# Technology and Demand Shocks in a Shopping Economy

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**Abstract**

We construct and estimate a business cycle model with search and matching frictions in the labor market and in the product market. We demonstrate that unemployment fluctuations are mostly demand-driven, while the technology shock accounts for the remaining 1/3 of the unemployment variance. At the same time, the technology shock is responsible for most of the variation in hiring and firing. These two findings are reconciled by the fact that the technology-driven labor turnover is mostly translated into a variation of the rate of churn.

Keywords: technology shocks, demand shocks, unemployment, business cycles.
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## 1 Introduction

How important are technology and demand shocks in driving the unemployment fluctuations? The real business cycle literature stemming from Kydland and Prescott (1982) famously concluded that business cycles are driven by shocks to technology. The new class of macroeconomic models with shopping frictions attempts to revisit this question. In particular, Michaillat and Saez (2015) incorporate search and matching frictions in the labor and the product markets into a general-disequilibrium model of Barro and Grossman (1971). They qualitatively conclude that the labor market fluctuations mostly reflect demand shocks rather than technology shocks.

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We complement these finding *quantitatively*. We construct a modern dynamic, stochastic, general equilibrium model which incorporates the frictional structure of markets from Michaillat and Saez (2015) while allowing for a more realistic setup of the labor market by including endogenous firing. The model is estimated on the US data using the Bayesian methods. We find that demand shocks, represented by the preference shock to the marginal utility from consumption and the monetary shock, account for 63% of the variance of unemployment, while the technology shock accounts for 37%. It would be premature, however, to conclude that technology shocks are of lesser importance for the labor market dynamics. In fact, technology is the major determinant of the volumes of workers fired and hired in our model, but technology-driven changes in turnover translate mostly into a variation in the rate of churn rather than the rate of unemployment.

In our model both the labor and the product markets are subject to search and matching frictions and nominal rigidities. Just as a firm posts a costly vacancy to hire a worker, a household embarks on costly shopping visits to purchase consumption goods. The probability of a successful match with a vendor depends, through the matching function, on the aggregate number of shopping visits and the aggregate production capacity. Crucially, as the demand for goods varies in response to shocks, producers experience fluctuations in both the price and the probability of trade. Facing worsening business conditions and sluggishly adjusting wages, producers strongly adjust the size of the work force. This intuitive transmission mechanism shows why demand shocks are so powerful in driving unemployment fluctuations in our model.

Our focus is on the labor market dynamics and we specialize the model in this direction by incorporating endogenous firing. Technology shocks prove to be important drivers of labor turnover. Due to nominal rigidities the demand for goods responds sluggishly to improvements in technology. As a result, the producers find it optimal to reduce employment in the short run, which is consistent with the empirical evidence of Gali (1999) and Basu et al. (2006). Underlying this response of the unemployment stock there is a sharp increase of the labor turnover: the firm is aggressively firing less productive workers and replacing them with new hires. This coincidence of firing and hiring — a churn — is an important feature of the US labor market (Burgess et al. 2000; Lazear and Spletzer 2012).

We calibrate the model using the Bayesian techniques on time series of US unemployment, consumption and the nominal interest rate. The model features two demand shocks: a preference shock to the marginal utility from consumption and a monetary policy shock, as well as a standard technology shock. The variance decomposition reveals that the unemployment is predominantly driven by the preference shock (56%), followed by the technology shock (37%) and the monetary policy shock (7%). While its impact on unemployment fluctuations is limited, the technology shock is the major force behind the fluctuations in hiring (94%) and firing (74%).

There is strong empirical evidence for search and matching frictions in the product markets. First, shopping is both costly and risky for consumers. In the US, individuals spend on average 42 minutes shopping daily (Petrosky-Nadeau et al. 2016) and face a non-trivial risk of 7.8% their desired products being temporarily unavailable in store (Bils 2016). On the other side of the market, frictions manifest themselves in the idle production capacity. Michaillat and Saez (2015) report that US workers are idle 14.8% and 17.3% of working time in nonmanufacturing sectors and in the manufacturing sector, respectively. Furthermore, insufficient demand is cited as the main reason for producing below the maximal capacity by 80% of plant managers (Boehm and Pandalai-Nayar 2018). Consistently with out model, both the shopping effort, measured by the time spent on shopping, and the capacity utilization are procyclical (Petrosky-Nadeau et al. 2016; Boehm and Pandalai-Nayar 2018).

The existing literature strongly supports incorporating shopping frictions into the business cycle models. Shopping frictions improve the propagation of the technology shocks (Petrosky-Nadeau and Wasmer 2015a), reconcile puzzles in international business cycles (Bai and Rios-Rull 2015) and are useful in explaining facts about inventories over the business cycles (Den Haan 2013; Duras 2016). More related to our work, the shopping frictions amplify the non-technology shocks, allowing to model deep recessions (Huo and Rios-Rull 2013). Bai et al. (2019) conclude that the preference shock similar to ours is a major force behind business cycle fluctuations, yet their model does not include unemployment.

The relative importance of technology and demand shocks for unemployment has been studied in the New Keynesian framework, which features oligopolistic competition and nominal rigidities. Galí et al. (2012) study the extension of the medium-scale DSGE model by Smets and Wouters (2003) with eight shocks and conclude that at the business cycle frequency demand shocks explain approximately 50% of the variance of unemployment, while the productivity shock explains less than 5%. In comparison, the approach of Michaillat and Saez (2015), on which we build on, allows to study unemployment and capacity utilization over a business cycle in a parsimonious and analytically tractable framework. As such, we view our findings as complementary to those of the New Keynesian literature.

## 2 Model

In this section we describe the building blocks of the economy: households, firms and the government, and we define the equilibrium.

### 2.1 Households

The representative household consists of a unit measure of members. Each household member inelastically supplies one unit of labor. Following Merz (1995) and Andolfatto

(1996), we assume that income and consumption is shared within the household, so that each member enjoys identical utility. Consequently, we will refer to the utility of the household rather than the utility of its individual member.

The product market is frictional. In order to purchase consumption $c$, a household member needs to make shopping visits $v_g$. Each successful visit allows to buy a unit of consumption good at a price $p$. Only a share $q_g$ of visits is successful, hence

$$c = q_g \cdot v_g. \tag{1}$$

A share of successful visits $q_g$ is an equilibrium object which, as we explain later, depends on the product market tightness. In addition, shopping visits, successful or not, incur a directly utility cost. This utility cost can be intuitively understood as a disutility from time or effort spent on shopping.

The household's period utility over consumption and shopping visits is $u\left(c, v_g, A_d\right)$, where $A_d$ is the aggregate preference shock which increases the marginal utility from consumption. Huo and Rios-Rull (2013) show that such preference shocks can be interpreted as an approximation for shocks to financial intermediation. We assume that $u$ is twice differentiable, strictly increasing in $c$, strictly decreasing in $v_g$ and concave in these two arguments. The household discounts future utility streams with a factor $\beta \in (0, 1)$. This formulation of preferences follows Bai et al. (2019).

The labor market operates as follows. At the beginning of a period, an employed household member losses the job with probability $\tilde{\sigma}$. Conditional on staying at the job, the member is paid a nominal wage $w$. If the member loses the job, he joins the pool of unemployed. Unemployed are paid a nominal benefit $b$. With probability $f_l$ an unemployed member is hired and starts the next period as an employee. Denote the share of household members who are employed at the beginning of the period by $N$. The household's employment rate at the beginning of the next period $N'$ is then

$$N' = (1 - \tilde{\sigma})N + f_l(1 - N + \tilde{\sigma}N). \tag{2}$$

The household holds bonds $a$ with a nominal interest rate $i$, but cannot borrow. In addition, the household pays a lump-sum tax $\tau$ and receives dividends $d$ from firms it owns. Denote the choice of next period bond holdings by $a'$ and the unemployment rate after the separations by $U = \tilde{\sigma}N$. The household budget constraint is

$$w(1 - U) + bU + (1 + i)a + d - \tau \geq pc + a'. \tag{3}$$

We formulate the household problem recursively. The relevant state is a vector $s = (a, N, A_d, A_z)$ consisting of, respectively, current bond holdings, the employment rate at the beginning of the period, the preference shock and the technology shock. The expected utility of a household at a state $s$ follows

$$V(s) = \max_{c,v_g,a'} u\left(c, v_g, A_d\right) + \beta \cdot \mathbb{E}\left[V(s') \mid s\right] \tag{4}$$

subject to the relation between consumption and shopping visits (1), the law of motion of the employment rate (2), the budget constraint (3), the laws of motion of the aggregate shocks $A_d$ and $A_z$ which we will specify later and the domain restrictions: $c \geq 0, v_g \geq 0, a' \geq 0$.

We use constraints to obtain expressions for $v_g$ and $a'$ and plug them into the Bellman equation. The first-order condition with respect to consumption is

$$u_c\left(c, v_g, A_d\right) + \frac{1}{q_g} \cdot u_{v_g}\left(c, v_g, A_d\right) = p\beta \cdot \mathbb{E}\left[V_a(s') \mid s\right] \tag{5}$$

and the envelope condition is

$$V_a(s) = \frac{1+i}{p}\left(u_c\left(c, v_g, A_d\right) + \frac{1}{q_g} \cdot u_{v_g}\left(c, v_g, A_d\right)\right). \tag{6}$$

In our framework consumption purchases require costly shopping visits. Consequently, the value of assets depends not only on the marginal utility from consumption, as in the standard model, but also on a marginal disutility from shopping effort and the probability with which each shopping visit is successful. Using the above equations, we can define a stochastic discount factor

$$\Delta(s, s') = \frac{p'}{1+i'} V_a(s') \cdot \left(\frac{p}{1+i} V_a(s)\right)^{-1}, \tag{7}$$

where $p'$ and $i'$ are the price and nominal interest rate in the state $s'$.

## 2.2 Firms

The representative firm operates a linear production technology with labor as the only input. The firm can adjust labor on two margins: by firing its workers or by creating vacancies. The firm's output is sold on the frictional product market, where only a fraction of firm's capacity is matched with the shopping household members.

Suppose that the firm starts a period with $n$ employees. First, a fraction $\sigma$ of employees separates from the firm for exogenous reasons. Second, the productivities of remaining workers are revealed. The productivity of each employee consists of two components: the aggregate technology shock $A_z \geq 0$ and the worker-specific productivity $a_z \geq 0$. The worker-specific component is drawn independently from the distribution $F$. Heterogeneous productivities induce selective firing of employees with $a_z$ below a chosen threshold $\tilde{a}_z$. Endogenous firing is subject to a cost, which we describe below. All the remaining workers are paid the nominal wage $w$.

The output capacity of the firm which starts a period with workforce $n$ and chooses a firing threshold $\tilde{a}_z$ is

$$A_z \int_{\tilde{a}_z}^{\infty} a_z dF(a_z) \cdot (1-\sigma)n. \tag{8}$$

The output capacity has three potential uses. First, the output capacity covers the cost of selective firing. Specifically, firing reduces the output capacity by $\phi F(\tilde{a}_z) \cdot (1-\sigma)n$, where $\phi > 0$ is the unit firing cost. Second, the output capacity covers the cost of vacancy creation. Job posting reduces the capacity by $\kappa_l v_l$, where $\kappa_l$ is the unit vacancy cost and $v_l$ is the number of posted vacancies.[1] The remaining output capacity is brought to the product market, where it is matched with the shopping household members.

Denote the output capacity which is brought to the product market by

$$T = A_z \int_{\tilde{a}_z}^{\infty} a_z dF(a_z) \cdot (1-\sigma)n - \phi F(\tilde{a}_z) \cdot (1-\sigma)n - \kappa_l v_l. \tag{9}$$

In the product market, the share $f_g$ of the capacity is matched with the shopping household members and produces consumption goods, which are sold at a unit price p. The rest of the output capacity is idle. Consequently, the share $f_g$ can be understood as capacity utilization and $Y = f_g T$ as output. Notice that, in contrast to the neoclassical paradigm, the output is not determined solely by the output capacity or the amount of production factors. It depends additionally on the rate $f_g$ at which consumers arrive and purchase goods. This means that output in our model is both supply- and demand-driven.

By the end of the period, the vacancies $v_l$ posted by the firm are being filled at the rate $q_l$. Consequently, the firm starts the next period with the workforce $n'$ which is equal to

$$n' = (1-\sigma)(1-F(a_z))n + q_l v_l. \tag{10}$$

The firm chooses its hiring and firing strategy in order to maximize the stream of real profits discounted by the stochastic discount factor of its owner - the household. The relevant state is $(n, s)$, where $n$ is the workforce at the beginning of the period and $s$ is the state of the household. Recall that the state of the household $s$ includes realizations of the aggregate shocks. The firm's real profit in state $(n, s)$ is given by the following maximization problem

$$J(n,s) = \max_{\tilde{a}_z, v_l, n'} f_g T - w/p \cdot (1-F(\tilde{a}_z)) \cdot (1-\sigma)n + \mathbb{E}\left[\Delta(s,s')J(n',s') \mid s\right] \tag{11}$$

[1] Alternatively, one could assume that recruitment and firing costs are expressed in consumption goods rather than in the output capacity. This, however, would require the firm to exert shopping effort in the product market, which may increase market congestion and potentially crowd out private consumption. Specifying the costs in the units of output capacity avoids this complication.

subject to the law of motion of the workforce (10), the laws of motion of household's state and the domain restrictions: $\tilde{a}_z \geq 0, v_l \geq 0, n' \geq 0$.

The solution to the firm's optimization problem can be characterized with three equations. First is the necessary condition with respect to the number of vacancies

$$f_g \kappa_l = q_l \cdot \mathbb{E}\left[\Delta(s,s') J_n(n',s') \mid s\right]. \tag{12}$$

It equates the marginal cost of posting one additional vacancy (equal to the real value of foregone output capacity that could otherwise be sold with probability $f_g$) with the marginal benefit from higher workforce next period, multiplied by the rate at which the vacancy is filled.

The second equation describes the optimal firing threshold $\tilde{a}_z$

$$\frac{w}{p} = f_g A_z \tilde{a}_z + f_g \phi + \mathbb{E}\left[\Delta(s,s') \cdot J_n(n',s') \mid s\right]. \tag{13}$$

The left-hand side is the marginal benefit of increasing the firing threshold due to lower wage bill. The marginal cost, on the right-hand side, consists of three elements: the reduction of real sales, the real value of firing cost and the reduction of discounted future profits due to lower workforce in the next period.

The third equation is the envelope condition, which can be expressed as

$$\frac{J_n(n,s)}{1-\sigma} = (1 - F(\tilde{a}_z)) \left( f_g A_z \mathbb{E}\left[a_z \mid a_z \geq \tilde{a}_z\right] - \frac{w}{p} + \frac{f_g \kappa_l}{q_l} \right) - F(\tilde{a}_z) f_g \phi. \tag{14}$$

The left-hand side is the value to the firm of an additional job which survives the exogenous separation. With probability $(1 - F(\tilde{a}_z))$ this job survives the selective firing and, hence, it increases the output capacity of the firm, contributes to a higher wage bill and lowers future vacancy posting expenses. With the remaining probability the job is not maintained and the firm needs to cover the real cost of firing the worker.

## 2.3 Matching in the product market and the labor market

In the product market, matching between shopping visits $v_g$ and available output capacity $T$ is described by a constant returns to scale function $M^g(v_g, T)$ which increases in each argument. It is useful to define a product market tightness $x_g = v_g/T$. Then the capacity utilization $f_g$ and the share of successful visits $q_g$ follow

$$f_g = \frac{M^g(v_g,T)}{T} = M^g(x_g, 1) \quad \text{and} \quad q_g = \frac{M^g(v_g,T)}{v_g} = M^g\left(1, \frac{1}{x_g}\right). \tag{15}$$

Naturally, the capacity utilization is increasing with the product market tightness $x_g$, while the share of successful visits is decreasing with $x_g$.

Matching in the labor market is analogous to that from the product market. In particular, the labor matching function is $M^l(v_l, U)$ which has constant returns to scale and is increasing in both arguments. Define the labor market tightness by $x_l = v_l/U$. The job finding rate $f_l$ and the vacancy filling rate $q_l$ are

$$f_l = \frac{M^l(v_l, U)}{U} = M^l(x_l, 1) \quad \text{and} \quad q_l = \frac{M^l(v_l, U)}{v_l} = M^l\left(1, \frac{1}{x_l}\right). \tag{16}$$

## 2.4 Price and wage setting

As argued by Michaillat and Saez (2015), a decentralized market features two variables that equate demand and supply: a price and a tightness. In other words, there are two equilibrium variables and only one equilibrium condition (which states that demand equals supply) and, therefore, there are infinitely many combinations of prices and tightnesses that satisfy that condition. Putting it differently, there infinitely many price mechanisms consistent with the market equilibrium. To handle this problem of indeterminacy, several microfounded price-setting protocols were proposed (e.g., Nash Bargaining or Competitive Search Equilibrium). Additionally, to solve this issue, economists have used hybrid mechanism that combine a microfounded protocol with an ad hoc component that enables to replicate the empirical properties of prices. Motivated by the latter approach, when resolving the indeterminacy of wages in the labor market, we follow the method suggested by Hall (2005), which assumes that wages are governed by an adaptive process, according to which the value of wage in the next period is a weighted average of its value in the current period and of a microfounded component that corresponds to the next period. This element, in turn, is pinned down by the Nash Bargaining protocol. When considering price-setting in the market for goods, the microfounded component is the price that decentralizes the optimal level of search effort associated with the corresponding social planner problem, which echoes the optimality achieved by the Competitive Search Equilibrium protocol by Moen (1997), while the ad hoc component imposes an increasing relationship between product prices and product market tightness. The latter aims at capturing the most basic pattern exhibited by prices: their positive response to a rise in demand and negative response to higher supply. As the rise in product market tightness can be generated either by higher demand or lower supply (described by an increase in $v_g$ and a drop in $T$, respectively), the imposed positive relationship between prices and product market tightness enables to capture that fundamental feature of how prices react to demand and supply shocks.

More specifically, the microfounded component $p_{opt}$, corresponding to price-setting in the product market, solves the following planner's problem:

$$W(s) = \max_{c, v_g, \tilde{a}_z, N', T, U} \left\{ u(c, v_g, A_d) + \beta \cdot \mathbb{E}[W(s') \mid s] \right\} \tag{17}$$

subject to

$$c = M^g(v_g, T), \tag{18}$$

$$N' = (1-\sigma)\cdot N \cdot \int_{\tilde{a}_z}^{+\infty} f(a_z)\, da_z + M^l(v_l, U), \tag{19}$$

where $W$ is planner's value function and $s$ is the state of the economy which we defined earlier. The first-order condition that pins down the optimal level of consumer search effort reads:

$$u_c(c, v_g, A_d)\cdot M^g_{v_g}(v_g, T) + u_{v_g}(c, v_g, A_d) = 0. \tag{20}$$

Therefore, to align individual search incentives described by (5) with the optimal ones described by (20), $p_{opt}$ has to satisfy[2]

$$p_{opt} = \frac{u_c(c, v_g, A_d)\cdot\left[1 + M^g_{v_g}(v_g, T)\right] + u_{v_g}(c, v_g, A_d)\cdot\left[1 + \frac{1}{q_g}\right]}{\beta\cdot\mathbb{E}[V_a(s')\mid s]}.$$

Now, to introduce the ad hoc component associated with product market tightness $x_g$, we assume that prices $p$ satisfies:

$$p = p^{ss}_{opt}\cdot\left(\frac{x_g}{x_g^{ss}}\right)^{\xi_g} \tag{21}$$

where $\xi_g > 0$ measures the responsiveness of prices to demand and supply shocks and superscript $ss$ denotes the steady-state value. An analogous approach, according to which changes in prices are governed by a function that relies on some ad hoc assumptions can be found, for example, in Den Haan et al. (2018).

Let us turn to wage-setting in the labor market. The microfounded component $w_{Nash}$ corresponds to solution of the standard Nash Bargaining problem as in Pissarides (2000), which is assumed to take place after separations. Let us begin the description by determining the surplus of the worker (i.e. the value of being employed):

$$V^e(s) = \frac{w}{p} + \mathbb{E}\left[\Delta(s,s')\cdot\left(\left(1-\tilde{\sigma}'\right)V^e(s') + \tilde{\sigma}'V^u(s')\right)\mid s\right] \tag{22}$$

where $\tilde{\sigma}'$ is the separation rate next period. Note that, according to our timing convention, an worker who is unemployed today will be hired and will receive a wage next period with probability $f_l(1-\tilde{\sigma}')$. Consequently, the value of being unemployed is

$$V^u(s) = \frac{b}{p} + \zeta + \mathbb{E}\left[\Delta(s,s')\cdot\left(f_l\left(1-\tilde{\sigma}'\right)V^e(s') + \left(1 - f_l\left(1-\tilde{\sigma}'\right)\right)V^u(s')\right)\mid s\right] \tag{23}$$

where, following Zanetti (2011), $\zeta \geq 0$ accounts for the non-monetary benefits of being unemployed, such as leisure and home production. Thus, a worker's surplus from a

[2] To check that it is indeed the case one can plug the expression for $p_{opt}$ into (5) to obtain (20).

successful match is given by $V^e(s) - V^u(s)$. The firm's surplus from a match that survived separations is

$$\tilde{J}_n(n,s) = f_g A_z \mathbb{E}\left[a_z \mid a_z \geq \tilde{a}_z\right] - \frac{w}{p} + \frac{f_g \kappa_l}{q_l}, \tag{24}$$

where we assumed that the firm is not blamed for unsuccessful negotiations. Denote the bargaining power of workers by $\lambda$. The solution to the Nash bargaining problem satisfies

$$\lambda \cdot \tilde{J}_n(n,s) = (1-\lambda) \cdot \left[V^e(s) - V^u(s)\right], \tag{25}$$

which yields a real wage

$$\begin{aligned} \frac{w_{Nash}}{p} &= \lambda f_g A_z \mathbb{E}\left[a_z | a_z > \tilde{a}_z\right] + (1-\lambda) \cdot \left(\frac{b}{p} + \zeta\right) \\ &\quad + \lambda \mathbb{E}\left[\Delta(s,s') \cdot \left(f_l J_n(n',s') - (1-f_l)(1-\sigma) F\left(\tilde{a}_z'\right) f_g' \phi\right) \mid s\right]. \end{aligned} \tag{26}$$

As mentioned before, we follow Hall (2005) and postulate an adaptive wage-setting process, in which next period wage is a weighted average of the current nominal wage and the microfounded component $w_{Nash}$, which we discussed above. Thus,

$$w' = (1-\xi_w) w + \xi_w w'_{Nash} \tag{27}$$

where $\xi_w \in [0,1]$ controls the stickiness of nominal wages.

## 2.5 Government

The government consists of two branches: a fiscal authority and a central bank. The fiscal authority collects taxes to finance unemployment benefits subject to a balanced budget:

$$\tau = bU. \tag{28}$$

The value of unemployment benefits is linked to steady state value of nominal wage $w^{ss}$ according to

$$b = \psi_b w^{ss}, \tag{29}$$

where $\psi_b \in (0,1)$ is the steady state replacement rate. The central bank sets the nominal interest rate according to a standard Taylor rule:

$$i' = \rho_i i + (1-\rho_i) \cdot \left(i^{ss} + \Phi_\Pi \cdot \left(\frac{p'}{p} - 1\right) + \Phi_y \cdot \frac{Y' - Y^{ss}}{Y^{ss}}\right) + \epsilon_i' \tag{30}$$

where $\rho_i \in (0,1)$ captures the interest rate inertia, $\Phi_\Pi$ and $\Phi_y$ are positive weights placed on, respectively, inflation and the deviation of output from its steady state value, and $\epsilon_i' \sim N(0, \sigma_i^2)$ is a monetary policy shock.

### 2.6 Equilibrium conditions

In equilibrium, the share of employed household members at the beginning of period is consistent with the initial workforce in the firm

$$N = n \tag{31}$$

and the workers' separation rate $\tilde{\sigma}$ is consistent with the firm's firing strategy

$$\tilde{\sigma} = \sigma + (1 - \sigma)F(a_z). \tag{32}$$

Bonds are in zero net supply, and hence the bond market clearing requires

$$a'(s) = 0 \tag{33}$$

for all values of state $s$. Finally, the preference and the technology shocks follow AR(1) processes

$$\log A'_d = \rho_d \log A_d + \epsilon'_d \tag{34}$$

$$\log A'_z = \rho_z \log A_z + \epsilon'_z, \tag{35}$$

with $\epsilon'_d \sim N(0, \sigma_d^2)$ and $\epsilon'_z \sim N(0, \sigma_z^2)$.

Now we can define the equilibrium.

**Definition.** Recursive Competitive Equilibrium consists of value functions $V$ and $J$, household policy functions $a'$, $c$, $v_g$, firm's policy functions $v_l$, $\tilde{a}_z$, $n'$, prices $p$, $w$, $i$, equilibrium objects $q_g$, $f_g$, $q_l$, $f_l$, $\tilde{\sigma}$, $\tau$, $d$, $b$, $\Delta$ and exogenous shocks $\epsilon_d, \epsilon_z, \epsilon_i$ such that:

1. $V$ solves the household's problem taking prices and equilibrium objects as given, and $a'$, $c$, $v_g$ are the associated policy functions.
2. $J$ solves the firm's problem taking prices and equilibrium objects as given, and $v_l$, $\tilde{a}_z$, $n'$ are the associated policy functions.
3. The unemployment benefit $b$ and the tax $\tau$ satisfy (28) and (29).
4. The product price satisfies (21), the nominal wage satisfies (27) and the interest rate follows the Taylor rule (30).
5. The market clearing conditions (31) and (33), the matching conditions (15) and (16) as well as the consistency condition (32) are satisfied.
6. The preference and the technology shocks follow (34) and (35), respectively.

## 3 Parametrization of the model

### 3.1 Functional forms

We consider a standard CRRA specification for households utility of consumption augmented with a linear term capturing the disutility of search for goods (treatment as in Duras 2016 and Bai and Rios-Rull 2015).

$$u\left(c, v_g | A_d\right) = A_d \frac{c^{1-\theta}}{1-\theta} - \kappa_g v_g \tag{36}$$

We follow Michaillat and Saez (2015) and assume that matching process on both the product and the labor market is symmetric and governed by the constant returns to scale function proposed by Den Haan et al. (2000). This specification guarantees that the derived flow rates are between zero and one.

$$M^g\left(v_g, T\right) = \left(T^{-\alpha_g} + v_g^{-\alpha_g}\right)^{-\frac{1}{\alpha_g}} \tag{37}$$

$$M^l\left(v_l, U\right) = \left(U^{-\alpha_l} + v_l^{-\alpha_l}\right)^{-\frac{1}{\alpha_l}} \tag{38}$$

The idiosyncratic component of workers' productivity $a_z$ is assumed to be uniformly distributed with support given by $[0, a_H]$.

### 3.2 Calibration

We start by calibrating the parameters relevant for the steady state allocation. To do so we utilize both the results from other studies and evidence from the US data. The results are summarized in Table 1.

We set the quarterly discount rate $\beta$ to 0.99, as is commonly done in the literature (e.g. Smets and Wouters 2003), which implies the annualized interest rate of 4%. We set the inverse elasticity of intertemporal substitution $\theta$ to 2 following Bai et al. (2019). The upper bound of idiosyncratic productivity is fixed at $a_H = 2$, so that the mean of its distribution is equal to one. Parameters $\kappa_G$ (costs of search) and $\alpha_g$(curvature of matching function) control the extent of product market frictions. We calibrate both parameters by targeting the US data on the capacity utilization in industry (a proxy for $f_g$) and the cost of searching in the goods market in terms of households foregone income as reported in Petrosky-Nadeau and Wasmer (2015b).

The labor market parameters are calibrated as follows. We set the workers bargaining power $\lambda$ to 0.5 following Zanetti (2011). The matching function is parametrized as is Den Haan et al. (2000), i.e. $\alpha_L = 1.27$. Following Hagedorn and Manovskii (2008), the recruitment cost $(\kappa_L)$ per filled vacancy is set to 4.5% of the steady-state wage level. The ratio of unemployment benefits to steady-state wages $(\psi_b)$ is chosen as a product of the replacement rate as published by OECD and the proportion of the unemployed in the US eligible for the payments (around 49%).

The remaining parameters ($\sigma$, $\phi$, $\zeta$) are fixed to match the long term average unemployment rate, the flow rate out of unemployment (corresponding to the probability that unemployed finds a job, $f_l$) and the ratio between the exogenous and the endogenous job destruction rates for the US, as reported by Bukowski et al. (2011).

Table 1: Calibration targets and parameter values

**Parameters set exogenously**

| | | |
|---|---|---|
| Risk aversion | $\theta$ | 2 |
| Range of idiosyncratic productivity variation | $a_H$ | 2 |
| Workers bargaining power | $\lambda$ | 0.5 |
| Curvature of matching function in the labor market | $\alpha_L$ | 1.27 |

**Parameters matched to the US data**

| **Target** | | **Parameter** | |
|---|---|---|---|
| Real interest rate | 4% | $\beta$ | 0.99 |
| Cost of shopping in terms of income | 7% | $\kappa_g$ | $2 \cdot 10^{-5}$ |
| Capacity utilization in manufacturing | 0.81 | $\alpha_g$ | 0.31 |
| Unemployment rate | 6.1% | $\zeta$ | 0.56 |
| Quarterly outflow from unemployment | 57% | $\sigma$ | 0.02 |
| Ratio of endogenous to exogenous job destruction | 0.85 | $\phi$ | 0.92 |
| Ratio of hiring cost to real wage | 4.5% | $\kappa_L$ | 0.03 |
| UB replacement rate $\times$ coverage | 0.27 | $\psi_b$ | 0.27 |

### 3.3 Estimation

We use the Bayesian methods to estimate the remaining ten parameters: the parameters of the stochastic processes ($\rho_z$, $\rho_d$, $\sigma_z$, $\sigma_d$, $\sigma_i$), the strength of nominal rigidities ($\xi_w$ and $\xi_p$) and the parameters of the Tylor rule ($\rho_i$, $\Phi_\Pi$, $\Phi_y$). As observable variables, we use the HP-filtered series of unemployment rate, consumption and 3-month interest rates from 1970Q1 to 2017Q4.[3] Importantly, observing the unemployment rate and consumption allows as to differentiate between the technology and the preference shocks. While the former shock implies a positive correlation between both variables, for the latter the opposite is true. We use the Kalman filter in the estimation process and a standard

[3]The data on the unemployment rate comes from the Bureau of Labor Statistics. The sources for consumption and interest rate series are, accordingly, Bureau of Economic Analysis and Reuters. We use the one-sided version of HP-filter to overcome the well-known problem that a standard double-sided HP-filter is not purely backward-looking. We set the HP-filter parameter $\lambda$ to 1600.

Table 2: Prior and posterior modes of estimated parameters

| **Parameter** | $\rho_z$ | $\sigma_z$ | $\rho_d$ | $\sigma_d$ | $\sigma_i$ | $\xi_p$ | $\xi_w$ | $\rho_i$ | $\Phi_p$ | $\Phi_y$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **Posterior** | 0.78 | 0.009 | 0.91 | 0.05 | 0.007 | 0.007 | 0.3 | 0.70 | 1.52 | 0.9 |
| **Prior** | 0.5 | 0.07 | 0.5 | 0.07 | 0.01 | 0.5 | 0.3 | 0.85 | 1.5 | 0.5 |
| **Distribution** | Beta | Inverse Gamma | Beta | Inverse Gamma | Inverse Gamma | Beta | Beta | Beta | Normal | Normal |

MCMC algorithm to obtain posterior densities for estimated parameters.

The prior distributions for the parameters governing the exogenous shocks and the wage inertia are set as in Smets and Wouters (2007). For Taylor rule parameters we refer to Christoffel et al. (2009), although we allow for a higher variance in the relevant prior distributions to account for the differences in the model setup. As the price setting mechanism in our model is different from the Calvo pricing used in both above-mentioned studies, we set a very loose prior on the price rigidity parameter.

The results of the estimation are presented in Table 2. While most estimates fall into a range of typical values, one should note a very high degree of price rigidity: $\xi_p = 0.007$. It implies a very limited response of price to the fluctuations of the product market tightness.

## 4 Results

We present the asymptotic contributions of each shock to the variance of key variables in Table 3. The preference shock explains 56% of the variance of unemployment and 84% of the variance of consumption (our proxy for GDP) over the business cycle. In contrast, the technology shock explains 37% and 2% of the variance of unemployment and consumption, respectively. Therefore, we quantitatively confirm the conclusion of Michaillat and Saez (2015) that the unemployment fluctuations are mostly demand-driven. We also support the finding of Bai et al. (2019) that consumption and output fluctuations are mostly generated by the preference shock. While the technology shocks are less important for the dynamics of unemployment and consumption, they are the main contributors to the variance of vacancy creation, firing and wages. The role of the monetary shock, apart from its obvious impact on the interest rate, is limited.

Table 3: Unconditional variance decomposition for selected variables (%)

| | c | T | u | $\tilde{a}_z$ | $v_L$ | w | p | $f_g$ | $i$ |
|---|---|---|---|---|---|---|---|---|---|
| $\epsilon_z$ | 2 | 66 | 37 | 72 | 94 | 66 | 69 | 69 | 1 |
| $\epsilon_d$ | 84 | 30 | 56 | 22 | 5 | 31 | 26 | 26 | 55 |
| $\epsilon_i$ | 13 | 4 | 7 | 6 | 1 | 2 | 6 | 6 | 44 |

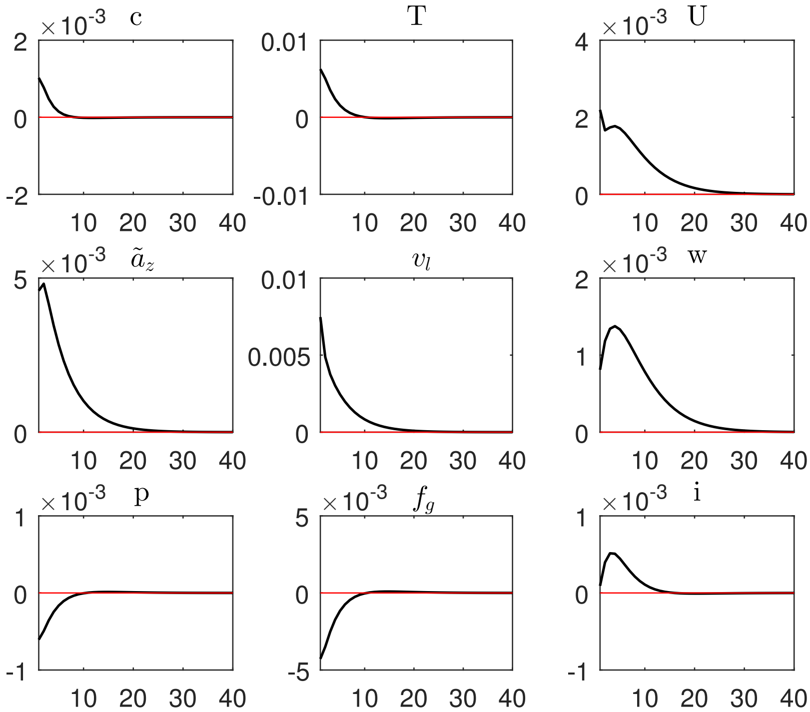
We dissect the impact of shocks on the economy by analyzing impulse response functions of a technology shock (Figure 1) and a preference shock (Figure 2). While both innovations trigger a spike in consumption and production capacity, underlying mechanisms are different. A positive technology shock directly affects firms' production capacity, which runs above the steady-state level for a number of quarters despite lower employment. As this translates to lower product market tightness, consumers are able to reach higher consumption level even with a slightly lower search effort compared to the steady state. In contrast, a positive preference shock induces households to put more effort into search for products, which translates into higher consumption and higher product market tightness. Firms are facing higher demand, which manifests itself with a higher probability of goods being sold, reduce firing and, hence, increase the production capacity. What is common for both preference and technology shocks is that they both increase instant marginal revenue and expected future returns from employing a worker, which results in a wage growth and a higher number of vacancies posted by the firms.

The key difference between technology and preference shocks is in how they affect unemployment. While a positive preference shock leads to lower unemployment, a positive technology innovation leads to higher unemployment. An employment drop following a technological improvement has been documented empirically by Gali (1999) and Basu et al. (2006). The intuition is as follows. Higher productivity mechanically implies higher productive capacity, which, due to nominal rigidities, reduces the tightness on the product market and makes it more difficult for firms to sell. Recall that production capacity can be also used to cover the firing cost and vacancy posting cost. As selling goods becomes more difficult, the firm prefers to spent the available capacity on laying off the least productive workers and replacing some of them with new hires, which results in a higher rate of churn: a coincidence of firing and hiring new workers at the same firm (Burgess et al. 2000; Lazear and Spletzer 2012). Furthermore, since hiring requires more time than firing, which additionally contributes to the employment drop. Importantly, we see that the technology shock leads to a positive correlation between the churn and the unemployment: a technology improvement leads to an intensified turnover of workers together with a lower overall employment level.

Regarding the impulse response to a monetary shock (Figure 3), the key variables respond in line with a general presumption that monetary policy tightening dampens both the inflation and the economic activity. However, monetary shocks are of limited relevance to the business cycle fluctuations of most variables in our model and, thus, we abstain from more detailed discussion on their propagation mechanisms.

Our findings confirm the results of Michaillat and Saez (2015) that in the models featuring product market frictions the demand shocks are the main determinant of unemployment fluctuations. However, as we work with a richer model fitted to the US data, we can add new angles to these results. Firstly, we are able to quantify the respective contribution of both the demand and the supply shocks to the variance of unemploy-

Figure 1: Responses to a positive technology shock




ment and other aggregates. While we confirm that preference shocks are able to explain most of the unemployment variance, approximately $1/3$ of the variance can be attributed to technology shocks. Furthermore, the role of technology shocks is larger when other labor market variables like wages, vacancy posting and layoffs are studied. Secondly, we note that technology shocks are unlikely to be a major driver of the unemployment fluctuations not only because they tend to generate a negative correlation between consumption and capacity utilization, as discussed in Michaillat and Saez (2015), but also for two more reasons. First, the technology shocks imply a negative correlation between employment and output, which is at odds with the data. Second, the technology shocks imply a positive correlation between the unemployment and the churn on the labor market. Lazear and Spletzer (2012) demonstrated that during the Great Recession the rate of churn has dropped together with the level of employment, which indicates that the technology shock did not play a major role in this slowdown.

Figure 2: Responses to a positive preference shock

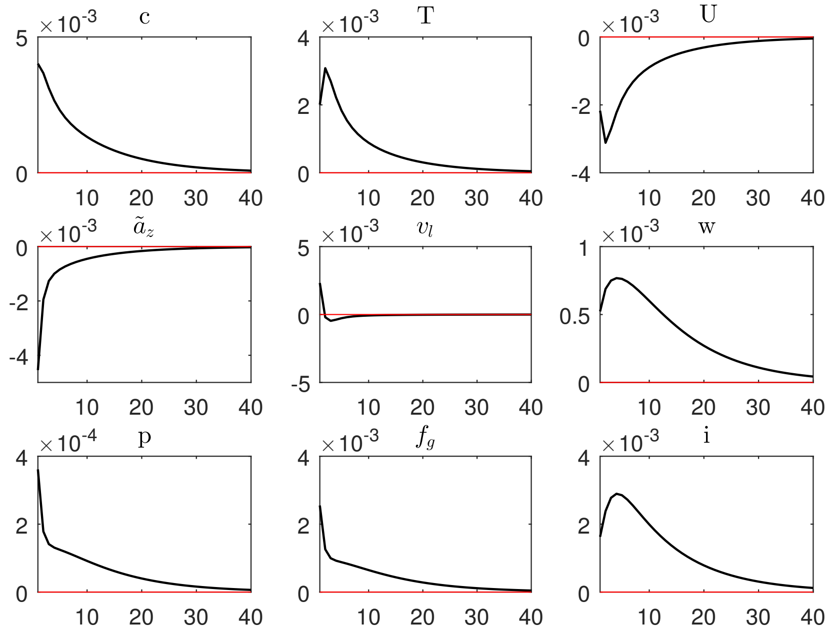
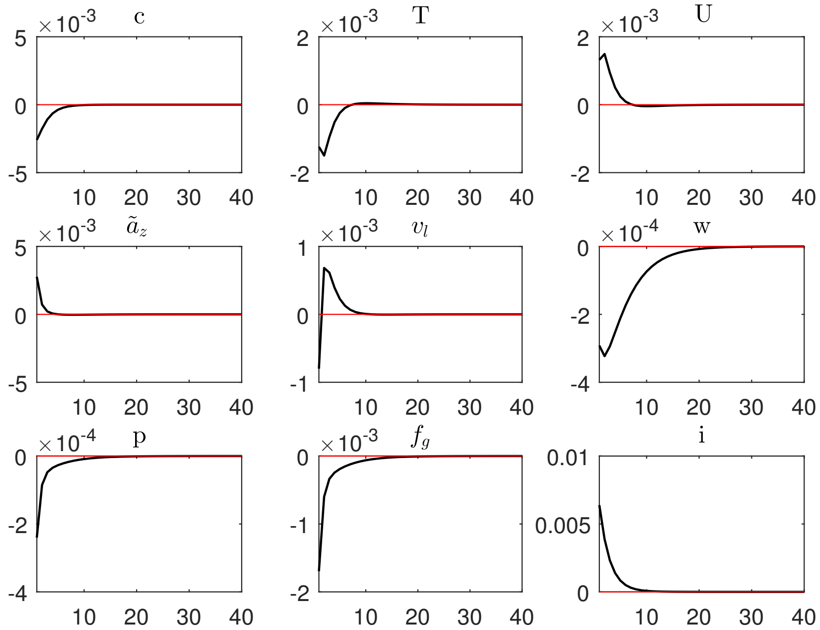



Figure 3: Responses to a positive monetary shock



## 5 Conclusions

In this paper we use an estimated business cycle model with shopping frictions to demonstrate that the demand shocks account for most of the variance of unemployment in US, while the technology shocks account for little more than 1/3 of the variance. Hence, we quantitatively support the conclusions of Michaillat and Saez (2015) regarding unemployment fluctuations being mostly demand-driven. More broadly, our paper contributes to the new strand of literature incorporating the search and matching frictions in the product market into the business cycle models.

Compared to other studies (e.g. Michaillat and Saez 2015; Huo and Rios-Rull 2013; Petrosky-Nadeau and Wasmer 2015b; Bai et al. 2019) our model features endogenous job destruction. We show that although the technology shocks have a limited impact on the unemployment fluctuations, they explain most of the variation in both hiring and firing. Hence, the technology driven labor turnover is mostly translated into fluctuations of the rate of churn rather than the rate of unemployment.

Our analysis can be extended in a number of directions. One of the avenues of research is the design of labor market institutions in an economy where the demand has a productive role. Landais et al. (2018b,a) examine how unemployment benefits should vary over the business cycle in a framework related to ours. A similar investigation could be conducted for other policy instruments, e.g. the mandated severance pay. Second, in our framework the main force behind the unemployment fluctuations is an exogenous shock to the marginal utility from consumption. A natural extension of our framework would be to provide explicit microfundations for this shock, for instance with shocks to wealth or to financial intermediation as in Huo and Rios-Rull (2013).

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