Monetary Policy and Heterogeneous Plants*

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Abstract

The paper presents a simple DSGE model that captures plant turnover and its relation with monetary policy. I analytically show that monetary policy has impact on reallocation of heterogeneous plants and inevitably changes the balance between the number of available varieties and aggregate productivity. It is shown that, under demand uncertainty, the gain of stabilization is higher when plant are homogeneous and when higher love for variety is embedded in the economy. The model is extended and calibrated in replicating the US product turnover. It broadly confirms the VAR evidence for the recent US economy followed by a monetary shock.

Keywords: *Monetary policy, entry, firm heterogeneity, product variety, reallocation*

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1 Introduction

Plant birth and death and implied product turnover are a salient feature of modern economy. It is often at the center of policy debate. Their turnover at high frequency is

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often seen as a healthier sign of economy without "sclerosis" (Caballero and Hammour, 2005) and "zombie firms" (Caballero et al., 2008), both of which preventing efficient allocation of resources.[1] This is more so because plant turnover inevitably involves job creation and destruction (Davis and Haltiwanger, 1990; Haltiwanger, 2012).[2] Despite such a widely spread Schumpeterian view, it is surprising to see that there is not enough systematic analysis that sheds light on its relation with monetary policy which has a sizable impact, at any time horizon, not only on firms' entry decision but also their turnover and hence the reallocation of resources. The current paper aims to fill this gap.

For this purpose, I present a New Keynesian model with entry and exit of heterogeneous firms and provide a stark example with which product turnover and implied reallocation is a new motivation for the conduct of monetary policy. The theoretical model shares common features of the DSGE model that embeds firm entry in the literature (Bilbiie et al., 2012; Ghironi and Melitz, 2005; Alessandria and Choi, 2007 and references therein). Firms enter in the market incurring fixed amount of sunk entry cost in terms of labor. Upon entry, they draw a specific productivity level. Due to fixed cost of production which is common for all firms, only a subset of efficient plants produce in monopolistically competitive market. Firms/establishments exit from the market due to exogenous depreciation while their plants can open or close its production lines along the business as described in Hamano and Zanetti (2017). Since the model features wage rigidity and workers face uncertainty about future demand in their wage setting, money is non-neutral and there is a substantial role for monetary policy.

Monetary policy ultimately controls aggregate nominal expenditure and thus profitability for plants. I show that a contractionary monetary policy shock engenders a "cleansing effect" (Caballero and Hammour, 1994). It wipes out inefficient producers and

[1]For instance, the Abe administration in Japan aims to improve the current 4 or 5 % level of annual establishment birth and death rate and to achieve 10 % level.

[2]Using Business Dynamic Statistics (BDS) data from 1980 to 2009 for US economy, Haltiwanger (2012) documents that annual job creation by new firms and establishment amounts to 6.3 % in total job creation and annual job destruction by firm and establishment exits account for 5.3 % in total job destruction.

improves aggregate productivity due to the resulted reallocation. Contrary, an expansionary monetary shock allows *zombies* to survive and reduces aggregate productivity. Monetary policy unavoidably changes the balance between extensive margins and their prices (efficiencies) in the economy. I derive the optimal monetary policy rules that restore the allocation under flexible wages and analytically show a *trade-off* that the central bank is thus facing in closing demand gap. It is shown that the gain of stabilization is higher when such a trade-off is less severe, namely when the love for variety is high and heterogeneity among plants is low.

The baseline model is simple enough and allow to have a closed form solution. In the following section, I extend the model with more realistic features and calibrate it to show quantitatively the implication of a contractionary monetary policy shock. With numerical exercises, I find that depending on the extent of entry adjustment cost, the "insulation effect" (Caballero and Hammour, 1994; Hamano and Zanetti, 2017) of entry on destruction margins comes into play: a massive fall in entry today insulates destruction not only on impact but also for subsequent future periods. Along the transitory dynamics, a significantly lower destruction following a monetary contraction and thus lower average productivity level are observed overturning the initial rise in destruction and disinflation.[3] Furthermore, I document empirical evidence that links monetary policy shock to establishment birth and death as well as total factor productivity for the recent US economy. The VAR evidence is found to be broadly consistent with the dynamics implied by the theoretical model.

While the current paper explores the relation between monetary policy and product turnover and its resulted reallocation effect, the relation between monetary policy and firm entry has been investigated in the literature. Bilbiie et al. (2007) derive a Phillips curve with firm entry and find the optimal monetary policy that stabilizes producer price inflation at zero. Bilbiie et al. (2014) analyze the optimal Ramsey policy and find the

[3]Caballero and Hammour (2005) call such recovery phases characterized with lower destruction rather than higher entry as "reversed-liquidationist view" which works against to the original Schumpeterian creative destruction. Hamano and Zanetti (2017) also confirm cumulatively low destruction following a recessionary productivity shock.

optimal long run inflation rate positive with empirically plausible values of love for variety. Lewis and Poilly (2012) introduce nominal wage rigidity as well as price rigidity and compare different specifications in reproducing empirically consistent markup fluctuations. With entry cost paid in capital goods and price rigidity, Bergin and Corsetti (2008) derive a similar welfare metric and show a new motivation for monetary authority in stabilizing extensive margins. All these papers, however, remain silent about the endogenous product destruction and its resulted reallocation and thus incapable to investigate its relation with monetary policy.[4] With heterogeneous firms and their endogenous destruction, whose mechanism is however different from the current paper, Totzek (2009) investigates the implication of monetary shock in a DSGE model and finds similar quantitative results. Introducing the nominal rigidities in the form of menu costs into the theoretical framework of Lentz and Mortensen (2005), Oikawa and Ueda (2018) analyze the reallocation effect of money growth. Finally, in open economy, Cacciatore and Ghironi (2014) investigate the Ramsey optimal monetary policy and its interaction with *international* reallocation of heterogeneous firms in exporting markets.

The paper is organized as follows. Section 2 provides a VAR evidence about establishment turnover for the recent US economy. The baseline model is presented in Section 3. In Section 4, I explore the monetary policy shock on product turnover and resulted reallocation effect. The optimal policy and its welfare gain is also discussed. The model is extended to have more realistic features and calibrated in Section 5. Finally Section 6 concludes.

[4] In open economy context, Bergin and Corsetti (2015) analyze the specialization across industries and hence dynamics of comparative advantage across countries due to the terms of trade fluctuations triggered by monetary policy. Hamano and Picard (2017) investigate the optimal exchange rate system with firm entry and show a higher welfare gain derived from fixed exchange rate system under lower preference for variety. Cacciatore et al. (2016) analyze the interaction between product and labor market (de)regulation and the optimal Ramsey policy in a monetary union.

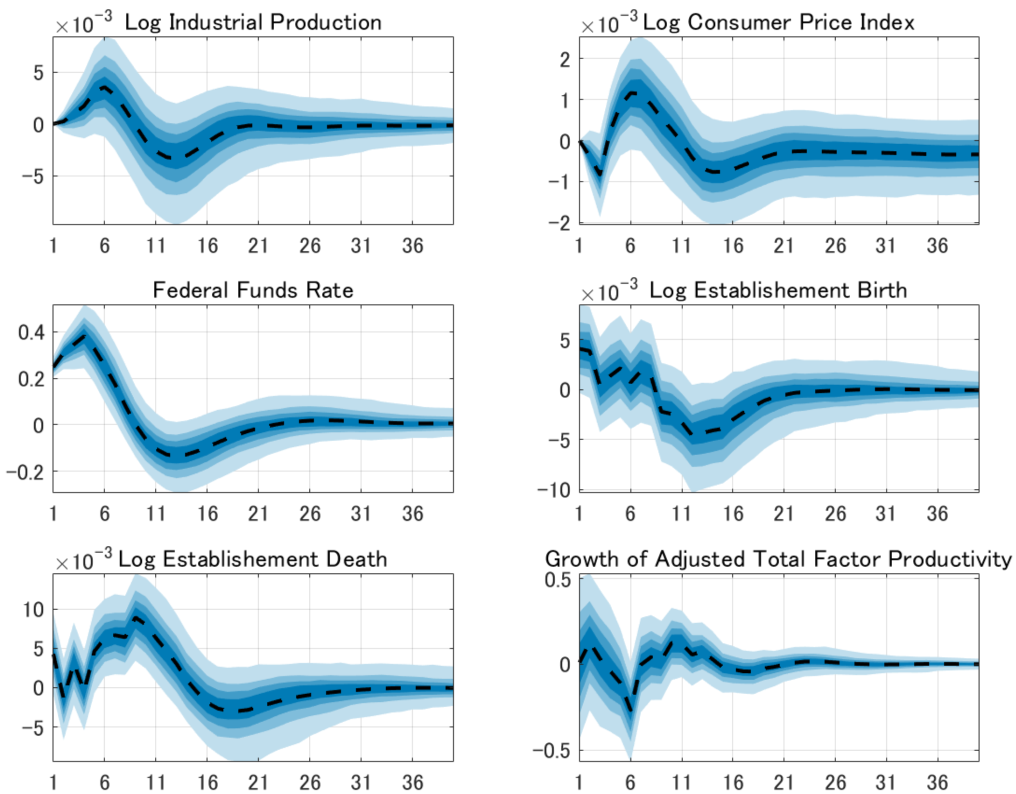
2 VAR Evidence

What would happen for entry, exit and reallocation following a monetary shock? A VAR evidence is provided for the US economy. Variables included are the log of industrial production index, log of consumer price index, global commodity price index and the effective federal funds rate. In addition, I include the log of establishment birth, establishment death taken from Business Employment Dynamics. The growth of utilization-adjusted total factor productivity, which is assumed to capture the productivity fluctuation due to the reallocation of resources among producers, taken from Fernald's web site (Fernald, 2012) and also put in the system. The detail about data sources is found in Appendix A. The sample periods covered is 1992Q3 to 2017Q1. In identification, I use Cholesky restriction and follow Christiano et al. (1999)'s "recursiveness" assumption. Bergin and Corsetti (2008) include "entry" (net business formation or new incorporation in their paper) at the end of Christiano et al. (1999)'s ordering of variables. The exact ordering considered here is thus log of industrial production index, log of consumer price index, global commodity price index, the effective federal funds rate, establishment birth, establishment death and the growth of adjusted total factor productivity. The number of lags is 4.[5]

Panels in Figure 1 provide the impulse response functions (IRFs) for each variable following a contractionary monetary policy shock together with 30%, 50%, 68% and 90% bootstrap confidence bands. Contrary to the classical evidence presented in Christiano et al. (1999), contractionary monetary shock is expansionary in short run using the recent US data as documented in Gertler and Karadi (2015) and Ramey (2016). On the other hand, the IRF of establishment birth decreases gradually after a short-lived expansionary period while the IRF of the establishment death increases gradually and peaks out and then *decreases* for several quarters as the impact of the shock dissipates. Total factor productivity slowdowns and recovers quickly within the first several quarters and then gradually improves showing a wedge-shaped pattern. Observe that the phases of TFP improvement roughly correspond to the periods of lower establishment entry and higher

[5] Lewis and Poilly (2012) find a similar VAR evidence using the same sample period as Bergin and Corsetti (2008) while in ordering they include net business formation before the monetary shock.

Figure 1: Monetary Policy Shock, Establishment Turnover and Reallocation Effect: a VAR evidence



Effects of unanticipated monetary policy shock, multivariate VAR, 1992Q3-2017Q1. Gray bands are 30%, 50%, 68% and 90% bootstrap confidence bands.

establishment death. I perform a similar exercise with establishment openings and closings that include temporally shut down and reopenings. The result is found in Appendix B and found to be very similar to Figure 1. Using the same establishments turnover data at BED, Uusküla (2016) also finds a similar VAR evidence. Finally, note that price level raises after a contractionary monetary shock in short run. The VAR evidence here shares thus the "price puzzle"(Sims, 1992; Eichenbaum, 1992) even with the inclusion of commodity price which is not presented in Figure 1.

As argued in Hamano and Zanetti (2017), "exit" as well as entry in extensive margins can be sizable in business cycle.The VAR exercise here confirms such a pattern. Furthermore, it points out systematic relation between establishment turnover and reallocation induced by a monetary policy shock. In Section 5, I present a model to replicate the IRFs found in this section. But before jumping to the quantitative analysis, I present a simple model to shed light on the relation between monetary policy and plant heterogeneity.

3 The Model

There is a unit mass of households each of which provides a differentiated labor service. Assuming wages are set one period in advance, labor supply should adjust following a demand shock that is unknown at the timing of wage setting. For simplicity, each firm/establishment/plant is assumed to produce one product variety which is imperfectly substituted.[6] Plants are heterogeneous in terms of their specific productivity level and they are resulted from forward looking investment and depreciated exogenously. On the other hand, plants can be shut down and reopened. The number of firms (each of which having one production plant) are denoted with N_t while the number of plants that engage in production activity are denoted with S_t at period t. Money exists just as a unit of account. However, because of nominal rigidity, money is non neutral. The model is simple enough and allow to have a closed form solution.

3.1 Households

The representative household maximizes her life time utility, $E_t \sum_{s=t}^{\infty} \beta^{s-t} U_t$, where β $(0 < \beta < 1)$ is exogenous discount factor. Utility of individual household j at time t depends on consumption $C_t(j)$ and labor supply $L_t(j)$ as follows

$$U_t(j) = \alpha_t \ln C_t(j) - \eta \frac{[L_t(j)]^{1+\varphi}}{1+\varphi},$$

where α_t is a stochastic demand shifter at time t. The parameter η represents the degree of (un)satisfaction in supplying labor while φ measures the inverse of the Frisch elasticity

[6] I do not model firms having multiple establishments and/or multiple plants. However, it is possible to interpret the model as if there were one large firm that has multiple production lines. See also Chugh and Ghironi (2015) and Hamano and Zanetti (2017).

of labor supply.

Consumption basket is defined as

$$C_t(j) = \left(\int_{\varsigma \in \Omega} c_t(j, \varsigma)^{1-\frac{1}{\sigma}} \, d\varsigma \right)^{\frac{1}{1-\frac{1}{\sigma}}} .$$

Only a subset of goods is available from the total universe of goods, Ω. $c_t(j, \varsigma)$ represents the demand addressed for individual product variety indexed by ς. $\sigma\,(> 1)$ denotes the elasticity of substitution among differentiated goods.

The optimal consumption for each variety is found to be

$$c_t(j, \varsigma) = \left(\frac{p_t(\varsigma)}{P_t} \right)^{-\sigma} C_t(j).$$

Price index that minimizes the nominal expenditure is given by

$$P_t = \left(\int_{\varsigma \in \Omega} p_t(\varsigma)^{1-\sigma} \, d\varsigma \right)^{\frac{1}{1-\sigma}} .$$

3.2 Production Decision and Pricing

There is a mass of H_t new entrants. Upon entry, firms draw their specific productivity level z from a distribution $G(z)$ on $[z_{\min}, \infty)$. $G(z)$ represents the productivity distribution of all firms. Prior to entry, these firms face sunk entry cost. They should hire $f_E = l_{E,t}$ amounts of labor which is composed of imperfectly differentiated labor services (indexed by j) such that

$$l_{E,t} = \left(\int_0^1 l_{E,t}(j)^{1-\frac{1}{\theta}} \, dj \right)^{\frac{1}{1-\frac{1}{\theta}}} , \tag{1}$$

where θ represents the elasticity of substitution among labor services. f_E is assumed to be exogenous. Total cost in creating a firm is thus $\int_0^1 l_{E,t}(j) W(j) \, dj$. Cost minimization yields the following labor demand for type i labor:

$$l_{E,t}(j) = \left(\frac{W_t(j)}{W_t} \right)^{-\theta} l_{E,t}, \tag{2}$$

where W_t denotes the corresponding wage index which is

$$W_t = \left(\int_0^1 W_t (j)^{1-\theta} \, dj \right)^{\frac{1}{1-\theta}}.$$

Only a subset of plants whose productivity level z is above the cutoff level $z_{S,t}$ produces by charging sufficiently lower prices and earning positive profits despite the existence of fixed operational cost f. For the scale of production, the firm that happens to draw a particular productivity level z demands $l_t(z)$ amount of labor as input in producing $y_t(z)$ amount of goods, that is referred as intensive margins. Production function of the firm with productivity level z is thus

$$l_t(z) = \frac{y_t(z)}{z} + f.$$

In the above expression, both variable and fixed cost for production are composed from imperfectly substituted labor as is the case for entry cost. $l_t(z)$ is thus defined as

$$l_t(z) = \left(\int_0^1 l_t(z, j)^{1-\frac{1}{\theta}} \, dj \right)^{\frac{1}{1-\frac{1}{\theta}}},$$

and the demand for type j labor by the firm with productivity level z is given by

$$l_t(z, j) = \left(\frac{W_t(j)}{W_t} \right)^{-\theta} l_t(z).$$

Each firm faces a residual demand curve with constant elasticity σ. The production scale is thus determined by demand and the profit maximization of the plant with productivity level z yields the following optimal pricing:

$$p_t(z) = \frac{\sigma}{\sigma - 1} \frac{W_t}{z}.$$

Finally, using the demand functions found previously and the symmetry among households in equilibrium and denoting the aggregate consumption as $C_t = \int_0^1 C_t(j) \, dj$, we can write profits $D_t(z)$ of the firm with productivity level z as

$$D_t(z) = \frac{1}{\sigma} \left(\frac{p_t(z)}{P_t} \right)^{1-\sigma} P_t C_t - f W_t.$$

Due to the presence of fixed operational cost for production f, however, the plant with productivity level z may not produce and shut down her production facilities.

3.3 Firm Averages

Given a distribution $G(z)$, a mass of N_t firms has a distribution of productivity levels over $[z_{\min}, \infty)$. Among these firms, a subset $S_t = [1 - G(z_D)] N_t$ number of plants produces. Following Melitz (2003), the average productivity level $\widetilde{z}_{S,t}$ is defined for active producers as follows

$$\widetilde{z}_{S,t} \equiv \left[\frac{1}{1 - G(z_{S,t})} \int_{z_{S,t}}^{\infty} z^{\sigma-1} dG(z) \right]^{\frac{1}{\sigma-1}}.$$

This average productivity level $\widetilde{z}_{S,t}$ summarizes all the information about the distribution of productivities for producers. Given this average, the average price and the average real profits are defined as $\widetilde{p}_{S,t} \equiv p_t(\widetilde{z}_{S,t})$ and $\widetilde{D}_{S,t} \equiv D_t(\widetilde{z}_{S,t})$, respectively.

3.4 Firm Entry and Exit

New entrants need one time period to built their production plants. Firm entry takes place until the expected value of entry is equalized with entry cost, leading to the following free entry condition:

$$\widetilde{V}_t = f_E W_t \tag{3}$$

where $\widetilde{V}_t$ is the expected value of entry which is discussed below. For simplicity, firms' production plants are assumed to depreciate 100 % after one period whether they actually produce or not. This extreme assumption will be replaced by a more realistic motion of firms in the following section.

3.5 Parametrization of Productivity Draws

The following Pareto distribution for $G(z)$ is considered:

$$G(z) = 1 - \left(\frac{z_{\min}}{z}\right)^{\kappa},$$

where $z_{\min}$ stands for the minimum productivity level, and $\kappa\,(> \sigma - 1)$ is a shape parameter of the distribution. With the above distribution, the productivity of average producers $\widetilde{z}_{S,t}$ is shown as

$$\widetilde{z}_{S,t} = z_{S,t}\left[\frac{\kappa}{\kappa-(\sigma-1)}\right]^{\frac{1}{\sigma-1}}.$$

.

Also, the share of producing plants in the total number of plants is given by

$$\frac{S_t}{N_t} = z_{\min}^{\kappa}\left(\widetilde{z}_{S,t}\right)^{-\kappa}\left[\frac{\kappa}{\kappa-(\sigma-1)}\right]^{\frac{\kappa}{\sigma-1}}. \tag{4}$$

Finally, there exists a firm with a specific productivity cutoff $z_{S,t}$ with which she earns zero profits: $D_t\left(z_{S,t}\right) = 0$. Combined with the above Pareto distribution, this implies the following zero cutoff profits (ZCP) condition:

$$\frac{1}{\sigma}\frac{P_t C_t}{S_t}\left[\frac{\kappa-(\sigma-1)}{\kappa}\right] = f_t W_t. \tag{5}$$

3.6 Household Budget Constraints and Intertemporal Choices

A typical household j faces the following budget constraint at time period t:

$$P_t C_t\,(j) + B_t\,(j) + x_t(j) N_{t+1}\widetilde{V}_t = (1+\nu)\,W_t\,(j)\,L_t\,(j) + (1+i_{t-1})B_{t-1}\,(j) + x_{t-1}(j) S_t \widetilde{D}_{S,t} + T_t^f, \tag{6}$$

where $B_t\,(j)$ and $x_t(j)$ denote bond holdings and share holdings of mutual funds, respectively. $1+\nu$ is the appropriately designed labor subsidy which aims to eliminate distortions due to monopolistic power in labor markets (see later). i_t represents nominal interest rate between t and $t+1$ and T_t^f represents a transfer from domestic government, which can be positive or negative.

The household j sets wages in advance at $t-1$ by maximizing her expected utility at t knowing the following labor demand:

$$L_t(j) = \left(\frac{W_t(j)}{W_t}\right)^{-\theta} L_t.$$

The first order condition with respect to $W_t(j)$ yields

$$W_t(j) = \frac{\eta\theta}{(\theta-1)(1+\nu)} \frac{\mathrm{E}_{t-1}\left[L_t(j)^{1+\varphi}\right]}{\mathrm{E}_{t-1}\left[\frac{\alpha_t L_t(j)}{P_t C_t(j)}\right]}. \tag{7}$$

Households set the wage so that the expected marginal cost by supplying additional labor services $\eta\theta W_t(j)^{-1}\mathrm{E}_{t-1}\left[L_t(j)^{1+\varphi}\right]$ equals to the expected marginal revenue $(\theta-1)(1+\nu)\mathrm{E}_{t-1}\left[\frac{\alpha_t L_t(j)}{P_t C_t(j)}\right]$.

Other choices occur within the same time period. The first order condition with respect to share holdings yields

$$\widetilde{V}_t = E_t\left[Q_{t,t+1}\frac{S_{t+1}}{N_{t+1}}\widetilde{D}_{S,t+1}\right] \tag{8}$$

where $Q_{t,t+1}$ is *nominal* stochastic discount factor defied as $Q_{t,t+1} = E_t\left[\frac{\beta\alpha_{t+1}P_t C_t(j)}{\alpha_t P_{t+1}C_{t+1}(j)}\right]$.

Finally the first order condition with respect to bond holdings is given by

$$1 = (1+i_t)E_t\left[Q_{t,t+1}\right].$$

3.7 General Equilibrium

In equilibrium, there is a symmetry across households so that $C_t(j) = C_t$, $L_t(j) = L_t$, $M_t(j) = M_t$ and $W_t(j) = W_t$. Furthermore, I follow Corsetti and Pesenti (2009) and Bergin and Corsetti (2008) and define monetary stance as

$$\mu_t = P_t C_t.$$

Note that combining with the Euler equation with respect to bond holdings, it is shown that

$$\frac{\alpha_t}{\mu_t} = \mathrm{E}_t \lim_{s\to\infty}\beta^s\frac{1}{\mu_{t+s}}\prod_{\tau=0}^{s-1}(1+i_{t+\tau}).$$

Monetary stance μ_t is expressed as a function of future expected pass of interest rates given the state of current demand α_t.[7]

Using the free entry condition (3), the average profits and the zero cutoff profit condition (5), the future number of firms is given by

$$N_{t+1} = \frac{\beta(\sigma-1)}{\sigma\kappa}\frac{\mu_t}{W_t f_E}\frac{E_t\left[\alpha_{t+1}\right]}{\alpha_t}. \tag{9}$$

Also from the ZCP,

$$S_t = \frac{\kappa-(\sigma-1)}{\sigma\kappa}\frac{\mu_t}{W_t f} \tag{10}$$

Using (4) the cutoff is given by

$$\widetilde{z}_{S,t} = z_{\min}\left[\frac{\kappa}{\kappa-(\sigma-1)}\right]^{\frac{1}{\sigma-1}}\left(\frac{S_t}{N_t}\right)^{-\frac{1}{\kappa}} \tag{11}$$

Also the average production scale of surviving firms is given by

$$\widetilde{y}_{S,t} = \frac{\sigma-1}{\sigma}\frac{\mu_t \widetilde{z}_{S,t}}{S_t W_t}, \tag{12}$$

Observe that plugging the solution for the number of surviving producers (10) the production scale of average surviving firms $\widetilde{y}_{S,t}$ is found to be proportional to its productivity level $\widetilde{z}_{S,t}$.

The model can be solved in closed form provided the solution of equilibrium wages W_t. Labor market clears so that $L_t = S_t l_t\left(\widetilde{z}_{S,t}\right) + N_{t+1} l_{E,t}$. This implies that[8]

[7] Note also that by adding the utility gain arising from money holdings $\chi \ln \frac{M_t(j)}{P_t}$ and savings in terms of money, the following first order condition with respect to money holdings is obtained:

$$\frac{\mu_t}{\alpha_t} = \frac{M_t}{\chi}\left(\frac{i_t}{1+i_t}\right).$$

Monetary stance can be also controlled by the quantity of money M_t given the current interest rate and the current state of demand.

[8] The labor market clearing condition (13) can be further rewritten as $W_t L_t = (\sigma-1)S_t\widetilde{D}_{S,t} + \sigma S_t f W_t + N_{t+1}\widetilde{V}_t$.

$$L_t = S_t \left(\frac{\widetilde{y}_{S,t}}{\widetilde{z}_{S,t}} + f \right) + N_{t+1} f_E \tag{13}$$

Plugging the expression for S_t, $\widetilde{y}_{S,t}$ and N_{t+1} into the labor market clearing condition (13) and using the optimal wage setting equation in equilibrium (7), we have the following solution for wages:

$$W_t = \left\{ \frac{\eta\theta}{(\theta-1)(1+\nu)} \frac{E_{t-1}\left[\left(\frac{\sigma-1}{\sigma} + \frac{\kappa-(\sigma-1)}{\sigma\kappa} + \frac{\beta(\sigma-1)}{\sigma\kappa} \frac{E_t[\alpha_{t+1}]}{\alpha_t} \right) \mu_t \right]^{1+\varphi}}{E_{t-1}\left[\left(\frac{\sigma-1}{\sigma} + \frac{\kappa-(\sigma-1)}{\sigma\kappa} + \frac{\beta(\sigma-1)}{\sigma\kappa} \frac{E_t[\alpha_{t+1}]}{\alpha_t} \right) \alpha_t \right]} \right\}^{\frac{1}{1+\varphi}}. \tag{14}$$

Wages depend not only on the next period of expected labor demand from the producing plants but also on the next period of expected investment (firm entry) which in turn depends on after the next period of demand due to the assumption of one time to build. For simplicity, it is assumed that $E_t[\alpha_{t+1}] = \alpha_t$ with $\alpha_{t+1} = \alpha_t \epsilon_{t+1}$ where ϵ_t stands for a stochastic shock with $E_t[\epsilon_{t+1}] = 1$. With this specific shock process, as can be seen in (9), for new entrants N_{t+1} demand shock becomes irrelevant for entry decision since future expected demand and current demand cancel out each other. I will relax later this assumption of unit root process in the extend version of the model. For the moment, however, this simple process is sufficient to capture the basic mechanism of the model. As a result, wage equation (14) is expressed as

$$W_t = \Gamma \left\{ \frac{E_{t-1}\left[\mu_t^{1+\varphi}\right]}{E_{t-1}[\alpha_t]} \right\}^{\frac{1}{1+\varphi}}, \tag{15}$$

where

$$\Gamma^{1+\varphi} \equiv \frac{\eta\theta}{(\theta-1)(1+\nu)}.$$

Finally, the balanced budget rule of the government implies that

$$T_t^f = \nu W_t L_t.$$

Having the solution of W_t, N_{t+1}, S_t and $\widetilde{z}_{S,t}$, other variables are easy to solve. The solution of the model for arbitrary monetary stance μ_t is provided in Table 1.

Table 1: The Model's Solution

Monetary Stance	$\mu_t = P_t C_t$
Wages	$W_t = \Gamma \left\{ \frac{E_{t-1}\left[\mu_t^{1+\varphi}\right]}{E_{t-1}[\alpha_t]} \right\}^{\frac{1}{1+\varphi}}$
Nb of Entrants	$N_{t+1} = \frac{\beta(\sigma-1)}{\sigma\kappa} \frac{\mu_t}{W_t f_E}$
Nb of Producers	$S_t = \frac{\kappa-(\sigma-1)}{\sigma\kappa} \frac{\mu_t}{W_t f}$
Average Productivity	$\widetilde{z}_{S,t} = \left[\frac{\kappa}{\kappa-(\sigma-1)} \right]^{\frac{1}{\sigma-1}} \left(\frac{S_t}{N_t} \right)^{-\frac{1}{\kappa}}$
Production Scale	$\widetilde{y}_{S,t} = \frac{\sigma-1}{\sigma} \frac{\mu_t \widetilde{z}_{S,t}}{S_t W_t}$
Average Price	$\widetilde{p}_{S,t} = \frac{\sigma}{\sigma-1} \frac{W_t}{\widetilde{z}_{S,t}}$
Price Index	$P_t = S_t^{-\frac{1}{\sigma-1}} \widetilde{p}_{S,t}$
Consumption	$C_t = S_t^{\frac{\sigma}{\sigma-1}} \widetilde{y}_{S,t}$
Dividends of Producers	$\widetilde{D}_{S,t} = \frac{1}{\sigma} \frac{\mu_t}{S_t} - f W_t$
Dividends of Firms	$\widetilde{D}_t = \frac{S_t}{N_t} \widetilde{D}_{S,t}$
Share Price	$\widetilde{V}_t = f_E W_t$
Labor Supply	$L_t = (\sigma-1) \frac{S_t \widetilde{D}_{S,t}}{W_t} + \sigma S_t f + N_{t+1} f_E$

4 Monetary Policy, Firm Entry and Reallocation Effect

In this section, I characterize the allocation and transmission implied by both demand and monetary shock. To do so, first I characterize the allocation under flexible wages. Then the allocation with nominal rigidities under which money is non-neutral is investigated.

4.1 Flexible Price Allocation

It is useful to first characterize the allocation under flexible wages as the benchmark. Throughout the exercise, I assume that monetary stance is constant as $\mu_t = \mu_0$. The solution of flexible wages obtained by removing expectation operator from the period $t-1$ in wage setting equation (15):

$$W_t = \Gamma \mu_0 \left(\frac{1}{\alpha_t} \right)^{\frac{1}{1+\varphi}} \tag{16}$$

Given the above wage solution, other variables under flexible wages are easy to solve. The expression (16) indicates that, following a positive demand shock, there is a reduction in wages whose extent depends on $\frac{1}{1+\varphi}$. When labor supply is more elastic with lower value of φ, wages decrease further given the same size of demand shift. Both the number of entrants N_{t+1} and producers S_t increase proportionally thanks to cost/wage reduction as can be seen in (9) and (10), respectively. On the other hand, these increased producers are less efficient since the productivity level of average producers $\widetilde{z}_{S,t}$ decreases with the predetermined number of firms N_t as inspected in (11). The scale of production on average $\widetilde{y}_{S,t}$ decreases accordingly. To sum up, under flexible wages, households enjoy a higher number of varieties S_t at the expense of efficiency that results in their higher nominal prices. As we will see, the extent of this trade-off between the number of varieties and their efficiencies is crucial in determining the gain of the optimal monetary policy.

Finally, note that it is possible to achieve the first-best Pareto efficient allocation under flexible wages by introducing appropriately designed subsidy which aims to reduce monopolistic power of workers such as

$$1 + \nu = \frac{\theta}{\theta - 1}$$

As argued extensively in Bilbiie et al. (2008), Lewis (2013) and Chugh and Ghironi (2015), it turns out to be optimal to leave monopolistic rents to firms that encourage them to enter in the market under the love for variety $1/(\sigma - 1)$ implied by the standard Dixit-Stiglitz (Dixit and Stiglitz, 1977) preference.[9]

[9] Having the standard Dixit-Stiglitz preference, there is no "static entry distortion" arising from misalignment between welfare benefit of variety creation and firms' markup nor "dynamic entry distortion" (Bilbiie et al., 2014) arising from endogenous markup fluctuations.

4.2 Allocation under Sticky Prices and Monetary Policy Shock

Compared to the above mentioned allocation under flexible wages, under sticky wages as presented in Section 3, both the future and current number of varieties (N_{t+1} and S_t) remain constant following demand shock. Neither the productivity level of average producers $\widetilde{z}_{S,t}$ (thus $\widetilde{y}_{S,t}$) change. The allocation under sticky wages is thus characterized by immutable responses of endogenous variables.

In the above situation, monetary authority has incentive to intervene and can indeed improve the allocation by changing monetary stance μ_t. Money is clearly non-neutral in this economy.

Proposition 1. *An expansionary (contractionary) monetary shock induces the survival of less (more) efficient producing plants within the same period. At the same time, it induces a higher (lower) number of entrants.*

Proof. See equation (10) and (11)

As is seen from (10), the number of producing plants S_t increases following a rise in monetary stance μ_t. At the same time, the productivity level of average incumbent $\widetilde{z}_{S,t}$ declines as can be seen in (11). A positive monetary shock works as a subsidy for firms and allow less efficient firms to stay in the market. It helps *zombie* firms to survive. On the other hand, a contractinary monetary shock works as a tax on profits and wipes out less efficient firms. It helps to *cleanse* the market. In short, surviving or depart of less efficient plants is *the reallocation effect* of monetary policy. Intuitively, monetary expansion (contraction) improves (deteriorates) the profitability of existing plants and induces a survival (depart) of less efficient plants.

Furthermore, by increasing stochastic discount factor $Q_{t,t+1}$, monetary expansion simultaneously boosts share price $\widetilde{V}_t$ and induces entry of new firms N_{t+1}. Monetary contraction works in the opposite way and induces the exit of new firms. With homogeneous firms, Bergin and Corsetti (2008) argue a similar mechanism for entry induced by monetary policy shock in a sticky price model. Next I characterize the optimal monetary policy *rule* in the presence of stochastic demand in contrast to the monetary shock as just explored.[10] $\square$

4.3 Monetary Policy Rules

Here the optimal monetary policy rule is discussed. First I derive the optimal policy rule solving the maximization problem of the benevolent central bank. Next welfare gain under the optimal policy rule is explored in comparison of without any stabilization policy.

4.3.1 The Optimal Policy

The central bank maximizes the expected utility of households, $E_{t-1}[U_t]$ using the instrument μ_t in the presence of stochastic demand shift α_t. The ex-ante (dis)utility supplying labor is constant.[11] The expected utility is thus given by

$$\mathrm{E}_{t-1}[U_t] = E_{t-1}[\alpha_t lnC_t] = \mathrm{E}_{t-1}\left[\frac{\sigma}{\sigma-1}\alpha_t \mathrm{ln}S_t + \alpha_t \mathrm{ln}\widetilde{y}_{S,t}\right] \tag{17}$$

Plugging the solution of S_t and $\widetilde{y}_{S,t}$ found previously, the above expression is further rewritten as (See Appendix C for the derivation),

[10] Oikawa and Ueda (2018) find that high monetary growth rate *improves* aggregate productivity in the economy due to the enhancing reallocation effect. The reason is that menu cost burden is heavier for small firms due to frequent price revisions triggered by high monetary growth rate. A similar result can be obtained by allowing higher fixed cost of production f which is common for all firms. See also Hamano and Zanetti (2017) that analyze the impact of "subsidy" shock captured by a permanent decrease in f.

[11] Note that from the labor market clearing condition and plugging the solution of wages in it, we have

$$E_{t-1}\left[L_t^{1+\varphi}\right] = E_{t-1}\left[\frac{\left(\frac{\sigma-1}{\sigma}+\frac{\kappa-(\sigma-1)}{\sigma\kappa}+\frac{\beta(\sigma-1)}{\sigma\kappa}\frac{E_t[\alpha_{t+1}]}{\alpha_t}\right)\mu_t}{W_t}\right]^{1+\varphi}$$

$$= E_{t-1}\left[\frac{\left(\frac{\sigma-1}{\sigma}+\frac{\kappa-(\sigma-1)}{\sigma\kappa}+\frac{\beta(\sigma-1)}{\sigma\kappa}\frac{E_t[\alpha_{t+1}]}{\alpha_t}\right)\mu_t}{\Gamma\left\{\frac{E_{t-1}\left[\left(\frac{\sigma-1}{\sigma}+\frac{\kappa-(\sigma-1)}{\sigma\kappa}+\frac{\beta(\sigma-1)}{\sigma\kappa}\frac{E_t[\alpha_{t+1}]}{\alpha_t}\right)\mu_t\right]^{1+\varphi}}{E_{t-1}\left[\left(\frac{\sigma-1}{\sigma}+\frac{\kappa-(\sigma-1)}{\sigma\kappa}+\frac{\beta(\sigma-1)}{\sigma\kappa}\frac{E_t[\alpha_{t+1}]}{\alpha_t}\right)\alpha_t\right]}\right\}^{\frac{1}{1+\varphi}}}\right]^{1+\varphi} = \left[\frac{\left(1-\frac{(\sigma-1)}{\sigma\kappa}(1-\beta)\right)}{\Gamma}\right]^{1+\varphi} E_{t-1}[\alpha_t],$$

which is constant.

$$E_{t-1}\left[U_t\right]=\left(\frac{1}{\sigma-1}+1-\frac{1}{\kappa}\right)\left[E_{t-1}\left[\alpha_t \ln \mu_t\right]-\frac{E_{t-1}\left[\alpha_t\right]}{1+\varphi}\ln E_{t-1}\left[\mu_t^{1+\varphi}\right]\right]+\text{cst.} \tag{18}$$

The first order condition with respect to μ_t with which the above expression is maximized can be derived.

Proposition 2. *The optimal policy is found to be* $\mu_t=\mu_0\alpha_t^{\frac{1}{1+\varphi}}$.

Proof. See Appendix C. □

Lemma 1. *Under the optimal policy rule, the allocation under flexible wages is achieved for real variables.*

Proof. By plugging the above policy rule in (10), (11), (12) and (9), it is found to be that the number of producers S_t, the entry of firms N_{t+1}, the productivity level $\widetilde{z}_{S,t}$ and the scale of production of average producers $\widetilde{y}_{S,t}$ coincide to those obtained under flexible wages argued in Section 4.1.

Note especially that under the above optimal policy, wages are constant as □

$$W_t=\Gamma\mu_0.$$

The optimal policy stabilizes nominal wages, not prices. Contrary to nominal wages, marginal cost and thus the average price $\widetilde{p}_{S,t}$ fluctuate because of fluctuations in the productivity level of average producers $\widetilde{z}_{S,t}$. In the above expression, μ_0 thus plays a role of "nominal anchor". Of course it is neither optimal to target welfare consistent CPI P_t that fluctuates due to changes in the number of available varieties S_t .

The implication is that due to the reallocation effect of policy, the standard inflation targeting would not be optimal. A monetary expansion (contraction) is followed by upward (downward) bias in nominal prices due to the selection of less (more) efficient firms into the market. A targeted inflation may materialize due to the reallocation and thus the survival of less efficient producers following a monetary expansion. Nonetheless, if the central banks stick to the inflation targeting rather than wage rate targeting, it would be more desirable to target a higher level of inflation rate than conventional rate.[12]

[12]By assuming $\alpha_{t-1}=1$ and implied expected demand shift as $E_{t-1}\left[\alpha_t\right]=\alpha_{t-1}$, wages in case of no

4.3.2 Welfare

In this section, the welfare gain implied by the optimal policy is discussed. Especially I argue the role played by plant heterogeneity and the love for variety. Difference in welfare under the optimal policy and incomplete stabilization which is characterized by constant monetary stance as $\mu_t = \mu_0$ is given by[13]

$$
\begin{aligned}
& E_{t-1}\left[U_t^S\right] - E_{t-1}\left[U_t^{NS}\right] \\
&\qquad = \left(\frac{1}{\sigma-1} + 1 - \frac{1}{\kappa}\right)\frac{1}{1+\varphi}\left(E_{t-1}\left[\alpha_t \ln \alpha_t\right] - E_{t-1}\left[\alpha_t\right]\ln E_{t-1}\left[\alpha_t\right]\right) \\
&\qquad = \left(\frac{1}{\sigma-1} + 1 - \frac{1}{\kappa}\right)\frac{1}{1+\varphi}\left(E_{t-1}\left[\epsilon_t \ln \epsilon_t\right]\right) > 0 \qquad (19)
\end{aligned}
$$

The difference in expected utility depends on three parameters, σ, κ and φ. The expression (19) highlights a *trade-off* with which monetary authority is facing and the following proposition is derived.

Proposition 3. *Under demand uncertainty, the policy gain (cost) of (in)stabilization is higher when households attache a higher preference for varieties produced by homogeneous plants (with lower value of σ and higher value of κ) and a higher labor supply elasticity φ^{-1} amplifies its gain (cost).*

Proof. Remembering that $\kappa > \sigma - 1$, the term $\left(\frac{1}{\sigma-1} + 1 - \frac{1}{\kappa}\right)\frac{1}{1+\varphi}$ is strictly positive and increasing function with respect to σ^{-1}, κ and φ^{-1}. □

stabilization (characterized by constant monetary stance as $\mu_t = \mu_0$) coincide to those obtained under the optimal policy:

$$
W_t^{NS} = \Gamma\mu_0 \left\{\frac{1}{E_{t-1}\left[\alpha_t\right]}\right\}^{\frac{1}{1+\varphi}} = \Gamma\mu_0
$$

Non-stabilization does not result in higher marginal cost as argued in Corsetti and Pesenti (2009) and Bergin and Corsetti (2008). As a result, the expected (average) allocations for both extensive and intensive margins are exactly the same with or without stabilization. However, a more general process of demand shock introduces uncertainty in future investment and thus uncertainty in future labor demand which exacerbate the distortion of nominal rigidities. See the equation (14).

[13] $f(\epsilon_t) = \epsilon_t \ln \epsilon_t$ is a convex function with respect to ϵ_t for $\epsilon_t > 0$. From the direct application of Jensen's inequality, we have thus $E_{t-1}\left[\epsilon_t \ln \epsilon_t\right] > E_{t-1}\left[\epsilon_t\right]\ln E_{t-1}\left[\epsilon_t\right]$. With $E_{t-1}\left[\epsilon_t\right] = 1$, $E_{t-1}\left[\epsilon_t \ln \epsilon_t\right] > 0$.

Think of the case of a monetary expansion that induces a higher number of but less efficient producers. Given the size of love for variety, $\frac{1}{\sigma-1}$, the reallocation effect of policy is smaller when firms are distributed at the lower end of distribution with high values of κ. Thus, the higher is κ, the less monetary authority is facing the trade-off between the number of producers S_t and their efficiencies $\widetilde{z}_{S,t}$. At its extreme case, when $\kappa = \infty$, all firms become homogeneous at the lower end of distribution and no reallocation effect, thus no trade-off. No zombies are created because of expansionary policy. The gain of monetary expansion achieves its best outcome in such a case. With this respect, the policy gain is higher, the lower is the firm heterogeneity (the higher the value of κ).

In a very similar way, given the extent of firm heterogeneity κ, the smaller (larger) value of love for variety $\frac{1}{\sigma-1}$ exacerbates (alleviates) the above mentioned reallocation effect and the gain of the optimal policy decreases (increases).

The policy gain is high (low) when φ is low (high), other things equal. Remembering that φ is the inverse of Frish elasticity of labor supply, the policy gain is higher when the elasticity is high. When the labor supply is completely inelastic ($\varphi = \infty$), there is no reason to conduct a monetary policy that aims to impact real variables through appropriate allocation of labor.

As a final remark, to shed a different light on the trade-off with which the monetary authority is facing, recall the expression of expected utility (17) which can be alternatively developed as

$$\mathrm{E}_{t-1}\left[U_t\right] = \frac{\sigma}{\sigma-1}\left[\mathrm{E}_{t-1}\alpha_t\mathrm{E}_{\mathrm{t}-1}\mathrm{ln}S_t + Cov(\alpha_t, \mathrm{ln}S_t)\right] + \mathrm{E}_{t-1}\alpha_t\mathrm{E}_{t-1}\mathrm{ln}\widetilde{y}_{S,t} + Cov(\alpha_t, \mathrm{ln}\widetilde{y}_{S,t}).$$

Since the expected number of producers S_t and their expected average production scale $\widetilde{y}_{S,t}$ (or the average productivity level $\widetilde{z}_{S,t}$) become the same with or without stabilization under the simple demand process assumed, the welfare wedge between stabilization and non-stabilization is solely driven by the covariance between demand shock and the number of available varieties $Cov(\alpha_t, \mathrm{ln}S_t)$ and the covariance between demand shock and the average efficiency in the economy $Cov(\alpha_t, \mathrm{ln}\widetilde{z}_{S,t})$. Monetary policy can realize a better congruence of one of these covariances at the expense of another.

5 Quantitative Exploration

I extend the theoretical model with a more realistic setting to explore its quantitative implication. The extensions are as follows: 1) Instead of one period of existence of plants, a more realistic motion of firms is introduced. 2) Instead of one period wage stickiness, Calvo type wage stickiness, hence wage inflation dynamics are introduced. 3) Adjustment cost in firm entry is introduced. 4) Monetary stance is specified according to the Taylor rule. I only mention theses points. The extended model is calibrated and the implication of monetary shock is analyzed. In particular the role played by firm heterogeneity and entry adjustment cost are discussed. In what follows, the welfare-based consumer price index, P_t, is chosen as numéraire and the real price of average producers is defined as $\widetilde{\rho}_{S,t} \equiv \frac{\widetilde{p}_{S,t}}{P_t}$. All other real variables are expressed with small letters.

5.1 The Model's Extensions

5.1.1 Household's Decisions and Wage Phillips Curve

Firms stay in the market until they are hit by exit inducing shock. The motion of firm is specified as $N_{t+1} = (1-\delta)(N_t + H_t)$ where H_t denotes the number of entrants at period t and δ stands for "death shock" that hit at the very end of the period. Households now finance all firms including entrants by purchasing a share of mutual funds. The *real* budget constraint for a household j is thus given by

$$C_t(j)+b_t(j)+x_t(j)(N_t+H_t)\widetilde{v}_t = (1+\nu)\,w_t(j)\,L_t(j)+(1+r_t)b_{t-1}(j)+x_{t-1}(j)N_t(\widetilde{v}_t+\widetilde{d}_t)+t^f{}_t \tag{20}$$

where real interest rate r_t is defined as

$$1+r_t \equiv \frac{1+i_{t-1}}{1+\pi_t}.$$

In the above expression, π_t denotes inflation rate of ideal consumption basket between period t and $t-1$. The first order condition with respect to share holdings and bond holdings are respectively given by

$$\widetilde{v}_t = \beta\left(1-\delta\right) E_t\left[\frac{\alpha_{t+1}C_t}{\alpha_t C_{t+1}}\left(\widetilde{v}_{t+1}+\widetilde{d}_{t+1}\right)\right]$$

and

$$1 = \beta E_t\left[\frac{\alpha_{t+1}C_t}{\alpha_t C_{t+1}}\frac{1+i_{t-1}}{1+\pi_t^c}\right].$$

In stead of one period stickiness, wages are set $\grave{a}$ la Calvo (1983) and only a fraction of $1-\vartheta$ household can re-optimize their wages. The first order condition with respect to wage setting yields (see Appendix D for derivation),

$$\left(\frac{W_t'}{W_t}\right)^{1+\varphi\theta} = \frac{\frac{\eta\theta}{(\theta-1)(1+\nu)}\sum_{k=0}^{\infty}\left(\beta\vartheta\right)^k E_t\left[\left(\frac{W_{t+k}}{W_t}\right)^{\theta(1+\varphi)} L_{t+k}^{1+\varphi}\right]}{\sum_{k=0}^{\infty}\left(\beta\vartheta\right)^k E_t\left[\frac{\alpha_{t+k}}{C_{t+k}}\frac{W_{t+k}}{P_{t+k}}\left(\frac{W_{t+k}}{W_t}\right)^{\theta-1} L_{t+k}\right]}, \tag{21}$$

which provides the following wage Phillips curve:

$$\pi_t^w = \beta E_t\left[\pi_{t+1}^w\right] - \frac{\left(1-\beta\vartheta\right)\left(1-\vartheta\right)}{\left(1+\theta\varphi\right)\vartheta}\widehat{\mu}_t^w,$$

where $\widehat{\mu}_t^w$ represents deviation of wage markup μ_t^w from its steady state value. The wage markup μ_t^w is given by

$$w_t = \mu_t^w\frac{\eta L_t^{\varphi}C_t}{\alpha_t}.$$

Note that there exists a link between wage inflation π_t^w and welfare-consistent inflation π_t as

$$\frac{w_t}{w_{t-1}} = \frac{1+\pi_t^w}{1+\pi_t}.$$

Adjustment cost in entry process is modeled following Lewis (2009) and Lewis and Poilly (2012) by assuming the probability of successful entry as

$$\varpi_t(H_t, H_{t-1}) = 1 - F_{N,t}(\frac{H_t}{H_{t-1}}),$$

and

$$w_t f_E = \widetilde{v}_t \varpi_t + \widetilde{v}_t \varpi_{1,t} H_t + \beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} \left(\widetilde{v}_{t+1} \varpi_{2,t+1} H_{t+1} \right) \right],$$

where ϖ_t denotes the probability of successful entry and ϖ_{it} is the first derivative of the success rate with respect to its ith argument. $F_{N,t}$ is the failure rate with $F_{N,t}(1) = F'_{N,t}(1) = 0$ and $F''_{N,t}(1) = \omega$. When the value of ω is high, entry process becomes more sluggish. When $\varpi_t = 1$, it gives the standard free entry condition as $w_t f_E = \widetilde{v}_t$.

GDP is defined from the income side as $Y_t = w_t L_t + N_{D,t} \widetilde{d}_t$. Noting Y_t^f as GDP under flexible wages, we specify the following Taylor rule:

$$i_t = (i_{t-1})^{\rho} \left[\left(\frac{P_t^e}{P_{t-1}^e} \right)^{\phi_\pi} \left(\frac{Y_t}{Y_t^f} \right)^{\phi_Y} \right]^{1-\rho} \upsilon_t,$$

where υ_t stands for a monetary policy shock. Given the inability of statistical agency in capturing all fluctuations in product turnover (Broda and Weinstein (2006, 2004)), we assume that monetary authority conducts policy based on imperfectly observed price P_t^e and its inflation π_t^e that capture fluctuations in nominal prices only as

$$1 + \pi_t^e = (1 + \pi_t) \left(\frac{S_t}{S_{t-1}} \right)^{\frac{1}{\sigma - 1}}.$$

Finally, I define plant destruction as

$$D_t = \frac{S_t}{N_t}.$$

The process of demand shifter is specified as $\ln \alpha_t = 0.8 \ln \alpha_{t-1} + \epsilon_t$ and monetary policy shock is specified as $\ln \upsilon_t = \epsilon_{\upsilon,t}$ where both ϵ_t and $\epsilon_{\upsilon,t}$ are assumed to be a zero mean i.i.d shock. The model is calibrated around the non stochastic zero inflation steady state where $\alpha_0 = \upsilon_0 = 1$. The steady state is thus identical with Hamano and Zanetti (2017). The whole system is summarized in Table 2 and Table 3.

5.2 Calibration

The theoretical model is calibrated with the parameters' values in Table 4. Discount factor β, the Frish elasticity of labor supply φ, the elasticity of substitution among varieties σ,

Table 2: The Model

Price Index	$1 = S_t^{-\frac{1}{\sigma-1}} \widetilde{\rho}_{S,t}$
Pricing	$\widetilde{\rho}_{S,t} = \frac{\sigma}{\sigma-1} \frac{w_t}{\widetilde{z}_{S,t}}$
Dividends of Firms	$\widetilde{d}_t = \frac{S_t}{N_t} \widetilde{d}_{S,t}$
Dividends of Producers	$\widetilde{d}_{S,t} = \frac{1}{\sigma} \frac{C_t}{S_t} - f w_t$
Free Entry	$w_t f_E = \widetilde{v}_t \varpi_t + \widetilde{v}_t \varpi_{1,t} H_t + \beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} \left(\widetilde{v}_{t+1} \varpi_{2,t+1} H_{t+1} \right) \right]$
Labor Market Clearing	$w_t L_t = (\sigma - 1) S_t \widetilde{d}_{S,t} + \sigma S_t f w_t + H_t \widetilde{v}_t$
Average Productivity	$\widetilde{z}_{S,t} = z_{\min} \left[\frac{\kappa}{\kappa - (\sigma-1)} \right]^{\frac{1}{\sigma-1}} \left(\frac{S_t}{N_t} \right)^{-\frac{1}{\kappa}}$
Zero Cutoff Profits	$\frac{1}{\sigma} \frac{C_t}{S_t} \left[\frac{\kappa - (\sigma-1)}{\kappa} \right] = f w_t$
Motion of firms	$N_{t+1} = (1 - \delta) \left(N_t + H_t \right)$
Euler Shares	$\widetilde{v}_t = \beta \left(1 - \delta\right) E_t \left[\left(\frac{\alpha_t C_{t+1}}{C_t \alpha_{t+1}} \right)^{-1} \left(\widetilde{v}_{t+1} + \widetilde{d}_{t+1} \right) \right]$
Euler Bonds	$1 = \beta E_t \left[\left(\frac{\alpha_t C_{t+1}}{C_t \alpha_{t+1}} \right)^{-1} \left(1 + r_{t+1}\right) \right]$
Plant Destruction	$D_t = \frac{S_t}{N_t}$
GDP Definition	$Y_t = w_t L_t + N_{D,t} \widetilde{d}_t$

Table 3: The Model (con't)

Real Return	$1 + r_t \equiv \frac{1+i_{t-1}}{1+\pi_t}$
Wage Markup	$w_t = \mu_t^w \frac{\eta L_t^{\varphi} C_t}{\alpha_t}$
Wage Inflation	$\left(\frac{W_t'}{W_t} \right)^{1+\varphi\theta} = \frac{\frac{\eta\theta}{(\theta-1)(1+\nu)} \sum\limits_{k=0}^{\infty} (\beta\vartheta)^k E_t \left[\left(\frac{W_{t+k}}{W_t} \right)^{\theta(1+\varphi)} L_{t+k}^{1+\varphi} \right]}{\sum\limits_{k=0}^{\infty} (\beta\vartheta)^k E_t \left[\frac{\alpha_{t+k}}{C_{t+k}} \frac{W_{t+k}}{P_{t+k}} \left(\frac{W_{t+k}}{W_t} \right)^{\theta-1} L_{t+k} \right]}$
CPI Inflation	$\frac{w_t}{w_{t-1}} = \frac{1+\pi_t^w}{1+\pi_t}$
Empirical Inflation	$1 + \pi_t^e = (1 + \pi_t) \left(\frac{S_t}{S_{t-1}} \right)^{\frac{1}{\sigma-1}}$
Monetary Policy	$i_t = (i_{t-1})^{\rho} \left[\left(\frac{P_t^e}{P_{t-1}^e} \right)^{\phi_\pi} \left(\frac{Y_t}{Y_t^f} \right)^{\phi_Y} \right]^{1-\rho} \upsilon_t$

Table 4: Calibration of the model

β	Discount factor	0.99
φ	Frish elasticity of labor supply	2
σ	Elasticity of substitution among varieties	11.5
γ	Risk aversion	2
δ	Exogenous death shock	0.059
κ	Pareto shape	11.5070
λ	Calvo wage revision	0.64
θ	Elasticity of substitution among workers	0.9524
ω	Entry adjustment cost	8.311
ρ	Interest smoothing on previous rate	0.8
ϕ_π	Inflation target	1.5
ϕ_Y	Output gap stabilization	0.1

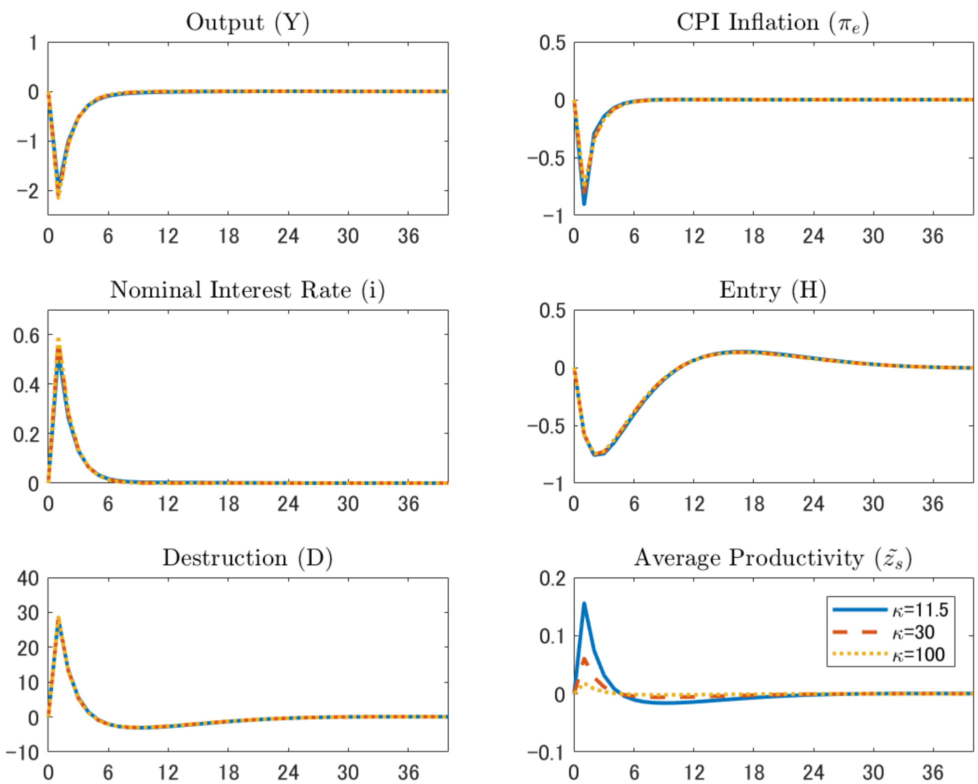
risk aversion γ, exogenous death shock δ, Pareto distribution κ are taken from Hamano and Zanetti (2017) that matches the business cycle moments of plant/product turnover described in Broda and Weinstein (2010). The values of parameters in Taylor rule (ρ, ϕ_π and ϕ_Y) are specified following Gertler et al. (1999). Adjustment cost for entry, ω, is calibrated based on Lewis and Poilly (2012). Parameters' values concerning the sticky wage (λ and θ) are chosen from the estimation results in Christiano et al. (2005).

5.3 Monetary Policy Shock

Figure 2 shows the IRFs of the theoretical model following a 1 % rise in monetary policy shock, $\epsilon_{v,t}$.[14] Each panel in the figure reports the IRF for output Y_t, empirically measured CPI inflation π_t^e, nominal interest rate i_t , the number of entrants H_t, plant destruction D_t and the labor productivity of average incumbent plants $\widetilde{z}_{S,t}$ with three different values of Pareto distribution, namely $\kappa = 11.50$ (solid lines), $\kappa = 50$ (dashed lines) and $\kappa = 100$ (dotted lines). On impact of such a contractionary policy shock, product destruction

[14]The results for demand shock are available upon on request.

Figure 2: Monetary Shock and Firm Heterogeneity (κ)



Each entry shows the percentage-point response of one of the model's variables to a one-percentage deviation of the monetary shock for the benchmark economy (solid line with $\kappa = 11.5$) and the economy with medium level of firm heterogeneity (dashed line with $\kappa = 30$) and the economy with low level of firm heterogeneity (dotted line with $\kappa = 100$).

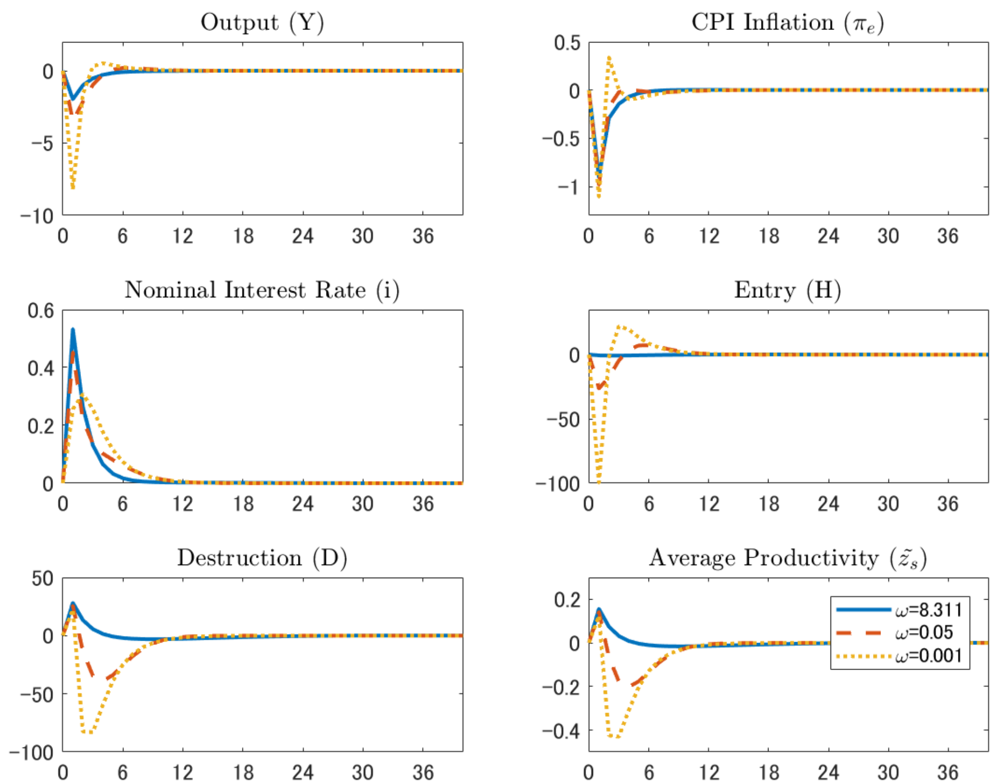
(D) increases and output decreases (Y). The impact on both destruction and output dissipates as the nominal interest rate (i) normalizes after six quarters. On the other hand, with the benchmark adjustment cost, firm entry (H) decreases gradually from the first to three quarters. It recovers slowly and then slightly increases with some persistence before achieving its initial level. While the monetary tightening wipes out inefficient producers and discourages entry, the productivity of average incumbents $(\widetilde{z}_S)$ increases and thus higher inflation (π^e) materializes due to the cleansing effect of monetary policy as discussed in Section 3. The cleansing effect is higher, the higher is the plant level heterogeneity κ. IRFs for the complete set of variables are found in Appendix E.

Contrary to the benchmark calibration that creates a slower downward adjustment in entry (H) following a contractionary policy shock, lower values of entry adjustment cost give rise to radical change of dynamics for all variables. Figure 3 shows the IRFs for the same contractionary monetary shock but with different values of entry adjustment costs, namely $\omega = 8.311$ (solid lines), $\omega = 0.05$ (dashed lines) and $\omega = 0.001$ (dotted lines). With lower values of adjustment cost, firm entry (H) declines sharply on impact (dashed and dotted lines for H). And such a dramatic decline in entry dampens the product destruction (D) not only on impact but also in the subsequent periods. Destruction can be even lower in transitory dynamics for lower values of entry adjustment cost (dashed and solid lines for D). The pattern is the *insulation effect* of entry on destruction argued in Caballero and Hammour (1994) and Hamano and Zanetti (2017). Furthermore, note that firm entry (H) itself can be also insulated in future periods: the self insulation is higher (entry increases in transitory dynamics), the higher is the initial drop in firm entry. Correspondingly when the adjustment cost is low, the productivity of average incumbent plants ($\widetilde{z}_S$) increases on impact due to the cleaning effect of monetary policy while it decreases along the transitory dynamics thanks to the insulation effect (dashed and solid lines for $\widetilde{z}_S$). Accordingly, inflation becomes lower due to the cleansing on impact while it can be mitigated thanks to the survival of inefficient plants in the subsequent periods. In particular when the adjustment cost is sufficiently low ($\omega = 0.001$), it even reverses the inflation dynamics from deflation to inflation (dotted line for π^e). IRFs for the complete set of variables are found in Appendix E.[15]

Except the puzzling short-run expansion in output and entry following a contractionary monetary shock in data (which I would attribute to the issue related to the identification of the monetary policy shock since mid-90's), the IRFs of the theoretical model reproduce overall those found in the VAR presented in Section 2. Monetary policy shock induces product turnover. It does also change the efficiency in the economy through the resulted reallocation. On the other hand, the comparison with the VAR evidence reveals some drawbacks of the theoretical model. For instance, there is an abrupt destruction in the theoretical model while the establishment death takes only gradually in data. The

[15]IRFs with $\omega = 0.001$ are very similar to those obtained without any entry adjustment cost.

Figure 3: Monetary Policy Shock and Entry Adjustment Cost(ω)



Each entry shows the percentage-point response of one of the model's variables to a one-percentage deviation of the monetary shock for the benchmark economy (solid line with $\omega = 8.311$) and the economy with medium level of entry adjustment cost (dashed line with $\omega = 0.05$) and the economy with low level of entry adjustment cost (dotted line with $\omega = 0.001$).

theoretical model would need a more realistic adjustment cost in destruction. Also persistence of inflation in the theoretical model is lower compared to the data, which would be attributed to the absence of staggered price setting in addition to staggered wage contract in the theoretical model.

6 Conclusion

The paper builds a simple DSGE model that aims to capture plant turnover and its relation with monetary policy. I finds that monetary policy has impact on reallocation of heterogeneous plants and inevitably changes the balance between the number of available varieties and their efficiencies (prices). A contractionary monetary shock cleanses the inefficient plants while an expansionary monetary shock allows the survival of inefficient plants. It is analytically shown that, under demand uncertainty, the gain of stabilization is higher when plants are homogeneous and when households or producer of final goods attach a higher love for product variety. A more realistic extended version of the model is calibrated in replicating US product turnover. I find that lower entry insulates destruction of the plants on impact and in the subsequent periods. The IRFs of the theoretical model confirms broadly the VAR evidence following a contractionary monetary shock in the recent US economy.

The theoretical model nesting on the standard New Keynesian literature would allow to have extensions in the number of direction. For instance, introducing financial friction for firms would be interesting. An extension to the open economy setting would be also important to see the welfare difference across different exchange rate regimes.

References

Alessandria, G. and H. Choi (2007). Do Sunk Costs of Exporting Matter for Net Export Dynamics? *The Quarterly Journal of Economics 122*(1), 289–336.

Bergin, P. R. and G. Corsetti (2008, October). The extensive margin and monetary policy. *Journal of Monetary Economics 55*(7), 1222–1237.

Bergin, P. R. and G. Corsetti (2015, July). Beyond Competitive Devaluations: The Monetary Dimensions of Comparative Advantage. CEPR Discussion Papers 10718, C.E.P.R. Discussion Papers.

Bilbiie, F., F. Ghironi, and M. Melitz (2007, Winter). Monetary policy and business cycles with endogenous entry and product variety. In *NBER Macroeconomics Annual 2007, Volume 22*, NBER Chapters, pp. 299–353. National Bureau of Economic Research, Inc.

Bilbiie, F. O., I. Fujiwara, and F. Ghironi (2014). Optimal monetary policy with endogenous entry and product variety. *Journal of Monetary Economics 64*(C), 1–20.

Bilbiie, F. O., F. Ghironi, and M. J. Melitz (2008, October). Monopoly power and endogenous product variety: Distortions and remedies. NBER Working Papers 14383, National Bureau of Economic Research, Inc.

Bilbiie, F. O., F. Ghironi, and M. J. Melitz (2012). Endogenous Entry, Product Variety, and Business Cycles. *Journal of Political Economy 120*(2), 304 – 345.

Broda, C. and D. E. Weinstein (2006, May). Globalization and the gains from variety. *The Quarterly Journal of Economics 121*(2), 541–585.

Broda, C. and D. E. Weinstein (2010, June). Product creation and destruction: Evidence and price implications. *American Economic Review 100*(3), 691–723.

Broda, C. and D. W. Weinstein (2004, May). Variety growth and world welfare. *American Economic Review 94*(2), 139–144.

Caballero, R. J. and M. L. Hammour (1994, December). The cleansing effect of recessions. *American Economic Review 84*(5), 1350–68.

Caballero, R. J. and M. L. Hammour (2005, 04). The cost of recessions revisited: A reverse-liquidationist view. *Review of Economic Studies 72*(2), 313–341.

Caballero, R. J., T. Hoshi, and A. K. Kashyap (2008, December). Zombie lending and depressed restructuring in japan. *American Economic Review 98*(5), 1943–77.

Cacciatore, M., G. Fiori, and F. Ghironi (2016). Market deregulation and optimal monetary policy in a monetary union. *Journal of International Economics 99*(C), 120–137.

Cacciatore, M. and F. Ghironi (2014). Trade, unemployment, and monetary policy. Technical report, mimeo.

Calvo, G. A. (1983, September). Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics 12*(3), 383–398.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (1999, August). Monetary policy shocks: What have we learned and to what end? In J. B. Taylor and M. Woodford (Eds.), *Handbook of Macroeconomics*, Volume 1 of *Handbook of Macroeconomics*, Chapter 2, pp. 65–148. Elsevier.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005, February). Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. *Journal of Political Economy 113*(1), 1–45.

Chugh, S. K. and F. Ghironi (2015, June). Optimal Fiscal Policy with Endogenous Product Variety. CEPR Discussion Papers 10674, C.E.P.R. Discussion Papers.

Corsetti, G. and P. Pesenti (2009, December). The simple geometry of transmission and stabilization in closed and open economies. pp. 65–116.

Davis, S. J. and J. Haltiwanger (1990, May). Gross Job Creation and Destruction: Microeconomic Evidence and Macroeconomic Implications. In *NBER Macroeconomics Annual 1990, Volume 5*, NBER Chapters, pp. 123–186. National Bureau of Economic Research, Inc.

Dixit, A. K. and J. E. Stiglitz (1977, June). Monopolistic competition and optimum product diversity. *American Economic Review 67*(3), 297–308.

Eichenbaum, M. (1992, June). 'Interpreting the macroeconomic time series facts: The effects of monetary policy' : by Christopher Sims. *European Economic Review 36*(5), 1001–1011.

Fernald, J. G. (2012). A quarterly, utilization-adjusted series on total factor productivity. Working Paper Series 2012-19, Federal Reserve Bank of San Francisco.

Gertler, M., J. Gali, and R. Clarida (1999, December). The Science of Monetary Policy: A New Keynesian Perspective. *Journal of Economic Literature 37*(4), 1661–1707.

Gertler, M. and P. Karadi (2015, January). Monetary Policy Surprises, Credit Costs, and Economic Activity. *American Economic Journal: Macroeconomics 7*(1), 44–76.

Ghironi, F. and M. J. Melitz (2005, August). International trade and macroeconomic dynamics with heterogeneous firms. *The Quarterly Journal of Economics 120*(3), 865–915.

Haltiwanger, J. (2012, May). Job Creation and Firm Dynamics in the United States. In *Innovation Policy and the Economy, Volume 12*, NBER Chapters, pp. 17–38. National Bureau of Economic Research, Inc.

Hamano, M. and P. M. Picard (2017, August). Extensive and intensive margins and exchange rate regimes. *Canadian Journal of Economics 50*(3), 804–837.

Hamano, M. and F. Zanetti (2017, October). Endogenous Turnover and Macroeconomic Dynamics. *Review of Economic Dynamics 26*, 263–279.

Lentz, R. and D. T. Mortensen (2005, August). Productivity Growth And Worker Reallocation. *International Economic Review 46*(3), 731–749.

Lewis, V. (2009, October). Optimal monetary policy and firm entry. Research series 200910-23, National Bank of Belgium.

Lewis, V. (2013, December). Optimal Monetary Policy And Firm Entry. *Macroeconomic Dynamics 17*(08), 1687–1710.

Lewis, V. and C. Poilly (2012). Firm entry, markups and the monetary transmission mechanism. *Journal of Monetary Economics 59*(7), 670–685.

Melitz, M. J. (2003, November). The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica 71*(6), 1695–1725.

Oikawa, K. and K. Ueda (2018). Reallocation effects of monetary policy. mimeo, Waseda University.

Ramey, V. (2016, August). *Macroeconomic Shocks and Their Propagation*, Volume 2 of *Handbook of Macroeconomics*, Chapter 0, pp. 71–162. Elsevier.

Sims, C. A. (1992, June). Interpreting the macroeconomic time series facts : The effects of monetary policy. *European Economic Review 36*(5), 975–1000.

Totzek, A. (2009). Firms' heterogeneity, endogenous entry, and exit decisions. Economics Working Paper No. 2009-11, Kiel University, Department of Economics, Kiel.

Uusküla, L. (2016). Monetary transmission mechanism with firm turnover. *Journal of Macroeconomics 50*(C), 1–18.

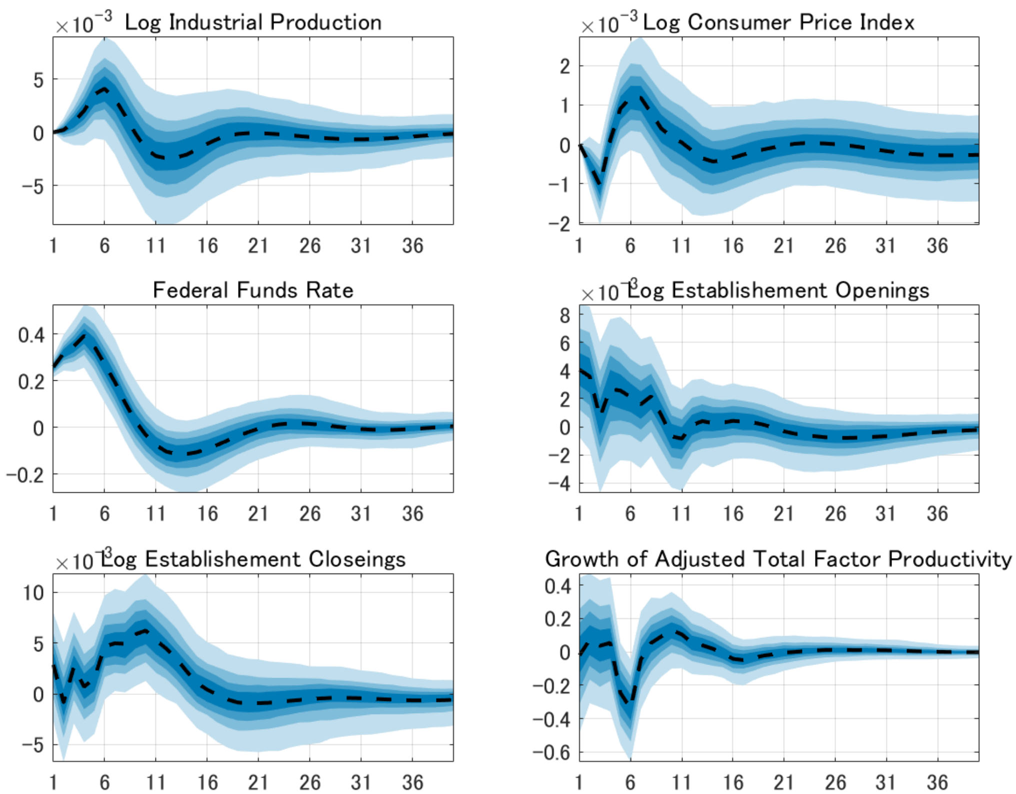
A Data

Table 5: Data

Series Name	Source
Industrial Production Index	St. Louis Fed
Consumer Price Index (changes for All)	St. Louis Fed
Effective Federal Fund Rates	St. Louis Fed
Global Commodity Index	IMF
Establishment Birth	Business Employment Dynamics
Establishment Death	Business Employment Dynamics
Establishment Openings	Business Employment Dynamics
Establishment Closings	Business Employment Dynamics
Adjusted Total Factor Productivity	Fernald's web site

B VAR with Openings and Closings

Figure 4: Monetary Policy Shock, Establishment Turnover and Reallocation Effect: a VAR evidence



Effects of unanticipated monetary policy shock, multivariate VAR, 1992Q3-2017Q1. Gray bands are 30%, 50%, 68% and 90% bootstrap confidence bands.

C Optimal Policy

By plugging the solutions found in Section 3, the expected utility $E_{t-1}[U_t]$ at time period t from the perspective of $t-1$ can be developed as

$$
\begin{aligned}
E_{t-1}\left[U_t\right] = E_{t-1}\left[\alpha_t \ln C_t\right] &= E_{t-1}\left[\alpha_t \ln S_t^{\frac{\sigma}{\sigma-1}} \widetilde{y}_{S,t}\right] \\
&= E_{t-1}\left[\alpha_t \ln S_t^{\frac{\sigma}{\sigma-1}} \frac{\mu_t \widetilde{z}_{S,t}}{S_t W_t}\right] + cst \\
&= E_{t-1}\left[\alpha_t\left(\frac{1}{\sigma-1}\ln S_t + \ln\mu_t - \ln W_t + \ln\widetilde{z}_{S,t}\right)\right] + cst \\
&= E_{t-1}\left[\frac{1}{\sigma-1}\alpha_t \ln\frac{\mu_t}{W_t f_t} + \alpha_t\left(\ln\mu_t - \ln W_t\right) + \alpha_t \ln\left[\frac{\mu_{t-1} W_t f_t}{\mu_t W_{t-1} f_{E,t-1}} \frac{E_{t-1}\left[\alpha_t\right]}{\alpha_{t-1}}\right]^{\frac{1}{\kappa}}\right] + cst \\
&= E_{t-1}\left[\left(\frac{1}{\sigma-1} + 1 - \frac{1}{\kappa}\right)\alpha_t\left(\ln\mu_t - \ln W_t\right)\right] + cst' \\
&= \left(\frac{1}{\sigma-1} + 1 - \frac{1}{\kappa}\right)\left[E_{t-1}\left[\alpha_t \ln\mu_t\right] - \frac{E_{t-1}\left[\alpha_t\right]}{1+\varphi}\ln E_{t-1}\left[\mu_t^{1+\varphi}\right]\right] + cst'.
\end{aligned}
$$

The above is the expression (18).

The first order condition with respect to μ_t yields,

$$
\left(\frac{1}{\sigma-1} + 1 - \frac{1}{\kappa}\right)\left[\frac{\alpha_t}{\mu_t} - \frac{E_{t-1}\left[\alpha_t\right]}{E_{t-1}\left[\mu_t^{1+\varphi}\right]} \frac{\left(\mu_t\right)^{1+\varphi}}{\mu_t}\right] = 0
$$

It is shown that the optimal policy satisfies $\mu_t = \mu_0 \alpha_t^{\frac{1}{1+\varphi}}$.

D Wage Dynamics

The household maximizes the following utility by setting $W_t'(j)$.

$$
E_t \sum_{k=0}^{\infty} (\beta\vartheta)^k U_t(C_{t+k}(j),\ L_{t+k|t}(j))
$$

where $L_{t+k|t}(j)$ are the consumption and labor supply at $t+k$ under the preset wage rate $W_t'(j)$.

The first order condition yields

$$
W_t'(j) = \frac{\frac{\eta\theta}{(\theta-1)(1+\nu)} \sum_{k=0}^{\infty} \left(\beta\vartheta\right)^k E_t\left[L_{t+k|t}^{1+\varphi}(j)\right]}{\sum_{k=0}^{\infty} \left(\beta\vartheta\right)^k E_t\left[\frac{\alpha_{t+k}}{C_{t+k}} \frac{W_{t+k}}{P_{t+k}} L_{t+k|t}(j)\right]}.
$$

Using

$$L_{t+k|t}(j) = \left(\frac{W_t(j)}{W_{t+k}} \right)^{-\theta} L_{t+k},$$

we have (21).

Using the definition of wage index and the low of large number, nominal wage dynamics are given by

$$\left(\frac{W_t'}{W_t} \right)^{1-\theta} = \frac{1 - \vartheta \pi_t^{w\theta-1}}{\vartheta}$$

Combining the log-linearized above equation and (21), we have the following wage dynamics:

$$\pi_t^w = \beta E_t \left[\pi_{t+1}^w \right] - \frac{(1-\beta\vartheta)(1-\vartheta)}{(1+\theta\varphi)\vartheta} \widehat{\mu}_t^w.$$

E IRFs

Figure 5: IRFs with different κ

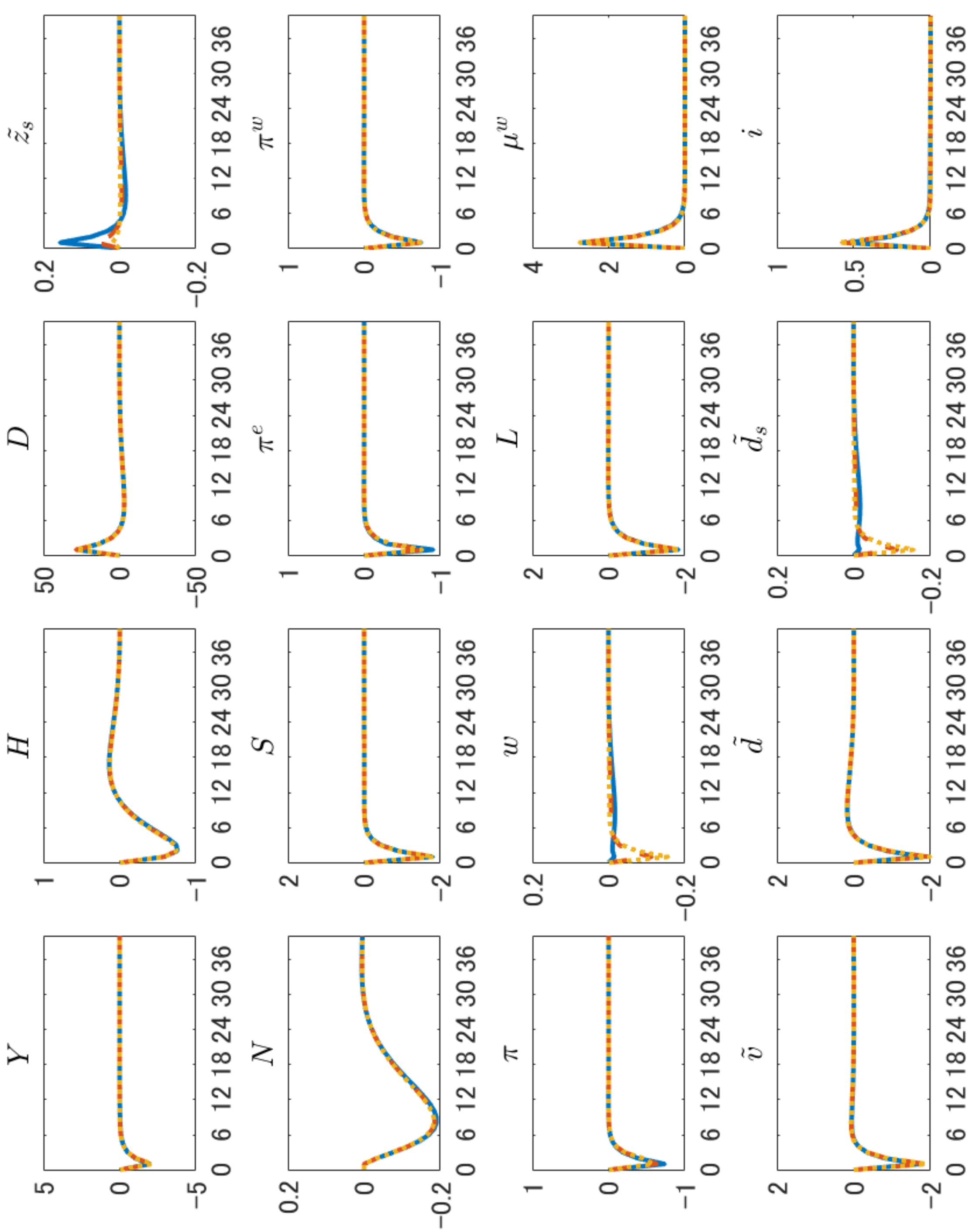


Figure 6: IRFs with different ω