meet the rise in demand. However, if this channel is muted, there is no aggregate response in aggregate employment and output and hence we are back to the result of money neutrality even under sticky prices. This transmission channel is clearly implausible as Broer et al. (2020) point out and greatly at odds with the pro-cyclical response of profits as observed in the data (Christiano et al., 2005).

Independently, in an environment more closely related to this paper, Bilbiie (2017) finds the same result of monetary neutrality for sticky prices with free entry of firms through a zero-profit condition. The condition's logic is the following: firms enter a sectoral market as long as profits are positive and exit as long as they are negative. A fixed cost of production ensures that in equilibrium there is a finite amount of firms in each industry. Bilbiie (2017) shows that for the standard workhorse model of monopolistic competition by Dixit & Stiglitz (1977) that free entry can replace price flexibility even if prices are fixed. Following an expansionary monetary policy shock, demand for each firm goes up increasing labour demand which in turn raises the real wage. Profits fall and as a consequence, under the assumption of free entry, firms exit. Aggregate quantities will not change but the distribution of production is different. There will be less firms (extensive margin), each producing more (intensive margin). Both effects perfectly offset each other. Yet again, the basis for this channel are counter-cyclical profits and elastic labour supply.

Including a DMP labour market on the one hand endogenously introduces wage rigidity and on the other hand ensures that the model is not prone to the neutrality result as in Broer et al. (2020) and Bilbiie (2017) as labour is supplied inelastically and search and matching friction determine employment. In order to demonstrate the different responses for the baseline model with elastic labour supply[7] and the baseline model with a DMP labour market as introduced above, we allow for free entry and exit through a zero-profit

[7] As defined in the appendix in section A.1.

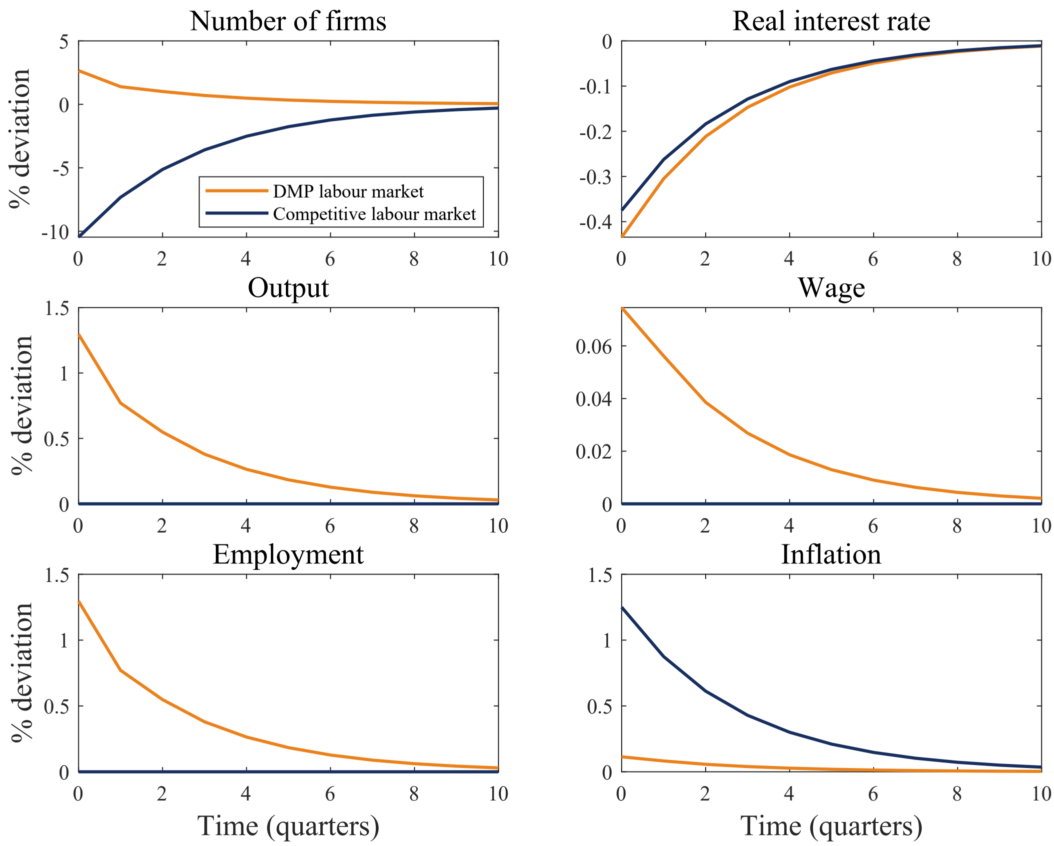

Fig. 1.1 Impulse response functions after an expansionary monetary policy shock.

Notes. Impulse response functions after a one percent shock to the nominal interest rate at $t = 0$. The solid orange line shows the responses of the baseline model with search and matching frictions and a zero-profit condition. The blue line denotes the responses when households supply labour elastically as in the standard textbook NK model (Details in the appendix in section A.1).

condition. Recall that entry is free and entrants use the same production technology as incumbent firms. Consequently, the aggregate zero-profit condition as shown below directly backs out the number of firms in each market:

$$Y_t - \frac{w_t}{A_t} Y_t - \frac{\theta_p}{2} (\pi_t - 1)^2 Y_t - M = 0, \tag{1.36}$$

where M is a fixed cost of production, set exogenously.

Figure 1.1 plots the impulse response functions for both the baseline model with a competitive labour market and with a DMP labour market and alternating offer bargaining. In both settings, the number of firms is determined endogenously through a static zero-profit condition. Both models are calibrated such that the steady-state amount of firms and the aggregate values of output and employment are the same.[8] In the competitive labour market case, there is no response in aggregate output nor employment but firms exit due to a counter-cyclical response in profits. Furthermore, the absolute change in the number of firms is much larger compared to the DMP labour market scenario as the extensive margin perfectly offsets the intensive margin without leaving any residual response in output. However, if households supply labour inelastically as in the DMP setup, free entry does not neutralize monetary policy with respect to output and employment. Moreover, as the DMP labour market endogenously introduces wage rigidity, free entry leads to pro-cyclical business creation which is consistent with empirical observations (see e.g. Fairlie & Fossen (2018)).

1.4 Generalized model with firm heterogeneity and dynamic entry

This section extends the baseline model by firm heterogeneity and dynamic entry of firms in order to gauge the effect of changes in the market structure and concentration for monetary policy and vice versa.

1.4.1 Intermediate production with heterogeneous firms

There is a fixed number of intermediate producers indexed by j that are organized in a fixed number of heterogeneous productivity categories denoted by s, similar to Andrés & Burriel (2018). Hence, the CES aggregation of the intermediate product can be written as:

$$Y_t = N_t^{\frac{1}{1-\zeta}} \left(\sum_{s=1}^{S} \sum_{j=1}^{N_t^s} \left(y_t(j,s) \right)^{\frac{\zeta-1}{\zeta}} \right)^{\frac{\zeta}{\zeta-1}}, \tag{1.37}$$

where S is the total number of productivity categories, and N_t^s is the number of firms in productivity class s. Note that the sector index i has been dropped as sectors are symmetric.

The input demand function and the price index associated with the intermediate good producers' optimization are as follows:

$$y_t(i,j,s) = \left(\frac{P_t(i,j,s)}{P_t(i)} \right)^{-\zeta} y_t(i),$$

[8] Details on the calibration are covered further down.

$$P_t(i) = N_t^{\frac{\zeta}{1-\zeta}} \left(\sum_{s=1}^{S} \sum_{j=1}^{N_t^s} \left(P_t(i,j,s) \right)^{1-\zeta} \right)^{\frac{1}{1-\zeta}},$$

Analogous to equation 1.13, the intermediate firms' profit maximization problem with heterogeneity in productivity can be written as follows:

$$\max_{y_{t+\tau}(i,j,s)} \mathbb{E}_t \sum_{s=0}^{\infty} m_{t,t+\tau} \left(P^j_{t+\tau}(i) y_{t+\tau}(i,j,s) - \frac{\vartheta_{t+\tau}}{z(i,s)A_{t+\tau}} P_{t+\tau} y_{t+\tau}(i,j,s) - \frac{\theta_p}{2} \left(\frac{P_{t+\tau}(i,j,s)}{Pt+\tau-1(i,j,s)} - 1 \right)^2 P_{t+\tau}(i,j,s) y_{t+\tau}(i,j,s) \right)$$

$$s.t. \qquad y_t(i,j,s) = \left(\frac{P_t(i,j,s)}{P_t(i)} \right)^{-\zeta} y_t(i) \tag{1.38}$$

where $z(i,s)$ is the idiosyncratic productivity factor of productivity category s in sector i. In order to keep the model tractable it is assumed that there are no shocks to firms' productivity. Furthermore, sectors are symmetric and each sector comprises the same number of firms of each productivity category and the same productivity distribution prevails. The first order condition of the firms' problem gives us an expression for the time-varying markup of firm j of productivity class s which is analogous to above:

$$P_t(i,j,s) = \mu_t(i,j,s) \frac{\vartheta_t}{z(i,s)A_t} P_t, \tag{1.39}$$

where

$$\begin{aligned} \mu_t(i,j,s) &= \frac{\Theta_t(i,j)}{(\Theta_t(i,j)-1)\left[1 - \frac{\theta_p}{2}(\pi_t(i)-1)^2\right] + \theta_p \pi_t(i)(\pi_t(i)-1) - \Gamma_t(i)}, \\ \Theta_t(i,j,s) &= \left[\frac{1}{\zeta} + \left(\frac{1}{\sigma} - \frac{1}{\zeta} \right) s_t(i,j,s) \right]^{-1}, \\ \Gamma_t(i) &= \theta_p \mathbb{E}_t \left[m_{t,t+1} \pi_{t+1}(i)^2 (\pi_{t+1}(i)-1) \frac{y_{t+1}(i,j,s)}{y_t(i,j,s)} \right], \end{aligned} \tag{1.40}$$

The expression is equivalent to the baseline model, except here markups differ between firms within a sector with respect to their individual level of productivity and corresponding market share.

Proposition 1 *A firms' markup over its marginal cost decreases with its market share. The standard monopolistic case is nested in the model for* $s_t(i,j,s) = 1$.

Log-linearising the markup of firm j around its steady state gives a firm-specific augmented Phillips curve similar to (Benigno & Faia, 2010; Bilbiie et al., 2014; Guilloux-Nefussi, 2016). Although, the concept of the Phillips curve looks at dynamics of inflation at the aggregate level, we aim to understand how the individual firm behaviour influences the aggregate results. The Phillips curve for a firm in productivity class s is given as

$$\pi_t(s) = \frac{\Theta_{ss}(s)-1}{\theta_p}\left(\frac{\hat{\vartheta}_t}{z(s)\hat{A}_t} + \hat{\mu}_t(s)\right) + \beta\mathbb{E}_t\pi_{t+1}(s). \tag{1.41}$$

The Phillips curve for the individual firm shows that the sensitivity of price adjustments to a change in marginal cost is decreasing in a firms' steady-state market power. Recall, that $\Theta_{ss}(s)$ is lower, the larger a firm is. Since the steady-state market shares vary for different producers depending on their relative productivity, the aggregate response depends on the market structure.

Proposition 2 *Large firms, the ones with higher productivity levels, respond less to changes in marginal cost as their Phillips curve is flatter.*

1.4.2 Dynamic entry of firms

Entry is dynamic as in Andrés & Burriel (2018). The number of operating firms is endogenous and as mentioned above, firms can have different exogenous steady state levels of productivity. This will consequently lead to different firm sizes. All potential entrants are of the lowest productivity level. Yet, a fraction of firms can transition to the nearest group size each period. More specifically, with probability p_u firms become more productive and subsequently larger and with probability p_l firms shrink in size, respectively. Furthermore, a fraction δ of firms independent of their productivity level stop producing each period. The law of motion for the number of firms in each productivity or size class can therefore be written as

$$N^s_{t+1} = p_u(1-\delta)N^{s-1}_t - p_l(1-\delta)N^{s+1}_t + (1-p_u-p_l)(1-\delta)N^s_t, \tag{1.42}$$

where the right hand side is the sum of those surviving firms which either increase in size, decrease in size or stay in the same productivity bin s. The overall number of operating firms can be written as the sum of surviving firms across all productivity classes and new entrants

$$N_{t+1} = (1-\delta)N^E + \sum_{s=1}^{S}(1-\delta)N^s_t. \tag{1.43}$$

The exit shock δ and the transition probabilities are assumed to be exogenous while entry is endogenous. Furthermore, there is a mutual fund of firm profits which pays a dividend to the representative household equal to the total amount of nominal profits of all firms producing in that period. The representative household can choose to buy shares s_t in the mutual fund of all the firms in the economy. The price of a share at time t is equal to the discounted present value of future profits streams averaged across firms which equals the average value of producing firms v_t. Hence, accommodating firm entry, the households budget constraint is given by:

$$C_t P_t + B_{t+1} + \sum_{s=0}^{S} v_t^s N_t^s s_t^s = B_t(1+i_t) + w_t P_t L_t + (1-L_t)P_t D_t$$
$$+ (1-\delta)\sum_{s=0}^{S} s_{t-1}^s N_{t-1}^s (p_u(\pi_t^{s+1} + v_t^{s+1}) + p_l(\pi_t^{s-1} + v_t^{s-1}) + (1-p_u-p_l)(\pi_t^s + v_t^s))$$

where s_t^s denotes the amount of shares and π_t^s denotes the profit streams of firms of productivity class s at period t. The latter part of the right hand side hence, denotes the sum of profits and remaining present values after transition of all surviving firms in the economy at that period. Households maximize over consumption, bonds purchases and investment in firms. First order conditions with respect to consumption and bonds give the Euler equation as above. Optimal investment in firms of each productivity class s has to satisfy:

$$v_t^s = \mathbb{E}_t\left[m_{t,t+1}\left(p_u(\pi_{t+1}^{s+1} + v_{t+1}^{s+1}) + p_l(\pi_{t+}^{s-1} + v_{t+1}^{s-1}) + (1-p_u-p_l)(\pi_{t+1}^s + v_{t+1}^s)\right)\right] \quad \text{for } s \in \{1,2,\ldots,S\} \tag{1.44}$$

where $m_{t,t+1} = \beta\frac{u'(C_{t+1})}{u'(C_t)}(1-\delta)$ is the stochastic discount factor.

Each period there is a continuum of potential entrants to the market of producing firms. Entry is subject to frictions. Firms have to pay an exogenous sunk entry cost f^E. Furthermore, firms remain idle for one period before starting to produce. Yet, new entrants face the same structural shocks δ as incumbent firms. By assumption entrants are of the lowest productivity class and can become more productive with probability p_u. Free entry ensures that firms will enter as long as their expected gain from producing equals the entry cost:

$$v_t^E = f^E, \tag{1.45}$$

where the sunk cost is identical across all sectors i and constant over time.

1.4.3 Aggregation and market clearing

Aggregate output is obtained by combining the definition of final good and intermediate CES aggregators and the linear production function of the intermediate good but now aggregating over all productivity groups s:

$$\begin{aligned}
Y_t &= \left(\int_0^1 \left(N_t^{\frac{1}{1-\zeta}} \left(\sum_{s=1}^{S} \sum_{j=1}^{N_t^s} y_t^{j,s\,\frac{\zeta-1}{\zeta}} \right)^{\frac{\zeta}{\zeta-1}} \right)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} \\
&= \left(\int_0^1 \left(N_t^{\frac{1}{1-\zeta}} \left(\sum_{s=1}^{S} \sum_{j=1}^{N_t^s} (z^s h_t^{j,s})^{\frac{\zeta-1}{\zeta}} \right)^{\frac{\zeta}{\zeta-1}} \right)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} \\
&= N_t^{\frac{1}{1-\zeta}} \left(\sum_{s=1}^{S} \sum_{j=1}^{N_t^s} (z^s h_t^{j,s})^{\frac{\zeta-1}{\zeta}} \right)^{\frac{\zeta}{\zeta-1}}
\end{aligned}$$

where in the third step we used the assumption that sectors are symmetric. For perfect substitutes, i.e. $\zeta \to \infty$, the expression boils down to

$$Y_t = \sum_{s=1}^{S} \sum_{j=1}^{N_t^s} (z^s h_t^{j,s}), \tag{1.46}$$

which is the sum of hired labour enhanced by the group specific productivity parameter z^s over all firms j and productivity classes s. As within each productivity class, firms are symmetric, the expression reduces further to $\sum_{s=1}^{S} N_t^s z^s h_t^s$. Total output can also be written using the average productivity across all firms in the economy, $Y_t = \bar{z} H_t$, where $\bar{z}$ is defined as follows for the case of perfect substitutes

$$\bar{z} = \frac{\sum_{s=1}^{S} N_t^s z^s h_t^s}{\sum_{s=1}^{S} N_t^s h_t^s}. \tag{1.47}$$

Prices must satisfy the following condition

$$1 = \sum_{s=1}^{S} \frac{N_t^s}{N_t} \left(\frac{P_t^s}{P_t} \right)^{1-\zeta}. \tag{1.48}$$

Table 1.1 Non-estimated parameters and calibrated values

Parameter	Value	Description	Reference
		Panel A: Parameters	
β	0.9926	Discount factor	Standard
γ	-1	Risk aversion	Standard
α	0.8	Taylor rule smoothing parameter	Standard
θ_π	1.5	Taylor rule inflation coefficient	Standard
θ_y	0.05	Taylor rule output gap coefficient	Standard
θ_p	5	Rotemberg coefficient of price adjustment cost	Standard
A	1	Economy wide TFP	Standard
σ	5	CES parameter across sectors	Atkeson & Burstein (2008)
ζ	10	CES parameter within sectors	Atkeson & Burstein (2008)
ρ	0.9	Job survival probability	Christiano et al. (2016)
M	60	Max. bargaining rounds per quarter	Christiano et al. (2016) adj.
δ	0.002	Probability of talks breaking down	Christiano et al. (2016) adj.
z^1	1	TFP of less productive firms	Fernández & López (2014)
z^2	1.5	TFP of efficient firms	Fernández & López (2014)
δ	2.5%	Business death rate	Jaimovich & Floetotto (2008)
p_u	1%	Probability of becoming more efficient	Own assumption
p_l	2.5%	Probability of becoming less efficient	Own assumption
		Panel B: Steady state values	
Q	0.70	Vacancy filling rate	Christiano et al. (2016)
u	0.05	Unemployment rate	Christiano et al. (2016)
D/w	0.4	Unemployment benefits relative to wage earnings	Christiano et al. (2016)
κ/Y	1%	Hiring cost/output	Christiano et al. (2016)
s/Y	0.05%	Vacancy cost/output	Christiano et al. (2016)
$N^1/(N^1+N^2)$	0.80	Share of small firms	Andrés & Burriel (2018)

Market clearing has to take into account the overall amount of sunk entry cost paid at each period

$$Y_t = C_t + \frac{\theta_p}{2}(\pi_t - 1)^2 Y_t + (s/Q_t + \kappa)x_t L_{t-1} + N^E f^E, \tag{1.49}$$

and the labour market has to clear

$$\sum_{s=1}^{S} N_t^s h_t^s = H_t = L_t. \tag{1.50}$$

1.5 Calibration

Table 1.1 documents the chosen parameter values and targeted steady state values for the calibration of the model. The parameters have been selected either using consensus values from the literature or were calibrated to reproduce some moments in the data. Starting with the non-estimated parameters, we use a discount factor of 0.9926 which is consistent with an annualized real interest rate of 3%. The household's utility function

exhibits constant relative risk aversion with $\gamma = -1$ which boils down to the nested case of log-utility. The Taylor rule with interest rate smoothing is specified according to standard values from the literature. Following the oligopolistic framework by Atkeson & Burstein (2008), elasticity of substitution across sectors (σ) has to be lower than within sectors (ζ). The chosen parameters lead to a steady-state markup of 1.25 for a single firm and a 10% markup for an infinite amount of firms within a sector. Recall that also within each sector, intermediate goods are defined as imperfect substitutes. The Rotemberg coefficient for price adjustment cost is chosen such that for a steady state markup of 1.25, the implied frequency of price changes equals a Calvo probability for a price change of 0.75.
The DMP labour market assumes a match survival rate $\rho = 0.9$ which is in line with the values used in Christiano et al. (2016) and Walsh (2003). Furthermore, the amount of subperiods over which an alternating offer bargaining process could extend is set to $M = 60$ which roughly equals the number of business day in a quarter as pointed out by Christiano et al. (2016). The value for the chance of a sudden breakup in wage negotiations is equal to the bayesian estimate of 0.2 percent by Christiano et al. (2016). In order to increase endogenous wage rigidity induced by the alternating bargaining process, the breakup probability and the number of subperiods are reduced. The model parameters η_m and ϕ are chosen, so that, conditional on the other parameter, the model produces a steady state unemployment rate of 5% and a steady state vacancy filling rate of $Q = 0.7$ which is consistent with Den Haan et al. (2000) and Ravenna & Walsh (2008). Unemployment benefits amount to 40% of prior wage earnings. The variable cost for posting vacancies κ and for meeting potential employees is calibrated such that the total amount of each cost position is 1% of the model economy's total output.
Without loss of generality and following Andrés & Burriel (2018), the model is calibrated for two productivity classes $s = 1,2$. Hence, there is a number of firms with a low productivity level z^1 and a number of more efficient firms with productivity $z^2 > z^1$ in each sector. Following the estimates by Fernández & López (2014), large firms' TFP is almost two times the productivity of small firms. In the simple model without firm heterogeneity, firms' productivity is set equal to the average productivity of the heterogeneous case. The number of firms are calibrated to reproduce the stylized facts such that most of the firms are small (roughly 80%) but that the majority of workers is employed by large firms. The latter is a result of the productivity differential between heterogeneous firms. As in the model with entry, the number of firms in each productivity class is endogenous, entry cost and transition probabilities are calibrated in order to replicate those facts.

Following Jaimovich & Floetotto (2008) the rate of exogenous business exit is $\delta = 2.5\%$ which determines the ratio of entrants in steady state and reflects empirical observations.

1.6 Monetary policy analysis

This section analyses the effect of a monetary policy shock. In order to gauge the effect of market structure on monetary policy and vice versa, we first compare the baseline model with homogeneous firms to the generalized model with heterogeneous firms yet without entry. Both models are calibrated such that average productivity is identical and they produce the same steady state results of aggregate variables. Second, in a separate analysis, the model is extended by dynamic entry, in order to disentangle the effect of firm heterogeneity and dynamic entry on the transmission of monetary policy. Again, in order to make the results comparable, the same steady states are targeted for both specifications.

1.6.1 Effect of firm heterogeneity on monetary policy

As shown above, we expect that large firms respond less to an increase in marginal cost than less productive firms. Figure 1.2 plots the impulse response functions of selected variables for an expansionary monetary policy shock. The plots shown compare the responses of a model with homogeneous firms, in blue, to the model with heterogeneous firms, in red, for two different levels of wage rigidity. The solid lines denote a regime with less sticky wages than denoted by the dotted lines.

The upper left panel plots the response in aggregate profits for the different model specifications. Clearly, imposing firm heterogeneity, profits respond more for any given value of wage rigidity. Moreover, there are levels of wage rigidity for which a model with homogeneous firms produces counter-cyclical profits, while an environment with heterogeneity in productivity achieves pro-cyclical profits. Hence, cyclicality in aggregate profits appears to depend on the market structure, specifically on the market concentration. The higher the market concentration in a sector, the more pro-cyclical becomes the response in aggregate profits. The reason is that heterogeneous firms face a common wage, yet following a monetary shock large firms will change their prices by less increasing their demand. If the change in demand is sufficiently large, this leads to pro-cyclical profits for the larger firms. As their steady state share of profits is also larger, aggregate profits will ultimately be also pro-cyclical.

Compared to the different responses in aggregate profits, the effect of firm heterogeneity appears to be rather small for the other aggregates plotted. Generally, for a higher level of wage rigidity employment and output react stronger as firms enjoy a larger share of rent which increases their incentive to expand employment. Heterogeneity in firms' productivity levels amplifies this effect. Large firms, the ones which are more efficient, raise their prices by less than small firms in response to an increase in marginal cost. Given that their market share is higher, aggregate inflation increases also by less than compared to a setting with homogeneous firms. Consequently, imposing firm heterogeneity, firms face on average a higher demand and increase their output by more. This in turn, reallocates labour to the more productive firms, boosting the response in output. As a result to this reallocation of employees, the labour share decreases. Although, the effect is small, the competition channel might contribute to the widely observed trend of a decline in labour shares (Barkai, 2016; Caballero et al., 2017; De Loecker & Eeckhout, 2017). Intuitively, the reallocation shift is larger for higher wage flexibility as this widens the gap between firms' marginal cost and therefore the productivity advantage of large firms compared to small firms becomes more relevant. While the aggregate effect of oligopolistic competition is rather small, heterogeneous firms clearly respond differently to a monetary policy shock as shown in figure 1.3. The figure plots the impulse response functions for selected firm-level variables. For the same two regimes of wage rigidity it shows the responses for a less productive firm versus a more efficient firm. As already indicated above, profits of the large firm will respond pro-cyclical given a minimum level of wage rigidity. However, as small firms lose market share to larger firms, they can face counter-cyclical profits. The average profit response will ultimately depend on how many firms of each type compete within a sector and how large their endogenous steady-state market shares are. The response in prices is as expected less strong for more productive firms, however, the difference is not large. Recall, that by assumption, the elasticity of substitution is bounded by the elasticity across and within sectors, $\Theta \in [\sigma, \zeta]$. Consequently, sales and subsequently market shares respond more for the dominant firms, which in turn reduces the market power of smaller firms. The competition channel hence, shifts labour from less productive firms to more efficient firms. As already indicated above, the shift of market shares and analogously employment from the small firms to the large firms is stronger if wages are less rigid.

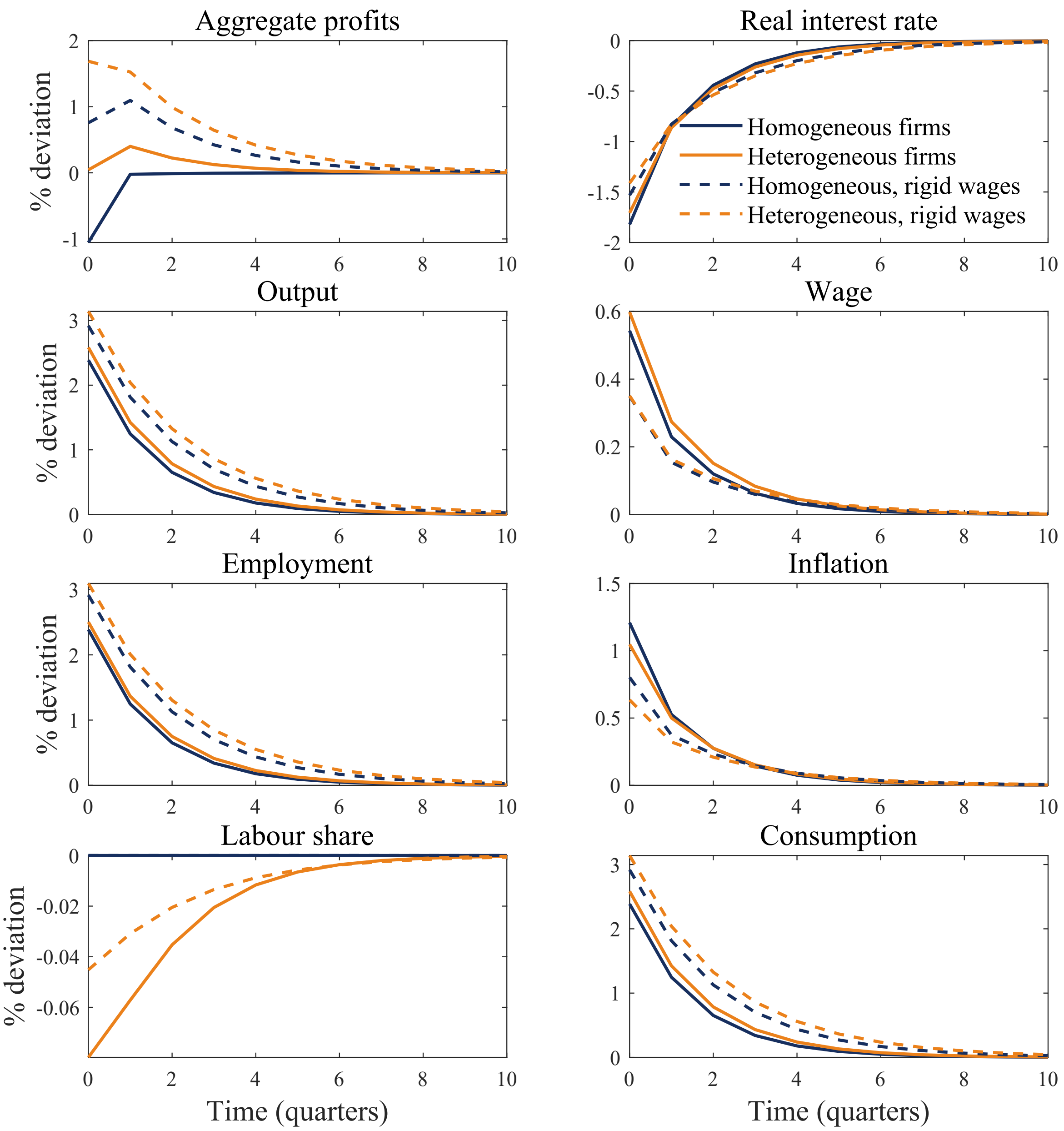

Fig. 1.2 Effect of firm heterogeneity on monetary policy response.

Notes. Impulse response functions after an expansionary one percent shock to the nominal interest rate at $t = 0$. The solid blue line shows the responses of the baseline model without firm heterogeneity. The red line denotes the responses when firms are heterogeneous in productivity. The dashed lines show responses for an increased level of wage rigidity by decreasing the probability of talks breaking down.

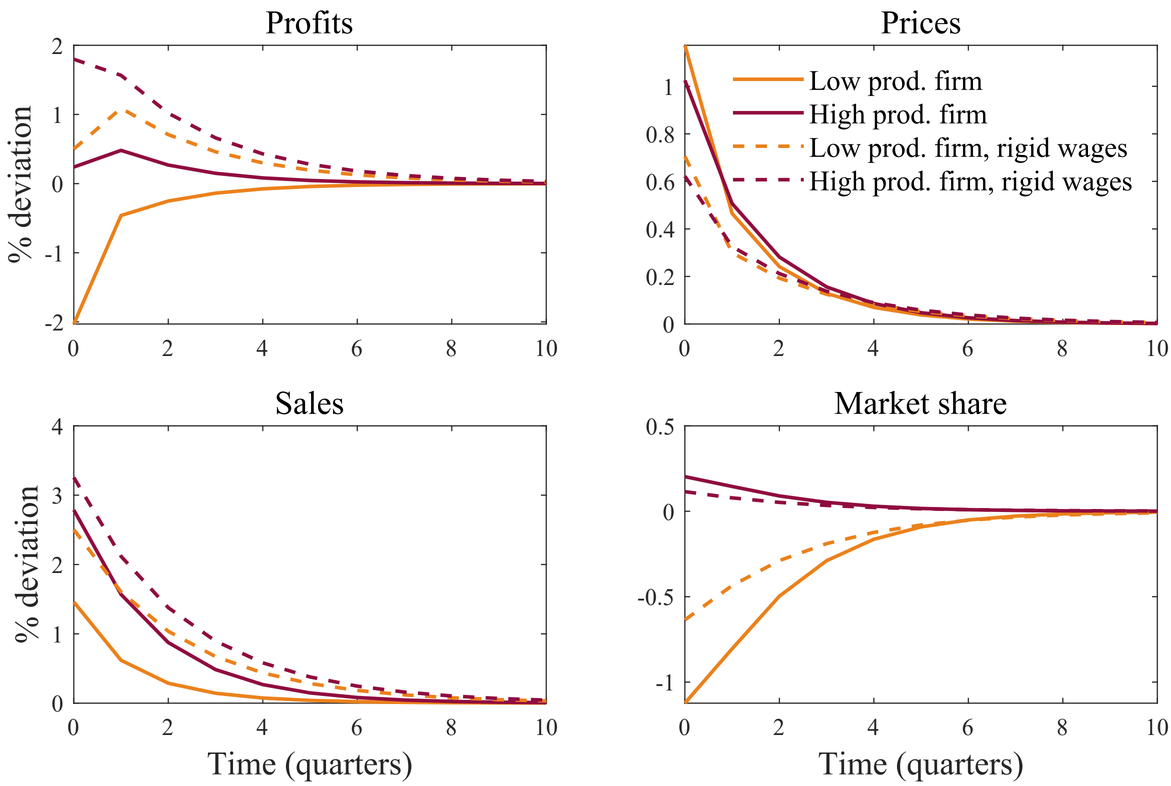

Fig. 1.3 Productivity-specific impulse responses

Notes. Impulse response functions after an expansionary one percent shock to the nominal interest rate at $t = 0$. The solid lines indicate a regime with less rigid wages, whereas the dotted lines denote a regime with higher wage rigidity.

1.6.2 Effect of dynamic entry on monetary policy

Figure 1.4 plots the corresponding impulse response functions for the case of dynamic entry compared to a model with firm heterogeneity but without entry or exit of firms. Two models of dynamic entry are considered, one with symmetric firms and one with firm heterogeneity. Again, all models are calibrated such that they are identical in their steady state values of the main aggregate variables of interest. The most striking result is that dynamic entry seems to strengthen the propagation of a monetary policy shock on output. Pro-cyclical business creation increases the demand for workers which leads to an increase in vacancy postings as shown by the lower left panel. This increases labour market tightness according to equation 1.25 which in turn decreases the vacancy filling rate following equation 1.26. The decrease is due to the concavity of the Cobb-Douglas matching function. Hence, the amount of matches increases by less than the job postings as the number of unemployed workers does not change instantly. Consequently, the hiring rate, shown in the lower right panel, increases and employment rises according to the law of motion defined in equation 1.16. This translates into an increase in output which is higher than in the case of no entry even for homogeneous firms. Due to the assumption that entrants have to wait one period before they produce, the responses of inflation and the real interest rate, respectively, differ significantly only after one quarter. Although, firms raise their prices similarly across models initially, new entrants and consequently a strengthening in oligopolistic competition induces downward pressure on firms' prices. This causes the response in inflation to drop as soon as entrants become productive.

Imposing firm heterogeneity enhances the response of output even further. A larger productivity differential raises the incentive of entering the market as expected profits are higher. Consequently, the immediate response in entrants is much higher for the case of firm heterogeneity as shown in the upper left panel. However, the lower the transition probability to the higher productivity level, the less pronounced is the effect. If the response in the number of entrants is strong enough, this could even lead to a decrease of inflation following an expansionary monetary policy shock after new firms become productive. Hence, pro-cyclical entry and subsequently enhanced competition might contribute to the price puzzle[9] often observed in the data.

Figure 1.5 illustrates the effects of firm heterogeneity and entry at the firm-level in response to an expansionary monetary policy shock. Again, large firms reset their prices by less than small firms and therefore, face a higher demand. Yet, the initial increase in

[9] Refers to a rise (fall) in the aggregate price level in response to a contractionary (expansionary) monetary policy shock.

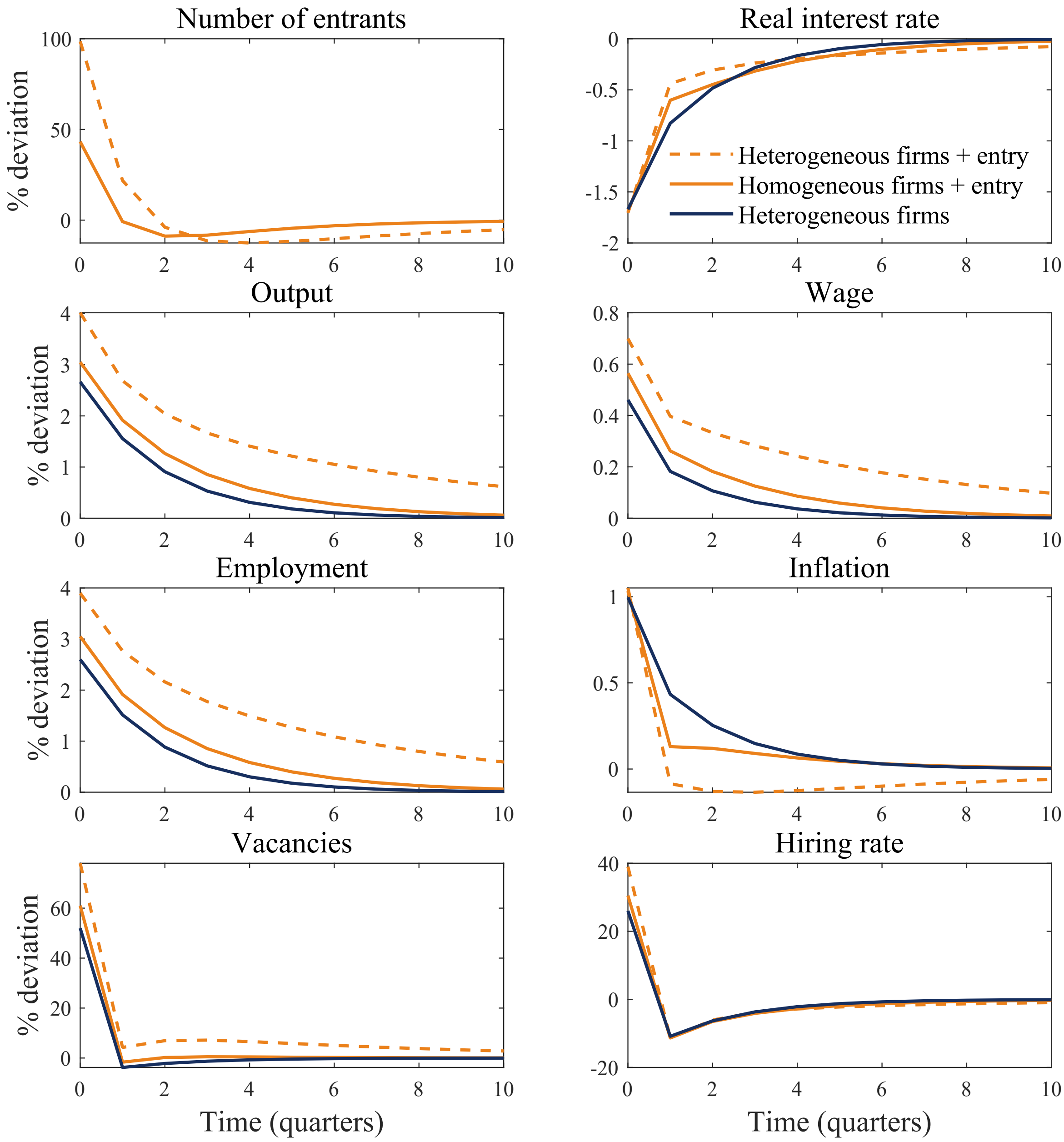

Fig. 1.4 Effect of entry on monetary policy response

Notes. Impulse response functions after an expansionary one percent shock to the nominal interest rate at $t = 0$. The solid red line shows the responses of the model with firm heterogeneity but without entry. The dashed green line denotes the responses when firms are homogeneous in productivity and there is entry. The solid green line shows responses for heterogeneity and entry.

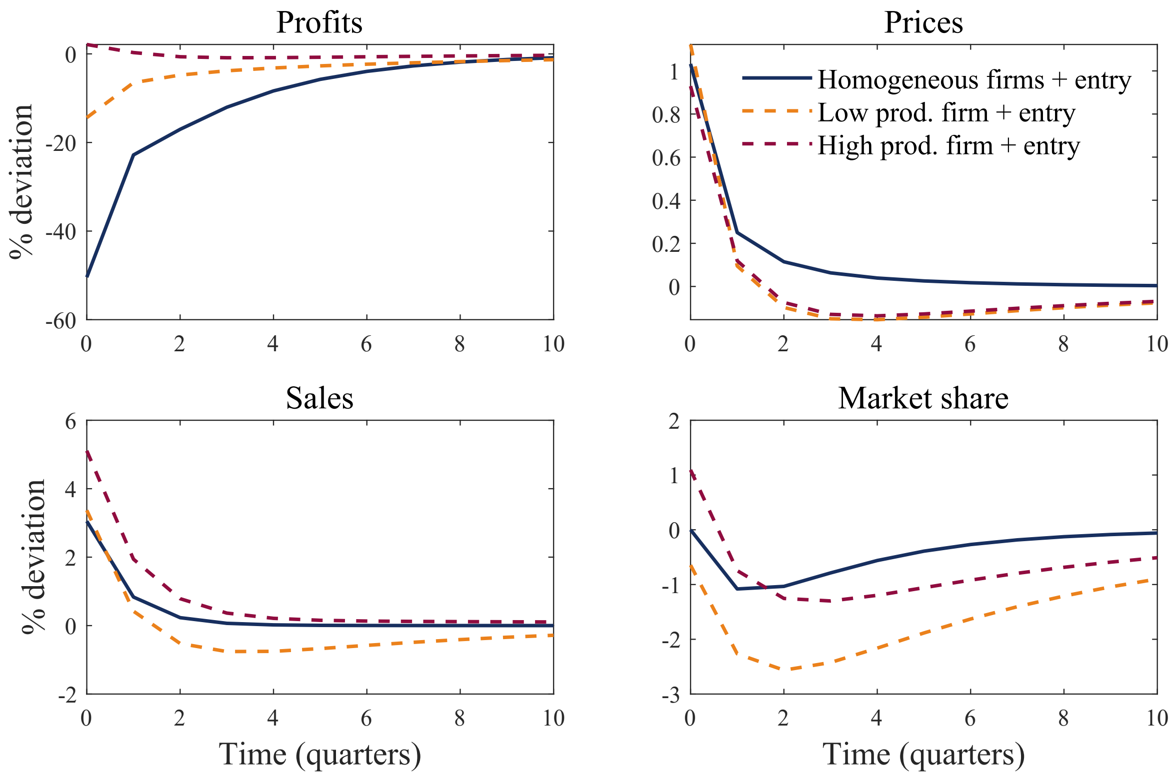

Fig. 1.5 Productivity-specific impulse responses with entry

Notes. Impulse response functions after an expansionary one percent shock to the nominal interest rate at $t = 0$. The solid green line shows the responses of the model with homogeneous firms and entry. The dashed lines show responses of the efficient firms and the less productive firms, respectively.

market share for large incumbents is followed by a decrease due to entry of new firms. Furthermore, entry has a negative impact on firms' profits. The increase in labour demand raises the response in wages, hence decreasing firms' profits. Consequently, in a setting with entry, aggregate profits are becoming counter-cyclical for the same parametrization a model without entry produced pro-cyclical profits.

1.7 Heterogeneous responses to monetary policy: Empirical evidence

This section provides empirical evidence on how the response of firms' sales and operating income after a monetary policy shock varies across firm size as a proxy for productivity. Section 1.7.1 describes the data sources. Section 1.7.2 describes the econometric framework used in order to estimate impulse response functions of firms' sales and operating income to a measure of monetary policy shocks. Section 1.7.3 presents the empirical results and section 1.7.4 checks whether the results are robust to different estimation specifications.

1.7.1 Data description

The empirical specification combines measures of monetary policy shocks and quarterly firm-level data.

Monetary policy shocks. An updated series of Romer & Romer (2004) (henceforth RR) monetary policy shocks is obtained from Wieland & Yang (2016). Their measure of monetary policy shocks is defined as the intended federal funds rate, inferred by quantitative and narrative records, and orthogonalised to internal forecasts prior to the meeting date of the committee. The updated quarterly time series spans the time frame from 1969q1 to 2007q4. The time series stops thereafter due to the binding zero lower bound. I define the time series of monetary policy shocks such that a positive value indicates an expansionary shock which makes the interpretation of regression coefficients more intuitive.

Firm-level data. Firm-level data is drawn from Compustat, a panel for publicly listed U.S. firms. The advantage of using Compustat are threefold: Firstly it offers quarterly data, a high enough frequency to study effects of monetary policy. Secondly, the panel starts in 1961 offering plenty of observations to study within-firm variation. Lastly, it contains a rich set of balance-sheet information. The main drawback is that it excludes private, smaller firms.

The analysis focuses on manufacturing firms corresponding to sub-sectors 311-339 according to the North American Industry Classification System (NAICS). The sample contains active as well as inactive firm in order to avoid any survival bias. Firm size is approximated using information on the total amount of assets per firm (ATQ). Following Crouzet & Mehrotra (2020), the cut-off level for large firms is defined as the 99th percentile of the distribution of assets.[10] The main variables of interest in correspondence to the theoretical model predictions are firms' sales (SALEQ) and inventory (INVTQ) proxying the firms' output as well as operating income before depreciation (OIBDQ) as a measure for firm profits.

1.7.2 Estimation framework

This section shortly outlines the empirical framework used to estimate potential differences in the response of firms to a monetary policy shock relative to their size. The estimation framework is analogous to the local projection method proposed by Jordà (2005). Impulse response functions to a monetary policy shock are estimated using the following specification:

$$\Delta y_{i,t,t+h} = \alpha_i + \alpha_t + \beta_h \epsilon_t^M \mathbb{1}_{\{i \in [99,100]\}} + \sum_{l \in L} (\gamma_l + \delta_l \epsilon_t^M) \mathbb{1}_{\{i \in \mathscr{L}\}} + \Gamma' Z_{i,t-1} + \mu_{i,t} \tag{1.51}$$

where y denotes the variable of interest in logs, i indexes the firm, t is the quarterly date and h is the horizon at which the impulse response is estimated. Firm-level and time fixed effects are denoted by α_i and α_t, respectively. The main coefficient of interest is β_h, measuring the semi-elasticity in y, h quarters after a standardized monetary policy shock ϵ_t^M relative to the benchmark group of the bottom 99% firms with respect to their size.[11] $\mathscr{L}$ refers to the three digit NAICS sub-sector specification and by introducing sub-sector dummies and interactions with the monetary policy shock, I control for sub-sector specific intercepts and slopes. $Z_{i,t-1}$ is a vector of additional firm controls such as leverage and sales growth lagged by one period. Standard errors are clustered in two ways to account for correlation within firms and within quarters.

[10] Results are pretty robust when instead setting the cutoff at the 90th percentile or the 95th percentile.

[11] Recall that the monetary policy shocks are defined such that a positive sign indicates an expansionary shock.

1.7.3 Empirical results

Figure 1.6 plots the estimated semi-elasticity differential β_h for sales, inventory and operating income over the horizon of eight quarters. The estimated responses seem to be mostly in line with the predictions of the theoretical model. The largest firms, which are assumed to be the most productive firms, seem to increase their output significantly more then smaller firms after an expansionary monetary policy shock as suggested by the response in sales and inventory. In fact, the top firms' output grows by roughly 7% more, two quarters after a one standard deviation monetary policy shock. Conditional on firm size being a good proxy for firm productivity the model showed exactly that. The model showed that the increase in households demand is matched by a proportionally larger increase in the sales of large firms compared to small firms. However, empirical estimates are likely to be biased as they include foreign sales, whereas the model is considering monetary shocks in a closed economy. Assuming that foreign sales do not change following a national (U.S.) monetary policy shock estimates are measured conservatively as this would induce a downward bias.[12]

Although, operating income also increases on average more for large firms directly after an expansionary monetary policy shock, the estimates are not significant in the baseline specification. It is very likely that firm profits exhibit more idiosyncratic within firm variance than sales or inventory as they are also affected by the cost side which would increase standard errors. Furthermore, in the baseline specification we compare the top 1% of manufacturing firms with the bottom 99% across all sectors. Clearly, this is an oversimplified and too aggregated view of the oligopolistic competition firms are facing. In order to address this issue, the following subsection also estimates more granular specifications.

1.7.4 Robustness

In order to check the robustness of the results, the strategy is twofold: First, a more granular definition of size indicators is used. Above, the percentiles for firm size were determined using the entire universe of manufacturing firms. However, as sectors are unlikely to be symmetric in the distribution of firms' total asset holdings, the effect is mostly explained by competition across sectors opposed to within sectors as proposed by the model. Hence,

[12] Yet, it is likely that foreign sales would increase following an expansionary monetary shock depreciating the national currency which would reduce this bias and depending on which effect is larger could eventually induce an upward bias. Unfortunately, Compustat firm-level data on sales does not distinguish between national and international sales to control for any bias.

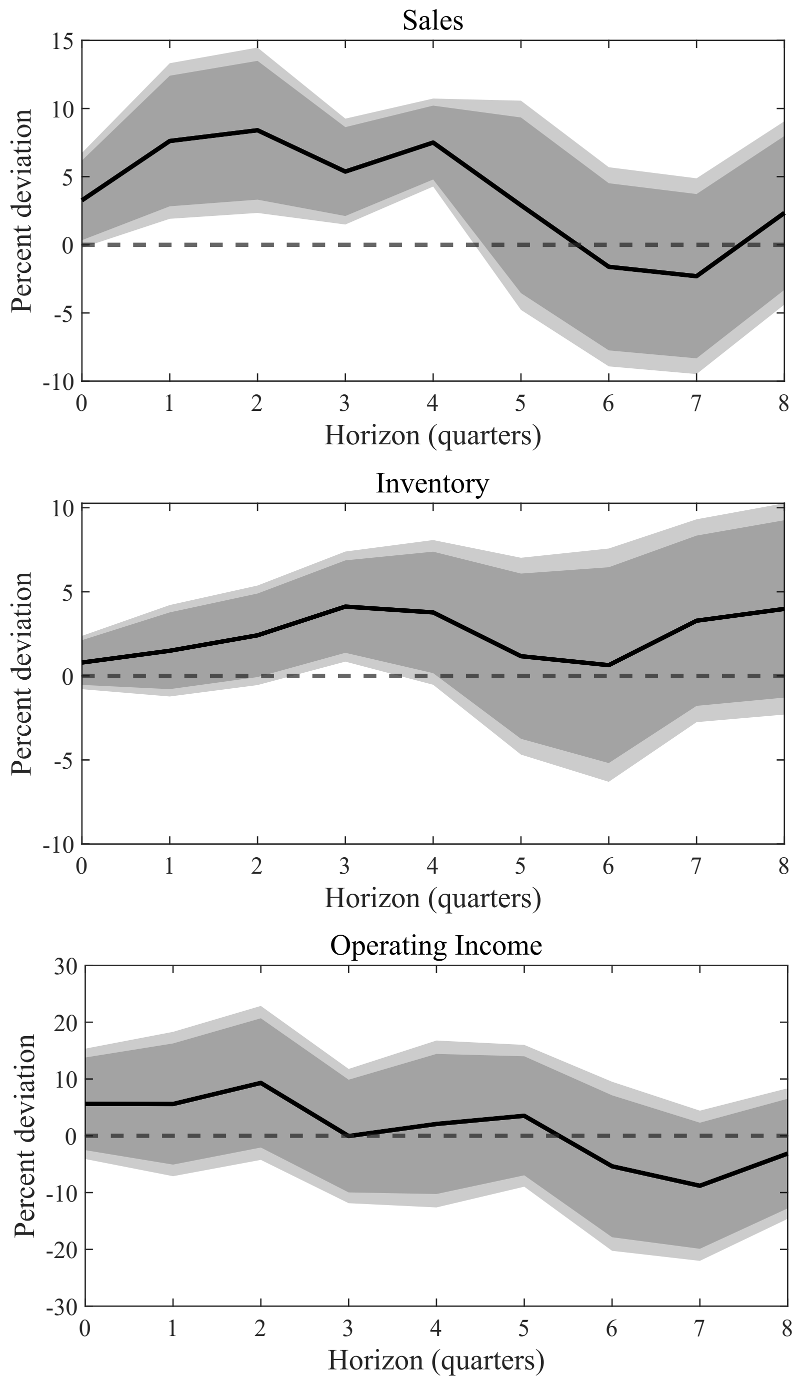

Fig. 1.6 Estimated sales and income response for top 1% firms vs. the rest

Note: Estimated response of sales and operating income for the top 1% firms in size relative to the bottom 99% to Romer & Romer (2004) monetary policy shocks using local projections. The shocks are normalized such that a positive sign denotes an expansionary shock. Standard errors are clustered at the firm-level and over time. The dark and light shaded areas represent the 90% and 95% confidence interval, respectively.

Table 1.2 Local projection results

Estimation specification	Quarter (h)				
	0	1	2	3	4
	Panel A: Sales projections				
Baseline	2.79	7.08***	7.93***	5.60***	7.01***
NAICS sub sectors	2.22	3.12	3.89*	1.41	5.35*
Gertler & Karadi (2015) (GK) shocks	6.35*	5.67**	4.47**	4.08*	5.70
NAICS sub sectors and GK shocks	1.78**	2.19*	1.7	1.16	1.37
	Panel B: Operating income projections				
Baseline	3.28	2.22	7.03	-2.07	-2.14
NAICS sub sectors	2.48	1.97	10.07**	8.17**	10.33**
Gertler & Karadi (2015) (GK) shocks	7.33	4.64	4.17	5.05	6.77
NAICS sub sectors and GK shocks	1.32	1.60	0.95	-0.28	1.18

Notes. Local projection coefficients of interaction between size indicator and standardized monetary policy shock measure in percent. Controlled for firm, industry and time fixed effects. Standard errors are robust to firm heteroskedasticity and autocorrelation. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

an alternative size indicator is calculated at three-digit NAICS sub-sector level. Second, an alternative proxy for monetary policy shocks is used. Gertler & Karadi (2015) (henceforth GK) offer a high-frequency approach of identifying shocks to the federal funds rate.

Table 1.2 lists the results of the alternative specifications over an horizon of four quarters. Defining size indicators at the three-digit NAICS level results in slightly lower and less significant estimates for the sales differential. In contrast, estimates for the operating income differential over time, are larger and significant two quarters after the monetary policy shock.

When using GK's monetary policy shock series instead of RR's, the sales response estimates are qualitatively in line and again slightly lower when using sub-sector size cutoffs. However, while the estimates for operating income show the correct sign for all but one horizon, they are not significant at standard levels. Overall, the data suggests that large firms' sales react stronger relative to the response of small firms in the aftermath of a monetary policy shock. This is in line with the predictions of the theoretical model above. However, while the point estimates of the response in operating income are mostly in line with the model predictions, they do not appear to be robust.

1.8 Conclusion

This paper presents a New Keynesian model with strategically interacting firms and search and matching frictions in the labour market. In a setting with firm heterogeneity, more productive firms exhibit a weaker response in their pricing after a change in marginal costs. Hence, oligopolistic competition induces higher price rigidity for large firms relative to small firms. As a consequence, the pro-cyclical response in firms' sales is larger for more productive firms as they face a higher (lower) demand after an expansionary (contractionary) monetary policy shock. Local projections using Compustat firm-level data and different measures of monetary policy shocks support those predictions and appear to be robust. In turn, this leads to a pro-cyclical response in large firms' market and employment shares. As large firms are more productive, this shift also reduces the aggregate labour share following an expansionary monetary policy shock. Hence, aggregate output responds more than in the case of homogeneous firms due to re-allocating labour from small to large, more productive, firms. This is in line with a very recent paper by Baqaee et al. (2021) who provide evidence for a pro-cyclical response in aggregate TFP and re-allocations to high-markup firms. Furthermore, I show that cyclicality in profits ultimately depends on the productivity differential between firms. More specifically, under heterogeneity, less rigid wages are necessary to obtain a pro-cyclical response in firm profits. Allowing for dynamic entry strengthens the response in output due to an increase in labour demand and enhances the effect of firm heterogeneity.

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Appendix A

Appendix for Chapter 1

A.1 Competitive labour market

As in the standard NK model, there is a representative household obtaining utility from consumption and disutility from supplying labour, which are additively separable. The problem is constrained by the nominal budget flow equation of the household

$$\max_{C_t, B_{t+1}, L_t} E_0 \Big[\sum_{t=0}^{\infty} \beta^t \left(u(C_t) - v(L_t) \right) \Big],$$

s.t.

$$C_t P_t + B_{t+1} = B_t(1+i_t) + w_t P_t L_t + \pi_t,$$

where w_t denotes real wages and π_t denotes the firm profits received. The FOCs are

Euler equation:

$$u'(C_t) = \beta E_t \Big[(1+i_t) \frac{P_t}{P_{t+1}} u'(C_{t+1}) \Big], \tag{A.1}$$

Labour supply:

$$v'(L_t) = u'(C_t) w_t, \tag{A.2}$$

with

$$v(L_t) = \psi \frac{L_t^{1+\eta}}{1+\eta} \tag{A.3}$$

where η is the Frisch elasticity of labour supply and ψ the weight of disutility of labour. In the calibration for figure 1, I assume $\eta = 1.5$ and $\psi = 1$. The labour demand is coming from the intermediate good producers' profits maximization.

A.2 Endogenous markup derivation

Derivation of markup for $\zeta \to \infty$[1]:

$$\max_{Y^j_{t+s}(i)} \sum_{s=0}^{\infty} E_t \left[Q_{t,t+s} \left(P_{t+s}(i) Y^j_{t+s}(i) - \frac{w_{t+s}}{A_{t+s}} P_{t+s} Y^j_{t+s}(i) - \frac{\theta_p}{2} \left(\frac{P_{t+s}(i)}{P_{t+s-1}(i)} - 1 \right)^2 P_{t+s}(i) Y^j_{t+s}(i) \right) \right]$$

$$s.t. \qquad P_t(i) = \left(\frac{Y_t(i)}{Y_t} \right)^{-1/\sigma} P_t = \left(\frac{Y^j_t(i) + Y^{-j}_t(i)}{Y_t} \right)^{-1/\sigma} P_t$$

FOC:

$$\begin{aligned} & P_t(i) - \frac{1}{\sigma} \left(\frac{n Y^j_t(i)}{Y_t} \right)^{-1/\sigma - 1} P_t Y^j_t(i) \frac{1}{Y_t} - \frac{w_t}{A_t} P_t - \theta \left(\frac{P_t(i)}{P_{t-1}(i)} - 1 \right) (-1/\sigma) \left(\frac{n Y^j_t(i)}{Y_t} \right)^{-1/\sigma - 1} P_t Y^j_t(i) \frac{1}{Y_t} \frac{1}{P_{t-1}} \\ & - \frac{\theta_p}{2} \left(\frac{P_t(i)}{P_{t-1}(i)} - 1 \right)^2 P_t(i) + \frac{\theta_p}{2} \left(\frac{P_t(i)}{P_{t-1}(i)} - 1 \right)^2 \frac{1}{\sigma} \left(\frac{n Y^j_t(i)}{Y_t} \right)^{-1/\sigma - 1} P_t Y^j_t(i) \frac{1}{Y_t} \\ & - \theta_p E_t \left[Q_{t,t+1} \left(\frac{P_{t+1}(i)}{P_t(i)} - 1 \right) \right] P_{t+1}(i) Y^j_{t+1}(i) \frac{P_{t+1}}{P^2_t(i)} \frac{1}{\sigma} \left(\frac{n Y^j_t(i)}{Y_t} \right)^{-1/\sigma - 1} P_t \frac{1}{Y_t} = 0 \end{aligned}$$

Re-substituting the expression for $P_t(i)$ and re-writing $\frac{P_t(i)}{P_{t-1}(i)}$ as π_t, we can simplify the expression as follows:

$$\begin{aligned} & P_t(i) - \frac{1}{\sigma} \frac{1}{n_t} P_t(i) - \frac{w_t}{A_t} P_t - \frac{1}{\sigma} \frac{1}{n_t} \theta_p (\pi_t(i) - 1) \pi_t(i) \\ & - \frac{\theta_p}{2} (\pi_t(i) - 1)^2 P_t(i) + \frac{1}{\sigma} \frac{1}{n_t} \frac{\theta_p}{2} (\pi_t(i) - 1)^2 P_t(i) \\ & - \theta_p E_t \left[Q_{t,t+1} (\pi_{t+1} - 1) \pi^2_t \frac{Y^j_{t+1}}{Y^j_t} \right] P_t(i) = 0 \end{aligned}$$

Solving for $P_t(i)$ we get:

$$P_t(i) = \mu_t(i) \frac{w_t}{A_t} P_t$$

$$\mu_t(i) = \frac{\sigma n_t(i)}{(\sigma n_t(i) - 1) \left[1 - \frac{\theta_p}{2} (\pi_t(i) - 1)^2 \right] + \theta_p \pi_t(i) (\pi_t(i) - 1) - \Gamma_t(i)}$$

$$\Gamma_t(i) = \theta_p E_t \left[Q_{t,t+1} \pi_{t+1}(i)^2 (\pi_{t+1}(i) - 1) \frac{Y_{t+1}(i) n_t}{Y_t(i) n_{t+1}} \right]$$

[1]For $\zeta < \infty$ analogously, just note that market share $s^j(i)_t \left(\frac{P^j_t(i)}{P_t(i)} \right)^{1-\zeta}$

A.3 Equilibrium conditions

Combining everything gives us the set of equations in order to solve for the steady state:

Household's problem:

$$u'(C_t) = \beta E_t \Big[(1+i_t) \frac{P_t}{P_{t+1}} u'(C_{t+1}) \Big] \tag{A.4}$$

Monetary authority:

$$ln(R_t/R_{ss}) = \rho_R ln(R_{t-1}/R_{ss}) + (1-\rho_R)[\theta_\pi ln(\pi_t/\pi_{ss}) + \theta_Y ln(Y_t/Y_{ss}) + v_t], \tag{A.5}$$

from firms' problem:

$$P_t^{j,s}(i) = \mu_t^{j,s}(i) \frac{\vartheta_t}{z^s(i) A_t} P_t, \text{ for s } \in \{1,2,...,S\} \tag{A.6}$$

where

$$\begin{aligned}
\mu_t^{s,j}(i) &= \frac{\Theta_t^j(i)}{(\Theta_t^j(i)-1)\left[1-\frac{\theta_p}{2}(\pi_t(i)-1)^2\right] + \theta_p \pi_t(i)(\pi_t(i)-1) - \Gamma_t(i)}, \\
\Theta_t^{s,j}(i) &= \left[\frac{1}{\zeta} + (\frac{1}{\sigma} - \frac{1}{\zeta}) s_t^{s,j}(i)\right]^{-1}, \\
\Gamma_t(i) &= \theta_p \mathbb{E}_t \left[m_{t,t+1} \pi_{t+1}(i)^2 (\pi_{t+1}(i)-1) \frac{y_{t+1}^{s,j}}{y_t^{s,j}} \right],
\end{aligned} \tag{A.7}$$

Dynamic entry of firms:

$$\begin{aligned}
v_t^s = \mathbb{E}_t \left[m_{t,t+1} \left(p_u(\pi_{t+1}^{s+1} + v_{t+1}^{s+1}) + p_l(\pi_{t+}^{s-1} + v_{t+1}^{s-1}) + (1-p_u-p_l)(\pi_{t+1}^s + v_{t+1}^s) \right) \right] \\
\text{for } s \in \{1,2,...,S\}
\end{aligned}, \tag{A.8}$$

and

$$v_t^E = f^E \tag{A.9}$$

DMP labour market with AOB:

$$L_t = (\rho + x_t) L_{t-1} \tag{A.10}$$

$$Q_t(J_t - \kappa) = s \tag{A.11}$$

$$J_t = \vartheta_t - \bar{w}_t + \rho E_t m_{t+1} J_{t+1} \tag{A.12}$$

$$V_t = \bar{w}_t + E_t m_{t+1} \left[\rho V_{t+1} + (1-\rho)(f_{t+1} V_{t+1} + (1-f_{t+1}) U_{t+1}))\right] \tag{A.13}$$

$$U_t = D + E_t m_{t+1} \left[f_{t+1} V_{t+1} + (1-f_{t+1}) U_{t+1}\right] \tag{A.14}$$

$$J_t = \beta_1 (V_t - U_t) - \beta_2 \phi_t + \beta_3 (\vartheta_t - D_t), \tag{A.15}$$

with $\beta_i = \alpha_{i+1}/\alpha_i$ for $i \in 1,2,3$

$$\alpha_1 = 1 - \delta + (1-\delta)^M,$$
$$\alpha_2 = 1 - (1-\delta)^M,$$
$$\alpha_3 = \alpha_2 \frac{1-\delta}{\delta} - \alpha_1,$$
$$\alpha_4 = \frac{1-\delta}{2-\delta} \frac{\alpha_2}{M} + 1 - \alpha_2,$$

$$Q_t = \eta_m \Xi_t^{-\eta} \tag{A.16}$$

$$\Xi_t = \frac{v_t L_{t-1}}{1 - \rho L_{t-1}} \tag{A.17}$$

$$Q_t = \frac{x_t}{v_t} \tag{A.18}$$

$$f_t = \frac{x_t L_{t-1}}{1 - \rho L_{t-1}} \tag{A.19}$$

Market clearing:

$$Y_t = N_t^{\frac{1}{1-\zeta}} \left(\sum_{s=1}^{S} \sum_{j=1}^{N_t^s} (z^s h_t^{j,s})^{\frac{\zeta-1}{\zeta}} \right)^{\frac{\zeta}{\zeta-1}} \tag{A.20}$$

$$1 = \sum_{s=1}^{S} \frac{N_t^s}{N_t} \left(\frac{P_t^s}{P_t} \right)^{1-\zeta} \tag{A.21}$$

$$Y_t = C_t + \frac{\theta_p}{2} (\pi_t - 1)^2 Y_t + (s/Q_t + \kappa) x_t L_{t-1} + N^E f^E \tag{A.22}$$

$$H_t = L_t \tag{A.23}$$

A.4 Additional Figures

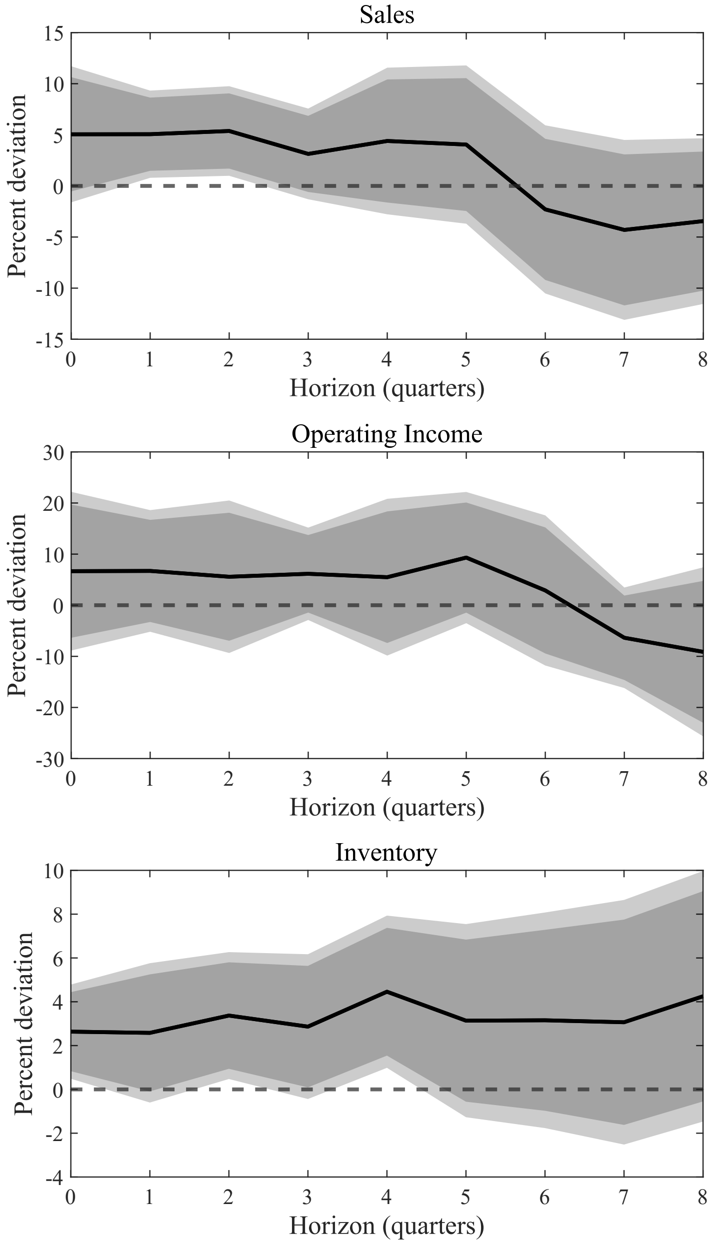

Fig. A.1 Estimated sales and income response for top 1% firms vs. the rest

Note: Estimated response of sales and operating income for the top 1% firms in size relative to the bottom 99% to GK monetary policy shocks using local projections. The shocks are normalized such that a positive sign denotes an expansionary shock. Standard errors are clustered at the firm-level and over time. The dark and light shaded areas represent the 90% and 95% confidence interval, respectively.