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Highlights

- Study model with endogenous countercyclical income risk.
- Model combines incomplete markets, nominal rigidities and labor market frictions.
- Model features amplification of shocks due to goods-labor markets interaction.
- Study impact of job separation and search efficiency shocks.
- Model can account for persistent drop in job finding rate during Great Recession.

Job Uncertainty and Deep Recessions

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Abstract

We study a model where households are subject to uninsurable unemployment risk, price setting is subject to nominal rigidities, and the labor market is characterized by matching frictions and inflexible wages. Higher risk of job loss and worsening job finding prospects during unemployment depress goods demand because of a precautionary savings motive. Lower goods demand reduces job vacancies and the job finding rate producing motion an amplification mechanism due to endogenous countercyclical income risk. Amplification derives from the combination of incomplete financial markets and frictional goods and labor markets. The model can account for key features of the Great Recession.

Keywords: Job uncertainty; unemployment; endogenous countercyclical income risk; amplification;

JEL classification: E21, E24, E31, E32, E52

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1. Introduction

The U.S. and many other Western economies have still not fully recovered from the Great Recession, the longest and deepest recession since the 1930's. The U.S. labor market outcomes during the Great Recession have been particularly grave involving not only a persistent rise in the level of unemployment, but also a surge in the share of longer-term unemployed workers. This paper proposes a macroeconomic theory that combines frictions in goods, labor and financial markets in which such labor market weaknesses are amplified. We apply the theory to the Great Recession and argue that the amplification mechanism helps in understanding the severity of the Great Recession.

We consider a model in which workers face job loss risk during employment and uncertain job finding prospects during unemployment. Workers cannot purchase unemployment insurance contracts and rely on government-provided unemployment benefits and private savings for consumption smoothing. This is embedded in a macro model with monopolistically competitive firms that face nominal rigidities in price setting and inflexible real wages.[1] Nominal rigidities is a simple way of allowing fluctuations in aggregate demand to impact on equilibrium allocations while the assumption of rigid wages is motivated by the lack of a decline in real wages in the U.S. during the Great Recession.

The labor market is modelled in a Diamond-Mortensen-Pissarides style matching framework extended with heterogeneity in workers' search efficiency that emerge either upon job loss (unobserved heterogeneity) or during an unemployment spell (negative duration dependence).[2] This aspect allows us to address the surge in longer-term unemployment but matters also for job uncertainty. The model is closed by introducing a fiscal authority that provides unemployment benefits and a monetary authority that sets the short-term nominal interest rate. We allow for aggregate shocks to the job separation rate and to the probability that unemployed workers have low search efficiency.

In this setting, changes in the risk of job loss or in the probability of finding a new job during unemployment impact on aggregate demand through employed workers' precautionary savings. Worsening labor market conditions can contract goods demand contraction by far more than the income loss of the workers that actually suffer a job loss.[3] Due to nominal rigidities, declining goods demand leads firms to post fewer vacancies reducing the job finding rate which further contracts goods demand thereby producing amplification. We simulate a calibrated version of the model in response to the short burst in the rate of inflow to unemployment observed in the U.S. at the onset of the Great Recession and to shocks to the risk of becoming a low search efficient unemployed worker. The model produces a rise in the unemployment rate and a drop in vacancy postings very similar to their empirical counterparts during the Great Recession. The model is also consistent with the movements along and the outward shift of the Beveridge curve observed in the Great Recession.

It is the combination of frictions in financial, goods and labor markets that generates amplification. Insurance against idiosyncratic risk neutralizes the amplification mechanism by removing the incentive to engage in precautionary savings against idiosyncratic risk. Absent nominal rigidities, price adjustments eliminate the transmission of shocks to labor demand. Fully flexible wages moderate the amplification mechanism unless workers have little bargaining power. Aggressive monetary policy can also neutralize the amplification mechanism by inducing price flexibility. We also show that the local indeterminacy region of the parameter space is large and depends crucially on agents' risk aversion.

We are not the first to study the impact of unemployment risks on the economy. Krusell and Smith (1999) and Krusell et al (2009) examine the impact of short-term and long-term unemployment risks with self-insurance. Challe and Ragot (2015) and Challe et al (2016) study like us the impact of precautionary savings in an incomplete markets setting. Guerrieri and Lorenzoni (2015) examine an incomplete markets setting with nominal rigidities focusing upon the impact of tightening borrowing constraints. den Haan, Rendahl and Riegler (2017) examine the importance of portfolio choices for the impact of unemployment risk in an incomplete markets setting. Gornemann, Kuester and Nakajima (2012) and McKay and Reis (2016) both study incomplete markets models with labor and goods market frictions but focus upon very different questions from us. Gornemann, Kuester and Nakajima (2012) examine the distributional effects of monetary policy when agents face unemployment risk while McKay and Reis (2016) focus upon the impact of automatic fiscal stabilizers.

Our analysis also relates to the literature on 'uncertainty shocks' that has followed Bloom (2009). However, whilst much of the existing literature has emphasized the impact of changes in second moments of aggregate shocks, we stress the effects of changes in the first moments of job separation and job finding rates. An interesting aspect of this is that uncertainty is partially endogenous and countercyclical.[4]

[1] For our quantitative evaluation, we only require that real wages are *downward* rigid.

[2] Ahn and Hamilton (2016) and Hornstein (2011) investigate the importance of duration dependence and heterogeneity for the increase in unemployment during the Great Recession.

[3] Carroll and Dunn (1997) and Carroll, Dynan and Krane (2004) also stress the impact of labor market uncertainties on demand due to precautionary savings. In our model, the equilibrium impact on *savings* is zero but precautionary savings matter for the real interest rates and for the equilibrium allocation.

[4] Leduc and Liu (2016) provide time-series evidence that changes in 'uncertainty' impact on aggregate demand and argue that labor market

2. The Great Recession and the Labor Market

The Great Recession lasted 18 months (December 2007 - June 2009), the longest since the Great Depression, and it triggered a major deterioration of U.S. labor market conditions. The unemployment rate rose from 4.7 percent in July 2007 to 10 percent by October 2009, and subsequently remained stubbornly high, see Figure 1. The increase in unemployment witnessed during this episode is large but not out of line with previous U.S. recessions, but compared to other recessions, the rise in unemployment was very persistent.

The flows in and out of unemployment provide useful insights into the determinants of unemployment. Figure 1 also illustrates the average instantaneous unemployment outflow rate, $\mathbf{p}_t^f = \frac{\mathbf{m}_t}{\mathbf{u}_{t-1}}$, and the average unemployment inflow rate, $\mathbf{p}_t^l = \frac{\mathbf{e}_t}{\mathbf{n}_{t-1}}$ ($\mathbf{u}_t$ is the level of unemployment, $\mathbf{n}_t$ the stock of employment, $\mathbf{m}_t$ the flow of workers from unemployment to employment, and $\mathbf{e}_t$ the number of job separations).[5] The initial rise in unemployment was triggered by a rapid increase in the unemployment inflow rate in the period from early 2008 to late 2009 but its persistence derives from a large and stubborn decline in the unemployment outflow rate which dropped dramatically during 2009 and has since struggled to recover.

Longer term unemployment surged during the Great Recession. In the postwar sample prior to the Great Recession, the share of longer term unemployed displays moderately countercyclical movements peaking at 26 percent during the early 1980's recession, see Figure 2. During the Great Recession instead, this indicator surged from 17.5 percent in August 2007 to 45.3 percent in April 2010 and remains high, see also Rothstein (2011) and Wiczer (2013). The rise in longer term unemployment is related both to deteriorating job finding prospects and to increased heterogeneity amongst the unemployed (or to measurement error). To see this, suppose that the job finding rate is constant within a month and that all unemployed face the same probability of finding a job. This induces the law of motion for the average duration of unemployment, $\mathbf{d}_t$:

$$\mathbf{d}_t = \left(1 - \mathbf{p}_t^f\right)(\mathbf{d}_{t-1} + 1)\frac{\mathbf{u}_{t-1}}{\mathbf{u}_t} + \mathbf{p}_t^l \frac{\mathbf{n}_{t-1}}{\mathbf{u}_t}. \tag{1}$$

Close to the non-stochastic steady-state $\mathbf{d} = \mathbf{1}/\mathbf{p}^f$ where $\mathbf{p}^f$ is the long-run value of the job finding rate. Figure 2 shows average U.S. unemployment duration together with the inverse of the average instantaneous job finding rate and the estimate of average unemployment duration derived from (1). The inverse job finding rate tracks the BLS estimate of the average unemployment duration very closely until the Great Recession. From late 2007, however, the BLS estimate of unemployment duration rises approximately twice as much as the inverse of the job finding rate. The estimated unemployment duration implied by (1) is essentially identical to the inverse of the job finding rate. Hence, there is evidence of increased heterogeneity in searchers' job finding prospects or of measurement error (in either duration or job flows data). We will concentrate on the first of these.

Figure 2 also illustrates the Beveridge curve (using CPS estimates of unemployment and JOLTS estimates of the number of vacancies). We discriminate between the pre-Great Recession period and the period from 2007:12. During the early parts of the recession, unemployment approximately doubled while the number of vacancies fell by around 50 percent producing a striking movement down the Beveridge curve. From late 2009, however, the Beveridge curve shifts outwards, indicating a less efficient matching between workers looking for employment and firms looking for new hires, see also Barlevy (2011).

In summary, the persistent decline in the job finding rate is key for understanding the large and persistent increase in unemployment during the Great Recession, the increase in average unemployment duration is related to heterogeneity in job finding prospects, and there have been substantial movements along the Beveridge curve followed by an outward shift in this relationship.

3. Model

Consider a heterogenous agents model with frictions in financial, labor and goods markets.

Workers. There is a continuum of mass 1 of risk averse and infinitely lived workers indexed by $i \in (0, 1)$ who maximize the expected present value of their utility streams. A worker is either employed or unemployed. Employed workers (indexed by $\mathbf{r}_{i,t} = n$) earn a real wage $\mathbf{w}_t$ but lose their current jobs with probability $\boldsymbol{\rho}_t \in [0, 1]$. Unemployed workers search for jobs and receive unemployment benefits $\boldsymbol{\xi} < \mathbf{w}_t$. There are two types of unemployed workers who differ in their search efficiency and therefore in their job finding probabilities, $\boldsymbol{\eta}_{r,t}$. High search efficiency unemployed workers ($\mathbf{r}_{i,t} = s$) face shorter expected unemployment spells than unemployed workers with low search efficiency ($\mathbf{r}_{i,t} = l$),

risks are important.

[5] All data were obtained from the Current Population Study (CPS) apart from $\mathbf{e}_t$ which we got from the Bureau of Labor Statistics.

$0 \leq \boldsymbol{\eta}_{l,t} \leq \boldsymbol{\eta}_{s,t} \leq 1$. Upon job loss, a newly unemployed worker enters the high (low) search efficiency pool with probability $\boldsymbol{\varphi}_{s,t} \in [0,1]$ ($\boldsymbol{\varphi}_{l,t} = 1 - \boldsymbol{\varphi}_{s,t}$). During an unemployment spell type s unemployed workers may transit to type l, an event that occurs with probability $\boldsymbol{\omega}_t \in [0,1]$. The model therefore includes two sources of heterogeneity in job finding rates, 'unobserved heterogeneity' and 'negative duration dependence.' Both imply that workers who have been unemployed for longer periods *on average* have lower job finding rates than newly unemployed workers.

The timing is as follows. At the beginning of the period, the aggregate labor market shocks are realized. After this, unemployed workers and firms with job vacancies match and new employment relationships are established. This is followed by production and consumption. At the end of the period, job separations are effectuated. Thus, employed workers face idiosyncratic uncertainty about the identity of job losers and about their search efficiency should they lose their jobs.

Workers cannot purchase unemployment insurance contracts and smooth consumption through government provided unemployment benefits and through self-insurance by saving in a riskless nominal bond, $\mathbf{b}^h_{i,t}$. Workers maximize utility subject to a borrowing constraint and sequence of budget constraints:

$$\mathbf{b}^h_{i,t} \geq \mathbf{b}^{\min},\ t \geq 0, \tag{2}$$

$$\mathbf{c}_{i,t} + \mathbf{b}^h_{i,t} = \mathbf{n}_{i,t}\mathbf{w}_t + (1-\mathbf{n}_{i,t})\,\boldsymbol{\xi} + \frac{\mathbf{R}_{t-1}}{1+\boldsymbol{\pi}_t}\mathbf{b}^h_{i,t-1},\ t \geq 0. \tag{3}$$

$\mathbf{n}$ indicates the household's employment state:

$$\mathbf{n}_{i,t} = \begin{cases} 1 & \text{if worker } i \text{ is employed in period } t, \\ 0 & \text{if worker } i \text{ is unemployed in period } t. \end{cases} \tag{4}$$

$\mathbf{b}^{\min}$ is a borrowing limit, $\mathbf{c}$ denotes a consumption basket, $\mathbf{R}$ is the gross nominal interest rate, and $\boldsymbol{\pi}$ denotes the net inflation rate.

Let $\mathbf{V}\left(\mathbf{b}^h_i, \mathbf{r}_i, \mathbf{S}\right)$ be the expected present discounted utility of a household given its bond holdings, its labor market status, $\mathbf{r}_i$, and the aggregate state vector, $\mathbf{S}$. Employed workers' Bellman equation is:

$$\begin{aligned} \mathbf{V}\left(\mathbf{b}^h_i, n, \mathbf{S}\right) &= \max_{\mathbf{c}_i, \mathbf{b}^{h\prime}_i} \{\mathbf{U}(\mathbf{c}_i) + \boldsymbol{\beta}\mathbb{E}\left(1 - \sum_{g=s,l} \boldsymbol{\rho}\boldsymbol{\varphi}_g\left(1-\boldsymbol{\eta}'_g\right)\right)\mathbf{V}\left(\mathbf{b}^{h\prime}_i, n, \mathbf{S}'\right) \\ &\quad + \boldsymbol{\beta}\mathbb{E}\sum_{g=s,l}\boldsymbol{\rho}\boldsymbol{\varphi}_g\left(1-\boldsymbol{\eta}'_g\right)\mathbf{V}\left(\mathbf{b}^{h\prime}_i, g, \mathbf{S}'\right)\}, \end{aligned} \tag{5}$$

subject to the borrowing constraint and to the budget constraint (3) setting $\mathbf{n}_i = 1$. $\mathbf{U}$ is an increasing and strictly concave utility function. $\boldsymbol{\beta} \in (0,1)$ is the subjective discount factor, and $\mathbb{E}$ is the conditional expectations operator. The terms on the right hand side of (5) are the instantaneous utility flow $\mathbf{U}(\mathbf{c}_i)$, the probability of being employed next period $(1 - \sum_{g=s,l}\boldsymbol{\rho}\boldsymbol{\varphi}_g\left(1-\boldsymbol{\eta}'_g\right))$ times its continuation value, and the probability of being state g unemployed next period $(\boldsymbol{\rho}\boldsymbol{\varphi}_g\left(1-\boldsymbol{\eta}'_g\right))$ times the respective continuation values.

The Bellman equation for a type s unemployed worker is:

$$\begin{aligned} \mathbf{V}\left(\mathbf{b}^h_i, s, \mathbf{S}\right) &= \max_{\mathbf{c}_i, \mathbf{b}^{h\prime}_i} \{\mathbf{U}(\mathbf{c}_i) + \boldsymbol{\beta}\mathbb{E}(1-\boldsymbol{\omega})\left[\boldsymbol{\eta}'_s\mathbf{V}\left(\mathbf{b}^{h\prime}_i, n, \mathbf{S}'\right) + (1-\boldsymbol{\eta}'_s)\,\mathbf{V}\left(\mathbf{b}^{h\prime}_i, s, \mathbf{S}'\right)\right] \\ &\quad + \boldsymbol{\beta}\mathbb{E}\boldsymbol{\omega}\left[\boldsymbol{\eta}'_l\mathbf{V}\left(\mathbf{b}^{h\prime}_i, n, \mathbf{S}'\right) + (1-\boldsymbol{\eta}'_l)\,\mathbf{V}\left(\mathbf{b}^{h\prime}_i, l, \mathbf{S}'\right)\right]\}, \end{aligned} \tag{6}$$

subject to (2) and (3) setting $\mathbf{n}_i = 0$. A type s unemployed worker remains type s with probability $(1-\boldsymbol{\omega})$ and makes a transition to type l with probability $\boldsymbol{\omega}$. Finally, the Bellman equation for a type l unemployed workers is:

$$\mathbf{V}\left(\mathbf{b}^h_i, l, \mathbf{S}\right) = \max_{\mathbf{c}_i, \mathbf{b}^{h\prime}_i}\{\mathbf{U}(\mathbf{c}_i) + \boldsymbol{\beta}\mathbb{E}\left[\boldsymbol{\eta}'_l\mathbf{V}\left(\mathbf{b}^{h\prime}_i, n, \mathbf{S}'\right) + (1-\boldsymbol{\eta}'_l)\,\mathbf{V}\left(\mathbf{b}^{h\prime}_i, l, \mathbf{S}'\right)\right]\}, \tag{7}$$

subject to (2) and (3) setting $\mathbf{n}_i = 0$. Since $\mathbf{w} > \boldsymbol{\xi}$, $\mathbf{V}\left(\mathbf{b}^h, n, \mathbf{S}\right) \geq \mathbf{V}\left(\mathbf{b}^h, s, \mathbf{S}\right)$ for all $\mathbf{b}^h$ and $\mathbf{S}$ so that no employed household has an incentive to voluntarily leave their current job. Under the condition that $\boldsymbol{\eta}'_s \geq \boldsymbol{\eta}'_l$, $\mathbf{V}\left(\mathbf{b}^h, s, \mathbf{S}\right) \geq \mathbf{V}\left(\mathbf{b}^h, l, \mathbf{S}\right)$ for all $\mathbf{b}^h$ and $\mathbf{S}$.

The consumption index $\mathbf{c}_i = \left(\int_j \left(\mathbf{c}^j_i\right)^{1-1/\gamma} dj\right)^{1/(1-1/\gamma)}$ is a basket of consumption goods varieties where $\mathbf{c}^j_i$ is household i's consumption of goods of variety j and $\gamma > 1$ is the elasticity of substitution between consumption goods. Household i's demand for variety j is given as:

$$\mathbf{c}^j_i = \left(\frac{\mathbf{P}_j}{\mathbf{P}}\right)^{-\gamma}\mathbf{c}_i. \tag{8}$$

$\mathbf{P}_j$ is the nominal price of variety j and $\mathbf{P} = \left(\int_j \mathbf{P}_j^{1-\gamma} dj\right)^{1/(1-\gamma)}$ is the price index.

Entrepreneurs. Consumption goods are produced by a continuum of measure $\Psi < 1$ of monopolistically competitive firms indexed by $j \in (0, \Psi)$ owned by risk neutral entrepreneurs. Entrepreneurs discount utility at the rate $\boldsymbol{\beta}$ and in return for managing (and owning) the firm, they are the sole claimants to its profits. Entrepreneurs can save but face a no-borrowing constraint. This no-borrowing constraint implies that the entrepreneur finances hiring costs through retained earnings.[6]

Output is produced according to a linear technology:

$$\mathbf{y}_{j,t} = \mathbf{n}_{j,t}, \tag{9}$$

where $\mathbf{n}_{j,t}$ denotes entrepreneur j's input of labor. Firms hire labor in a frictional labor market. The law of motion for employment in firm j is given as:

$$\mathbf{n}_{j,t} = \left(1 - \boldsymbol{\rho}_{t-1}\right) \mathbf{n}_{j,t-1} + \boldsymbol{\psi}_t \mathbf{v}_{j,t}. \tag{10}$$

$\mathbf{v}_{j,t}$ denotes vacancies posted, and $\boldsymbol{\psi}_t$ is the job filling probability. Firms are sufficiently large that $\boldsymbol{\psi}_t$ can be interpreted as the *fraction* of vacancies that leads to a hire. The cost of posting a vacancy is given by $\boldsymbol{\mu} > 0$. Real marginal costs are:

$$\mathbf{mc}_{j,t} = \mathbf{w}_t + \frac{\boldsymbol{\mu}}{\boldsymbol{\psi}_t} - \boldsymbol{\beta}\mathbb{E}_t \left[\left(1 - \boldsymbol{\rho}_t\right) \frac{\boldsymbol{\mu}}{\boldsymbol{\psi}_{t+1}}\right]. \tag{11}$$

Following Rotemberg (1982), firms face quadratic costs of price adjustment. Given risk neutrality, entrepreneurs set prices to maximize the present discounted value of profits:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \boldsymbol{\beta}^s \left(\left(\frac{\mathbf{P}_{j,t+s}}{\mathbf{P}_{t+s}} - \mathbf{mc}_{j,t+s} \right) \mathbf{y}_{j,t+s} - \frac{\phi}{2} \left(\frac{\mathbf{P}_{j,t+s} - \mathbf{P}_{j,t+s-1}}{\mathbf{P}_{j,t+s-1}} \right)^2 \mathbf{y}_t \right), \tag{12}$$

subject to:

$$\mathbf{y}_{j,t} = \left(\frac{\mathbf{P}_{j,t}}{\mathbf{P}_t}\right)^{-\gamma} \mathbf{y}_t. \tag{13}$$

Equation (13) is the demand for goods variety j. $\mathbf{y}_t$, can be interpreted as aggregate real income. $\phi \geq 0$ indicates the severity of nominal rigidities in price setting with $\phi = 0$ corresponding to flexible prices. The first-order condition for this problem is:

$$\begin{aligned} \left(1 - \gamma + \gamma \mathbf{mc}_{j,t} \frac{\mathbf{P}_t}{\mathbf{P}_{j,t}}\right) \mathbf{y}_{j,t} \quad &= \quad \phi \frac{\mathbf{P}_t}{\mathbf{P}_{j,t-1}} \left(\frac{\mathbf{P}_{j,t} - \mathbf{P}_{j,t-1}}{\mathbf{P}_{j,t-1}}\right) \mathbf{y}_t \\ &\quad - \phi\boldsymbol{\beta}\mathbb{E}_t \left[\left(\frac{\mathbf{P}_{j,t+1}}{\mathbf{P}_{j,t}^2}\right) \left(\frac{\mathbf{P}_{j,t+1} - \mathbf{P}_{j,t}}{\mathbf{P}_{j,t}}\right) \mathbf{P}_t \mathbf{y}_{t+1} \right]. \end{aligned} \tag{14}$$

The entrepreneurs' consumption and savings decisions solve:

$$\mathbf{W}\left(\mathbf{b}_j^e, \mathbf{n}_j, \mathbf{S}\right) = \max_{\mathbf{d}_j, \mathbf{b}_j^{e\prime}, \mathbf{h}_j} \left\{\mathbf{d}_j + \boldsymbol{\beta}\mathbb{E}\mathbf{W}\left(\mathbf{b}_j^{e\prime}, \mathbf{n}_j', \mathbf{S}'\right)\right\}, \tag{15}$$

subject to (10) and to:

$$\mathbf{d}_j + \mathbf{b}_j^{e\prime} + \mathbf{w}\mathbf{n}_j + \boldsymbol{\mu}\frac{\mathbf{h}_j}{\boldsymbol{\psi}} \quad = \quad \frac{\mathbf{P}_j}{\mathbf{P}}\mathbf{n}_j - \mathbf{T}^e + \frac{\mathbf{R}_{-1}}{1 + \boldsymbol{\pi}}\mathbf{b}_j^e, \tag{16}$$

$$\mathbf{b}_j^{e\prime} \quad \geq \quad 0, \tag{17}$$

where $\mathbf{d}_j$ denotes entrepreneur j's consumption and $\mathbf{b}_j^{e\prime}$ their bond purchases. Condition (17) imposes the no-borrowing constraint on entrepreneurs. $\mathbf{T}^e$ denotes a lump-sum tax imposed on employers to cover the government provided unemployment benefits.

Labor Market. We assume that $\mathbf{w}_t = \overline{\mathbf{w}}$ as long as $\overline{\mathbf{w}}$ is consistent with the joint match surplus being non-negative and with workers preferring to work rather than being unemployed.[7] We will later investigate the importance of this assumption.

[6] In the stationary equilibrium, $\boldsymbol{\beta} < 1/\left(\mathbf{R}/\left(1 + \boldsymbol{\pi}\right)\right)$ so entrepreneurs will be borrowing constrained. This derives from the assumption that households are risk averse while entrepreneurs are assumed risk neutral.

[7] We have checked that the match surplus is positive for all matches in all the results that we report.

The matching technology is given as:

$$\mathbf{m}_t = \varrho \left(\mathbf{u}_{a,t}\right)^{\alpha} \left(\mathbf{v}_t\right)^{1-\alpha}, \tag{18}$$

where $\mathbf{m}_t$ denotes the measure of matches at date t, and $\mathbf{v}_t$ is the aggregate measure of vacancies posted by the firms. $\varrho > 0$, and $\alpha \in (0,1)$ are constant parameters. $\mathbf{u}_{a,t}$ is a measure of the number of 'active' searchers at the beginning of the period:

$$\mathbf{u}_{a,t} = \left(\left(1-\boldsymbol{\omega}_{t-1}\right)\mathbf{u}_{s,t-1} + \boldsymbol{\rho}_{t-1}\boldsymbol{\varphi}_{s,t-1}\mathbf{n}_{t-1}\right) + \mathbf{q}\left(\mathbf{u}_{l,t-1} + \left(\boldsymbol{\omega}_{t-1}\mathbf{u}_{s,t-1} + \boldsymbol{\rho}_{t-1}\boldsymbol{\varphi}_{l,t-1}\mathbf{n}_{t-1}\right)\right), \tag{19}$$

where $\mathbf{u}_{r,t}$ is the measure of type r unemployed workers at date t. Type s unemployed workers search every period while type l search with probability $\mathbf{q} \in (0,1]$. When $\mathbf{q} < 1$, type l unemployed workers face longer expected unemployment spells than type s unemployed workers. The vacancy filling probability and the job finding probabilities are given as:

$$\boldsymbol{\psi}_t = \varrho \boldsymbol{\theta}_t^{-\alpha}, \tag{20}$$

$$\boldsymbol{\eta}_{l,t} = \mathbf{q}\boldsymbol{\eta}_{s,t} = \varrho \mathbf{q} \boldsymbol{\theta}_t^{1-\alpha}, \tag{21}$$

where $\boldsymbol{\theta}_t = \mathbf{v}_t / \mathbf{u}_{a,t}$ denotes labor market tightness. The laws of motion of the stocks of employed and unemployed workers are given as:

$$\mathbf{n}_t = \left(1-\boldsymbol{\rho}_{t-1}\right)\mathbf{n}_{t-1} + \mathbf{m}_t, \tag{22}$$

$$\mathbf{u}_{s,t} = \left(1-\boldsymbol{\eta}_{s,t}\right)\left(\left(1-\boldsymbol{\omega}_{t-1}\right)\mathbf{u}_{s,t-1} + \boldsymbol{\rho}_{t-1}\boldsymbol{\varphi}_{s,t-1}\mathbf{n}_{t-1}\right), \tag{23}$$

$$\mathbf{u}_{l,t} = \left(1-\boldsymbol{\eta}_{l,t}\right)\left(\mathbf{u}_{l,t-1} + \left(\boldsymbol{\omega}_{t-1}\mathbf{u}_{s,t-1} + \boldsymbol{\rho}_{t-1}\boldsymbol{\varphi}_{l,t-1}\mathbf{n}_{t-1}\right)\right). \tag{24}$$

Government. We assume that the government balances the budget period-by-period:

$$\mathbf{u}_t \boldsymbol{\xi} = \Psi \mathbf{T}_t^e, \tag{25}$$

where $\mathbf{u}_t = \mathbf{u}_{s,t} + \mathbf{u}_{l,t}$.

Monetary policy is specified by a rule for the short-term nominal interest rate:

$$\mathbf{R}_t = \overline{\mathbf{R}} \left(\frac{1+\boldsymbol{\pi}_t}{1+\overline{\boldsymbol{\pi}}}\right)^{\delta}, \tag{26}$$

where $\overline{\mathbf{R}}$ is the long-run nominal interest rate target, $\overline{\boldsymbol{\pi}}$ is the inflation target, and δ denotes the (semi-) elasticity of the nominal interest rate to deviations of inflation from its target. In Section 5 we investigate further the role of the monetary policy rule.

Stochastic Shocks. We allow for shocks to the job separation rate[8], $\boldsymbol{\rho}_t$, and to $\boldsymbol{\varphi}_{l,t}$ and $\boldsymbol{\omega}_t$, which determine the heterogeneity in search efficiency. We assume that:

$$\boldsymbol{\rho}_t = \overline{\boldsymbol{\rho}} + \mathbf{z}_{\boldsymbol{\rho},t}, \tag{27}$$

$$\boldsymbol{\varphi}_{l,t} = \overline{\boldsymbol{\varphi}}_l + \mathbf{z}_{\boldsymbol{\varphi},t}, \tag{28}$$

$$\boldsymbol{\omega}_t = \overline{\boldsymbol{\omega}} + \mathbf{z}_{\boldsymbol{\omega},t}, \tag{29}$$

$$\mathbf{z}_{\mathbf{i},t} = \boldsymbol{\lambda}_{\mathbf{i}}\mathbf{z}_{\mathbf{i},t-1} + \boldsymbol{\varepsilon}_{\mathbf{i},t}, \ \mathbf{i} = \boldsymbol{\rho}, \boldsymbol{\varphi}, \boldsymbol{\omega}. \tag{30}$$

$\overline{\boldsymbol{\rho}}, \overline{\boldsymbol{\varphi}}_l, \overline{\boldsymbol{\omega}} \in (0,1)$ determine the steady-state values of $\boldsymbol{\rho}, \boldsymbol{\varphi}_l$, and $\boldsymbol{\omega}$ and $\boldsymbol{\lambda}_{\boldsymbol{\rho}}, \boldsymbol{\lambda}_{\boldsymbol{\varphi}}, \boldsymbol{\lambda}_{\boldsymbol{\omega}} \in (-1,1)$ their persistence. We assume that $\boldsymbol{\varepsilon}_t \sim \mathcal{N}(0, \mathbf{V}_{\boldsymbol{\varepsilon}})$ where $\boldsymbol{\varepsilon}_t = (\boldsymbol{\varepsilon}_{\boldsymbol{\rho},t}, \boldsymbol{\varepsilon}_{\boldsymbol{\varphi},t}, \boldsymbol{\varepsilon}_{\boldsymbol{\omega},t})'$. $\boldsymbol{\varepsilon}_{\boldsymbol{\rho},t}$ is assumed orthogonal to $\boldsymbol{\varepsilon}_{\boldsymbol{\varphi},t}$ and $\boldsymbol{\varepsilon}_{\boldsymbol{\omega},t}$ while these two latter shocks may be correlated.

We take no firm stand on the sources of the shocks to search efficiency, $\boldsymbol{\varepsilon}_{\boldsymbol{\varphi},t}$ and $\boldsymbol{\varepsilon}_{\boldsymbol{\omega},t}$. Hall (2015) argues that the composition of job losers during the Great Recession shifted towards those with on average smaller job finding rates. Sahin et al (2014) instead document an increase in occupational and cross-industry "mis-match" between vacancies and job seekers during the Great Recession. Sterk (2015) suggests that falling house prices may have limited labor mobility during the Great Recession. Each of these observations would be consistent with a positive innovation to $\boldsymbol{\varepsilon}_{\boldsymbol{\varphi},t}$.

[8]The job separation rate can be endogenized by e.g. introducing match specific shocks, see Mortensen and Pissarides (1994). However, we find it useful to assume exogenous job separations to capture the impact of a variety of different shocks (such as productivity shocks, financial shocks, idiosyncratic demand shocks).

Kroft et al (2016) instead document an increase in negative duration dependence after 2008 as would be consistent with innovations to either $\varepsilon_{\varphi,t}$ or $\varepsilon_{\omega,t}$.

Equilibrium. We focus upon a recursive equilibrium in which workers act competitively taking all prices for given while firms act as monopolistic competitors setting the price of their own variety taking all other prices for given. In equilibrium, firms will be symmetric because of the absence of idiosyncratic productivity shocks, state contingent pricing and because we assume that they are large enough that job separation and vacancy filling probabilities can be treated like fractions. We denote relative prices by $\mathbf{p}_{j,t} = \mathbf{P}_{j,t}/\mathbf{P}_t$. In the symmetric equilibrium $\mathbf{p}_{j,t} = 1$ and the optimal price setting condition simplifies to:

$$1 - \gamma + \gamma \mathbf{mc}_t = \phi \boldsymbol{\pi}_t (1 + \boldsymbol{\pi}_t) - \phi \boldsymbol{\beta} \mathbb{E}_t \left[\boldsymbol{\pi}_{t+1} (1 + \boldsymbol{\pi}_{t+1}) \frac{\mathbf{y}_{t+1}}{\mathbf{y}_t} \right]. \tag{31}$$

Models with incomplete markets and aggregate shocks are cumbersome to solve numerically. In this paper we follow Krusell, Mukoyama and Smith (2011) and impose that the borrowing constraint $\mathbf{b}^{\min} = 0$. Under this assumption there is no aggregate savings vehicle available to workers and, in equilibrium, since unemployed workers cannot issue debt, **all** workers consume their income every period. Nonetheless, since employed workers face the risk of losing their job, they have an incentive to save and will therefore be on their Euler equations.[9] For the same reason, although workers cannot save in equilibrium, the model still features a precautionary savings motive which impacts on equilibrium quantities through the real interest rate. Given this borrowing constraint, the wealth distribution is degenerate which simplifies the computational aspects of the model very considerably. In Appendix 8 we show that allowing for individual savings - and therefore for a non-degenerate wealth distribution - has only limited impact on aggregate dynamics. We define the equilibrium formally in Appendix 1.

4. Quantitative Results

4.1. Calibration

Given the degenerate wealth distribution, we can solve the model numerically using a standard perturbation approach (see the Appendix for details). Tables 1 reports the calibration targets and parameter values.

A model period corresponds to one month. The household utility function is assumed to be given as:

$$\mathbf{U}(\mathbf{c}_{i,t}) = \frac{\mathbf{c}_{i,t}^{1-\sigma} - 1}{1 - \sigma}, \ \sigma \geq 0. \tag{32}$$

σ is the degree of relative risk aversion. We set $\sigma = 1.5$ which is in the mid-range of empirical estimates of Attanasio and Weber (1995), Eichenbaum, Hansen and Singleton (1988), and many others. We assume an annual steady-state real interest rate of 5 percent and set the subjective discount factor equal to 0.992 for both workers and entrepreneurs. This value is low relative to standard representative agent models[10] but because of idiosyncratic risk and incomplete markets, agents have a strong incentive to engage in precautionary savings requiring a low real interest rate to induce zero savings in equilibrium.

We target a steady-state unemployment rate of 5 percent. The parameters $(\mathbf{q}, \boldsymbol{\varphi}_s, \boldsymbol{\omega})$ and the steady-state job finding probability for type s unemployed workers, $\boldsymbol{\eta}_s$, are calibrated by targeting the following moments: First, according to CPS data for the post 1970 sample, on average 15 percent of job losers experience unemployment spells of 6 months or more. Secondly, the monthly hazard rate for the newly unemployed is 43 percent, see Rothstein (2011). Third, we introduce information on duration dependence from Kroft et al (2016). These authors assume that the job finding rate depends on the length of the unemployment spell, d, and on labor market tightness as:

$$\boldsymbol{\eta}_t(\boldsymbol{\theta}_t, d) = \mathbf{A}(d) m_0 \boldsymbol{\theta}_t^{1-\nu}, \tag{33}$$

$$\mathbf{A}(d) = (1 - a_1 - a_2) + a_1 e^{-b_1 d} + a_2 e^{-b_2 d}. \tag{34}$$

Using panel data from the CPS for the 2002-2007 sample (and controlling for demographic variables), Kroft et al (2016) estimate $\widehat{a}_1 = 0.314$, $\widehat{a}_2 = 0.393$, $\widehat{b}_1 = 1.085$ and $\widehat{b}_2 = 0.055$. We target the implied values of the relative hazard, $\mathbf{A}(d)/\mathbf{A}(0)$, for integer values of d going up to 15 months.

[9] The equilibrium real interest rate has to be consistent with employed workers' Euler equation. Strictly speaking, this determines an upper bound on the real interest rate, see also Krusell, Mukoyama and Smith (2011).

[10] Recall that we calibrate to monthly data so that the annual discount factor is 0.908 which is low relative to standard calibrations typically assuming values around 0.96.

We find that $\mathbf{q} = 0.468$, $\overline{\boldsymbol{\varphi}}_l = 0.229$, $\overline{\boldsymbol{\omega}} = 0.219$ and $\boldsymbol{\eta}_s = 0.586$. Thus, 77 percent of job losers flow into the high search efficiency state upon job loss and thereafter face a moderate risk of 22 percent per month of loss of search efficiency during unemployment. Unemployed workers with high search efficiency are more than twice as likely to find a job (per month) as low search efficiency unemployed workers. In the steady-state, these parameter values imply that the average duration upon job loss of type s (l) unemployed workers is 1.48 months (4.10 months), and that the share of unemployed workers out of work for 6 months or more is 15.9 percent. The calibration matches closely the hazard function estimated by Kroft et al (2016).[11] Finally, to match the 5 percent unemployment rate, we set $\overline{\boldsymbol{\rho}}$ equal to 3.9 percent per month.

The benefit level, $\boldsymbol{\xi}$, is calibrated by targeting a decline in consumption of 11.7 percent upon unemployment which matches the average household spending impact of a job loss estimated by Hurd and Rohwedder (2011).[12] The elasticity of matching function to unemployment, α, is set equal to 65 percent and we normalize $\varrho = 1$. $\boldsymbol{\mu}$, the vacancy cost parameter, is calibrated by targeting an average hiring cost of 4.5 percent of the quarterly wage bill per worker as estimated by Silva and Toledo (2009). Given other parameters, this implies that $\boldsymbol{\mu} = 0.19$.

We set the average mark-up equal to 20 percent and therefore assume that γ, the elasticity of substitution between goods, equals 6. ϕ, which determines the importance of price adjustment costs, is calibrated to match a price adjustment frequency of 5 months. This value is consistent with the estimates of Bils and Klenow (2004).[13] This implies that $\phi = 96.9$. The inflation target is set equal $\overline{\pi} = 0$ so that the central bank pursues price stability and we set $\delta = 1.5$, a conventional value in the new Keynesian literature.

Finally, we estimate the parameters of the stochastic processes for $\boldsymbol{\rho}_t$, $\boldsymbol{\varphi}_{l,t}$ and $\boldsymbol{\omega}_t$. The persistence of $\boldsymbol{\rho}_t$ and the variance of its innovation are estimated using JOLTS data on layoffs and BLS estimates of the employment rate for a sample ranging from 2003 to 2014. This implies that $\widehat{\lambda}_\rho = 0.91$ and $\widehat{v}_\rho/\overline{\boldsymbol{\rho}} = 0.0067$. To estimate the persistence and volatility of $\boldsymbol{\varphi}_{l,t}$ and $\boldsymbol{\omega}_t$ we use the model to 'back out' processes these processes given the estimates of $\mathbf{q}$, ϱ and α, and data on the unemployment outflow rate and labor market tightness. It follows from the matching function that:

$$\mathbf{u}_{a,t} = \mathbf{u}_{t-1}\left(\frac{\widetilde{\boldsymbol{\eta}}_t}{\varrho}\right)^{1/\alpha}\left(\frac{\mathbf{v}_t}{\mathbf{u}_{t-1}}\right)^{1-1/\alpha}, \tag{35}$$

where $\widetilde{\boldsymbol{\eta}}_t$ is the average job finding rate amongst the stock of unemployed. We further assume proportionality between $\boldsymbol{\varphi}_{l,t}$ and $\boldsymbol{\omega}_t$ which implies that the disturbances to these two flows are perfectly correlated, i.e. $\frac{\overline{\boldsymbol{\omega}}}{\overline{\boldsymbol{\varphi}}_l}\mathbf{z}_{\boldsymbol{\omega},\mathbf{t}} = \mathbf{z}_{\boldsymbol{\varphi},\mathbf{t}}$. The estimates of $\mathbf{u}_{a,t}$ together with the transition equations (23) – (24), can then be applied to derive estimates of $\boldsymbol{\varphi}_{s,t}$ and $\boldsymbol{\omega}_t$, see Appendix 3 for details. Using data from JOLTS and the CPS (for the 2003-2014 sample) we find $\widehat{\lambda}_{\boldsymbol{\varphi}} = \widehat{\lambda}_{\boldsymbol{\omega}} = 0.99$ and $\widehat{v}_{\boldsymbol{\varphi}}/\overline{\boldsymbol{\varphi}}_l = \widehat{v}_{\boldsymbol{\omega}}/\overline{\boldsymbol{\omega}} = 0.072$.[14]

4.2. Results

The Impact of Labor Market Shocks. We first examine the impact of job separation shocks and changes in the composition of unemployed workers. We compare the benchmark economy with two alternative economies. The first of these assumes that prices are flexible ($\phi = 0$) but retains the incomplete markets assumption. This is informative about the extent to which nominal rigidities matter. In the second alternative economy individuals can insure against idiosyncratic shocks within large families but retain nominal rigidities. In this alternative economy there is therefore no precautionary savings against idiosyncratic risk. The family here maximizes utility subject to the single budget constraint:

$$\mathbf{c}_t + \mathbf{b}_t^h = \mathbf{n}_t\mathbf{w}_t + (1-\mathbf{n}_t)\,\boldsymbol{\xi} + \frac{\mathbf{R}_{t-1}}{1+\boldsymbol{\pi}_t}\mathbf{b}_{t-1}^h,\ t \geq 0, \tag{36}$$

where $\mathbf{n}_t$ is the fraction of employed household members in period t.

Figure 3 illustrates the responses of key aggregate variables to a one standard deviation increase in $\boldsymbol{\rho}_t$. Variations in the job termination rate have only moderate effects in standard matching models because rising unemployment implies declining job filling costs which triggers higher vacancy postings. In the benchmark model we instead find that an

[11]Figure A.1 in the Appendix illustrates the hazard function implied by our model evaluated in the steady-state together with the estimate of Kroft et al (2016).

[12]See Hurd and Rohwedder (2011), Table 21. Browning and Crossley (2001) estimate a similar average consumption loss due to unemployment shocks in Canadian household data.

[13]To be precise, we calibrate ϕ by exploiting the equivalence between the log-linearized Phillips curves implied by our model and by the Calvo model.

[14]Monthly job openings and layoffs are noisy and we pre-smooth the data using a 6 month moving average filter. The parameters of the shock processes are obtained by regressing the shock variables on their values lagged with one year. We then compute the monthly persistence parameters implied by the regressions.

increase in job separations produces a large and persistent increase in unemployment in addition to persistent declines in vacancy postings and in the job finding rate plus a surge in the share of longer term unemployed workers.[15]

Figure 4 repeats the analysis for a joint one standard deviations increase in $\boldsymbol{\varphi}_{s,t}$ and in $\boldsymbol{\omega}_t$. This combination of shocks decrease average search efficiency since more job losers flow into type l unemployment and more existing high search efficiency unemployed workers suffer a loss of search efficiency. These shocks also produce a persistent increase in the level of unemployment and in the share of longer term unemployed workers. Similarly to the job separation shock, the decline in search efficiency leads to a persistent decline in vacancy postings and in the job finding rate.

To understand the results it is instructive to consider the Euler equation for employed workers and the first order condition for price setting:

$$\begin{aligned}\mathbf{U}_c(\mathbf{c}^n) &= \boldsymbol{\beta}\mathbb{E}\frac{\mathbf{R}}{1+\boldsymbol{\pi}'}\{(1-\boldsymbol{\rho}[\boldsymbol{\varphi}_s(1-\boldsymbol{\eta}'_s)+(1-\boldsymbol{\varphi}_s)(1-\boldsymbol{\eta}'_l)])\mathbf{U}_c(\mathbf{c}^{n\prime}) \\ &\quad +\boldsymbol{\rho}\boldsymbol{\varphi}_s(1-\boldsymbol{\eta}'_s)\mathbf{U}_c(\mathbf{c}^{u,s\prime})+\boldsymbol{\rho}(1-\boldsymbol{\varphi}_s)(1-\boldsymbol{\eta}'_l)\mathbf{U}_c\left(\mathbf{c}^{u,l\prime}\right)\},\end{aligned} \tag{37}$$

$$1-\gamma+\gamma\left(\mathbf{w}+\frac{\boldsymbol{\mu}}{\boldsymbol{\psi}}-\boldsymbol{\beta}\mathbb{E}(1-\boldsymbol{\rho}_x)\frac{\boldsymbol{\mu}}{\boldsymbol{\psi}'}\right)=\phi(1+\boldsymbol{\pi})\boldsymbol{\pi}-\boldsymbol{\beta}\phi\mathbb{E}(1+\boldsymbol{\pi}')\boldsymbol{\pi}'\frac{\mathbf{y}'}{\mathbf{y}}, \tag{38}$$

where $\mathbf{c}^n$, $\mathbf{c}^{u,s}$ and $\mathbf{c}^{u,l}$ denote the consumptions level of an employed worker, a high search efficiency unemployed worker and a low search efficiency unemployed worker, respectively, and $\mathbf{U}_c(\mathbf{c}) = \partial\mathbf{U}(\mathbf{c})/\partial\mathbf{c}$.

Employed workers are on their Euler equation because they have an incentive to save. Declining search efficiency and worsening job finding prospects during unemployment stimulate higher desired savings because it implies lower expected income and because of increased idiosyncratic employment risk. Thus, when labor market conditions worsen, employed workers' demand for consumption goods falls at the current real interest rate. This puts downward pressure on the real interest rate, on inflation (since $\delta > 1$) and on nominal interest rates.

Equation (38) is the optimal price setting condition in the symmetric equilibrium. Due to nominal rigidities, firms find it optimal to phase in changes in the optimal price level gradually over time. In the face of downward pressure on inflation, marginal costs have to decline. Since the real wage is assumed inflexible, lower marginal costs come from a decline in the cost of hiring (requiring vacancies to drop). Thus, fewer jobs are available and this explains the persistent drop in the job finding rate. It follows that adverse labor market shocks trigger declining goods demand that induces a fall in labor demand. It is this feedback mechanism from the demand side to the supply side that produces amplification.[16]

The amplification mechanism depends crucially on the combination of nominal rigidities and lack of insurance against unemployment. Figures 5 and 6 also report the impact of the labor market shocks for the two alternative economies described above. Absent nominal rigidities, price adjustments neutralize the need for a fall in marginal costs and firms exploit low hiring costs to post more vacancies. The job finding rate therefore falls only marginally which stops the amplification mechanism. Shocks to search heterogeneity increases hiring costs making it costlier to fill vacancies but price flexibility eliminates the need for a large cut in vacancies. When workers can insure against idiosyncratic employment shocks, changing labor market conditions no longer impact on idiosyncratic risk and savings are determined by intertemporal considerations. An increase in the job separation rate has minor effects on expected *family* income making aggregate demand unresponsive to changes in the job separation rate. The intertemporal savings motive is also small in the case of shocks to the share of low efficiency searchers. Thus, there is therefore little amplification of labor market shocks when households can insure against idiosyncratic risk.

The Great Recession. We now examine the extent to which the mechanisms of the model may be important for understanding the Great Recession.[17] We derive estimates of the sequences of the shocks, $(\boldsymbol{\varepsilon}_{\rho,t}, \boldsymbol{\varepsilon}_{\boldsymbol{\varphi},t}, \boldsymbol{\varepsilon}_{\boldsymbol{\omega},t})_{t=2007:1}^{2014:8}$ and feed them into the model to produce counterfactual experiments. $\boldsymbol{\varepsilon}_{\rho,t}$ is estimated by matching the observed U.S. time-series on the employment-to-unemployment transition rate while $\boldsymbol{\varepsilon}_{\boldsymbol{\varphi},t}$ and $\boldsymbol{\varepsilon}_{\boldsymbol{\omega},t}$ are estimated using the same approach as above on the basis of BLS and JOLTS data by matching the observed matching function residual. In order to avoid having too erratic shocks, we smooth both data series with a 6 months moving average filter.

The upper panels of Figure 5 illustrate the estimated shocks. The Great Recession witnessed a spur of job separations which started in early 2008, peaked in early 2009, and lasted only until the end of that year. We find a drop in search

[15]The increase in job separations produces an initial short-lived drop in the fraction of long-term unemployed workers because of the inflow of newly unemployed workers.

[16]Our timing assumptions matter for this feedback mechanism. Assuming alternatively that workers cannot immediately search when losing their jobs would impact on the feedback mechanism because the job finding rate would not appear in (37). However, this is an artefact of the simplifying assumptions we have made imposing $\mathbf{b}^{\min} = 0$. Allowing for savings would reinstate the feedback through the savings choice.

[17]In Appendix 5, we compare the results for the Great Recession with those for the early 1990's recession.

efficiency due to increased heterogeneity which is very persistent. The drop in the average search efficiency starts in 2008 and continues throughout 2009/10 peaking in early 2011 and thereafter slowly diminishes. It is useful to compare this shock to search heterogeneity with other measures. For that purpose we also illustrate $\varepsilon_{m,t}$:

$$\varepsilon_{m,t} = \log\left(\left[\frac{1}{\varrho}\left(\frac{\mathbf{m}_t}{\mathbf{u}_{t-1}}\right)\right]^{1/\alpha}\left(\frac{\mathbf{v}_t}{\mathbf{u}_{t-1}}\right)^{1-1/\alpha}\right). \tag{39}$$

$\varepsilon_{m,t}$ is the matching function residual assuming homogeneous search efficiency amongst the unemployed. Similarly to Barlevy (2011) we find a 40-45 percent adverse shock to the matching function over the 2007-2011 period and a 20 percent recovery thereafter. We also illustrate the fraction of newly unemployed workers who report to have suffered "permanent" job separations. As argued by Hall and Schulhofer-Wohl (2014), such job losses are associated with low job finding rates (relative to other types of job losers) and variations in this fraction therefore reflect changes in average search efficiency. This fraction increases from 23 percent prior to the recession in 2007 to 45 percent by early 2010. Thereafter it gradually declines towards its pre-recession level. It therefore mirrors quite precisely the search efficiency shock that we estimate.

Figure 6 illustrates the impact of the shocks on the level of unemployment, longer term unemployment, and on vacancies. A key focus of our analysis is whether the model can account for the persistent decline job finding rate observed in the U.S. following the financial crisis. The answer to this is affirmative: The model reproduces both the timing and the size of the fall in the job finding rate and the very persistent nature of the declining job finding prospects. Figure 6 also reports the share unemployed workers out of employment for 6 months (out of total unemployment). The benchmark economy is consistent with the rise in the incidence of longer term unemployment in the early part of the recession and with the very stubborn nature of the rise in this labor market indicator. The model, however, is not fully able to account for the size of the rise in longer term unemployment. Nevertheless, the model does generate a significant shift in the composition of the unemployed towards unemployment states with longer duration. Finally, the bottom left panel of Figure 6 displays the conditional standard deviation of income one month ahead for currently employed workers, scaled by the current level of income.[18] This is a measure of the income uncertainty in the model which partly is endogenous as it depends on the job finding rate. Income uncertainty surges during 2008 and remains at an elevated level until 2013, after which it decreases somewhat. Comparing with the corresponding measure in the economy without nominal rigidities we can evaluate the endogenous component of this uncertainty measure. Income uncertainty rises significantly less in the flexible price economy than in the benchmark model especially in the early part of the recession (the rise in income uncertainty by early 2009 is almost twice as large in the benchmark economy as in the flexible price version of the model).

The Beveridge curve implications are also illustrated in Figure 6. The counter-clockwise Beveridge curve movements observed during the Great Recession are not unusual during recessions but the current episode is more dramatic than what is observed during most other recessions. We find that the model accounts very accurately for both the movement down the Beveridge curve that occurred in 2008-2009 and the subsequent outward shift of the Beveridge curve for the reasons just discussed.

Figure 6 also displays the paths of the relevant aggregates when we assume that the U.S. economy was hit only by job separation shocks. In the absence of these shocks, the model accounts for the initial rise in unemployment in late 2008 and for the initial drop in vacancies but neither for the size nor persistence of the rise in unemployment or for the very long and deep decline in job vacancies.

Assuming flexible prices, the labor market shocks leave vacancies almost unaffected. For that reason, the worsening labor market conditions have little impact on unemployment lead to a very minor rise in the incidence of longer term unemployment. Perhaps most strikingly, the flexible price model implies an extremely counterfactual horizontal Beveridge curve. Interestingly, the model with insurance against idiosyncratic shocks generates very similar results to the flexible price model. Labor market shocks have minor impact on aggregate goods demand in this economy inducing a limited increase in unemployment, a minor increase in the incidence of longer term unemployment, and a very counterfactual horizontal Beveridge curve. Hence, the amplification mechanism derives from the combination of frictions in goods, labor and financial markets.

In summary, the model produces substantial amplification of labor market shocks and it matches closely the experiences of the U.S. economy during the Great Recession including the persistent drop in the job finding rate and the movements along and outward shift of the Beveridge curve.

[18]To compute the conditional standard deviations we use a Gauss-Hermite approximation with 36 nodes. We do not plot the uncertainty measure for the full insurance version of the model, as it is close to zero throughout the sample.

5. Extensions and Robustness Analysis

We now investigate three further issues: The importance of the *sources* of heterogeneity in search efficiency amongst the unemployed; the impact of inflexible wages; and the impact of monetary policy.

Search Efficiency Heterogeneity: Amplification vs. Propagation. We have allowed for heterogeneity in search efficiency to materialize either upon job loss or during an unemployment spell. Heterogeneity in job search efficiency upon job loss impacts on employed workers' consumption and savings decisions directly, cf. the Euler equation (37), and propagates shocks over time through the impact on search efficiency. Increased risk of loss of search efficiency *during* an unemployment spell in contrast does not directly influence employed workers' savings choices but still propagates shocks through the impact on search efficiency.

We now investigate these two flows' importance separately. Figure 7 repeats the Great Recession experiment from the previous section assuming either that the probability of search efficiency loss during an unemployment spell remains constant during the Great Recession (and equal to its steady-state value of $\overline{\boldsymbol{\omega}} = 21.9$ percent per month) or that $\boldsymbol{\omega} = 0$ so that negative duration dependence is eliminated altogether.

Assuming $\boldsymbol{\omega}_t = \overline{\boldsymbol{\omega}}$ generates results similar to those of the benchmark model indicating that unobserved heterogeneity is quantitatively much more important than increased negative duration dependence. This is consistent with Ahn and Hamilton (2016) who - studying CPS data - find that recessions are times when there is an increased inflow of workers with low job finding probabilities into unemployment. Our results go one step further and demonstrate that such a compositional change is important for the severity of the Great Recession because of its impact on aggregate demand.

Eliminating negative duration dependence altogether ($\boldsymbol{\omega} = 0$) again delivers results very similar to the benchmark model. The reason for this is that type s workers in the steady-state only face a minor (13 percent) risk of experiencing a transition to state l during an unemployment spell. This risk is too small to matter much quantitatively. Thus heterogeneity in search efficiency upon job loss is much more important for macroeconomic outcomes than negative duration dependence.

The Role of Wage Flexibility. The assumption of inflexible real wages is consistent with the experiences of the Great Recession (see Figure A.5 which shows average real compensation per hour worked in the Business Sector). We now ask to which extent do our results depend on this rigidity and whether are there circumstances in which a lack of a fall in real wages may arise as an equilibrium outcome?

For this purpose we assume that wages are determined according to a non-cooperative Nash bargaining game between firms and workers. Once workers and firms have been matched (but before a wage has been bargained), we assume that regardless of the workers' prior unemployment status, they enter the two unemployment pools with probability $\boldsymbol{\varphi}_{s,t}$ and $1-\boldsymbol{\varphi}_{l,t}$, respectively (exactly as an employed worker). This assumption combined with the borrowing constraint, makes the outcome under Nash bargaining particularly simple because the wage offered to a new worker is independent of their unemployment state.

We report results for a wide range of values of the workers' bargaining power which includes both the calibration of Hagedorn and Manovskii (2008) that workers receive 5 percent of the match surplus to 'traditional' values of this parameter of 50 percent. Figure 8 illustrates the impact of a job separation shock on unemployment and on real wages. We report the maximum increase in unemployment relative to the corresponding value in the benchmark model. Similarly, we show the maximum decline in the real wage as a percentage of the steady-state real wage.[19]

Higher bargaining power on the part of workers implies higher wage flexibility in equilibrium and a significantly smaller maximum response of unemployment. Low values of the workers' bargaining power instead imply similar responses to labor market shocks to those we found when assuming inflexible real wages. To understand this, consider the impact of an increase in the job separation rate on the joint surplus. A higher job separation rate lowers the value of a filled job and it worsens the workers' outside option because of its impact on the job finding rate. Hence, the joint match surplus declines and this puts a downward pressure on real wages which relieves the pressure on firms to cut vacancy postings. The higher the workers' bargaining power, the larger is the fall in real wages and the smaller is the decline in vacancy postings. Whether the increase in job separations impact mostly on real wages or on vacancy postings matters for employed workers' savings choices because the former of these have no impact on the precautionary savings motive and therefore matters for the amplification mechanism.

The Role of Monetary Policy. It is standard intuition that aggressive responses of nominal interest rates to inflation can neutralize the inefficiencies that derive from nominal rigidities while too weak responses to inflation produce locally

[19] We assume that workers enjoy leisure when unemployed and calibrate the utility value of leisure so that the steady-state equilibrium real wage implies a 5 percent unemployment rate.

indeterminate equilibria. It is unclear whether similar results hold in the heterogenous agents model considered in the current paper but the strength of the amplification mechanism implies that the monetary policy response may potentially be very important.

To investigate this issue, Figure 9 reports the impact of job separation rate shocks on unemployment as a function of two key parameters, δ and σ. δ determines the response of the nominal interest rate to deviations of inflation from its target[20] while σ determines the extent to which workers respond to employment risk. We indicate by different colors the amplification of the labor market shocks in the benchmark economy by normalizing the *maximum* impact on unemployment of the job separation shock with the equivalent response in a flexible price economy. A dark blue color means no amplification relative to the flexible price economy with lighter shades of blue and yellow and orange colors indicating ever increasing degrees of amplification. The white area corresponds to combinations of δ and σ that are inconsistent with local determinacy of the equilibrium where inflation is on target.

Sufficiently aggressive monetary policy rules neutralize the amplification mechanism while interest rate rules similar to those typically assumed in the New Keynesian literature produce a large amount of amplification. More aggressive of monetary policy responses provide stabilization by moderating the agents' expectations regarding the impact of the shocks on equilibrium inflation and vacancy postings and thus impact directly on the mechanism through which labor market shocks are amplified.

Our results also show that higher degrees of risk aversion demand more aggressive policy rules in order to provide stabilization. The higher is the degree of risk aversion, the more aggressive rules need to be to ensure local indeterminacy of the intended equilibrium because risk aversion impacts on precautionary savings. In the indeterminacy region, equilibria can exist in which agents' expectations of worsening labor market outcomes and low inflation drives down aggregate demand thereby motivating firms to hire less labor and leading the economy to a high-unemployment-cum-low-inflation self-fulfilling equilibria. Thus, the design of the monetary reaction function is critical in the incomplete markets set-up analyzed in this paper.

6. Conclusions and Summary

We have shown how frictions in labor markets that interact with goods and financial markets frictions can lead to a significant amplification of labor market shocks in a general equilibrium framework. At the heart of our theory is the idea that labor market shocks that produce job uncertainty can reduce aggregate goods demand because of precautionary savings. A calibrated version of the model can account not only for the increase in unemployment observed in the U.S. during the Great Recession but also for much of the movements in the Beveridge curve. It is the transmission of weak aggregate demand to aggregate supply that produces these results because of an endogenous amplification mechanism.

Our emphasis on job uncertainty deriving from idiosyncratic employment risk and uncertain outcomes of labor market search offers an additional route through which macroeconomic uncertainty can impact on the economy. We abstracted from aggregate savings and imposed that workers cannot go into debt. These assumptions are appealing from a computational perspective but it would be interesting to relax them both so that one can also evaluate the impact on aggregate savings and investment. It would also be interesting to investigate the impact of unemployment insurance policies.

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[20] Alternatively, one could allow the policy rule to respond to e.g. the output gap, unemployment or other indicators. The central issue in terms of stabilization is whether the rule can stabilize the equilibrium real interest rate around the natural real interest rate (the real interest rate in the flexible price equilibrium).

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Steady-state argets			Stationary State Values		
u	0.05	unemployment rate	c^n	0.830	consumption employed
η_s	0.586	job finding rate among searchers	$c^{u,s}$	0.733	consumption unemployed in s-pool
$\frac{\mu}{\psi 4\overline{w}}$	0.045	hiring cost as fraction of quarterly wage	$c^{u,l}$	0.733	consumption unemployed in l-pool
	0.15	fraction of unemployed (> 6 months)	η_s	0.586	job finding rate unemployed in s-pool
$\frac{\xi}{\overline{w}}$	0.117	consumption loss upon unemployment	η_l	0.274	job finding rate unemployed in l-pool
π	0	net inflation rate (π)	u_s	0.017	mass in s-pool
$R^{12}-1$	0.05	annual net interest rate	u_l	0.033	mass in l-pool
	5	avg. price duration (Calvo equivalent)			
Parameter values			**Parameter values**		
ϕ	96.9	price adjustment cost parameter	λ_φ	0.99	persistence search heterog. shock l-pool
γ	6	elast. subst. goods varieties	$100\nu_\omega/\overline{\varpi}$	7.20	std. dev. ω shock as a percentage of $\overline{\varpi}$
β	0.992	discount factor	μ	0.19	matching efficiency parameter
σ	1.5	coefficient of relative risk aversion	q	0.468	prob. of search for unemployed in l-pool
δ	1.5	interest rate rule parameter on inflation	$\overline{w}$	0.830	real wage
$\overline{\rho}$	0.039	steady state job termination rate	α	0.65	matching function elasticity
λ_ρ	0.91	persistence termination rate shock	ξ	0.733	unemployment benefit
$100\nu_\rho/\overline{\rho}$	0.667	std. dev. ρ shock as a percentage of $\overline{\rho}$	$\overline{R}-1$	0.004	steady-state net nominal interest rate
$\overline{\varphi}_l$	0.229	s.s. fraction of job losers into s-pool	$\overline{\varpi}$	0.219	steady state fraction from s-pool to l-pool

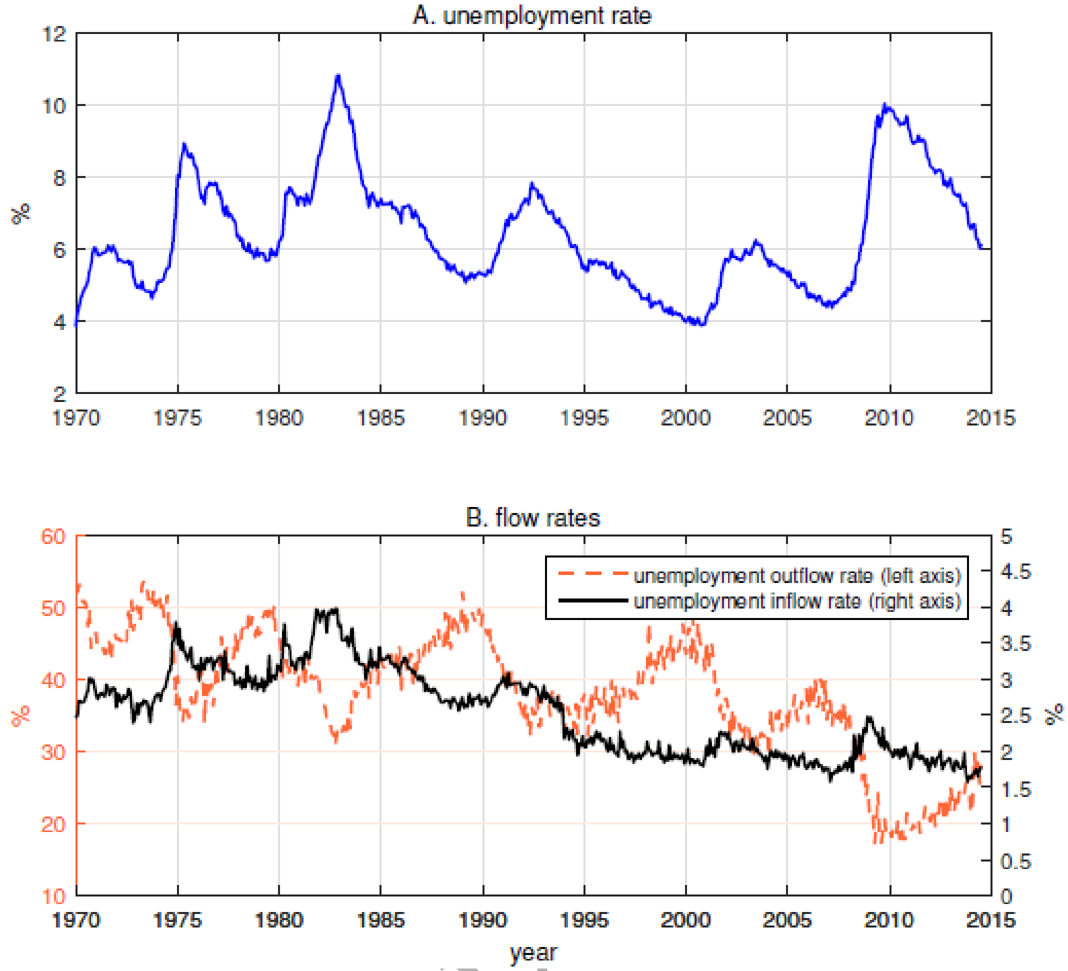

Figure 1: Unemployment and Job Flows in the U.S.

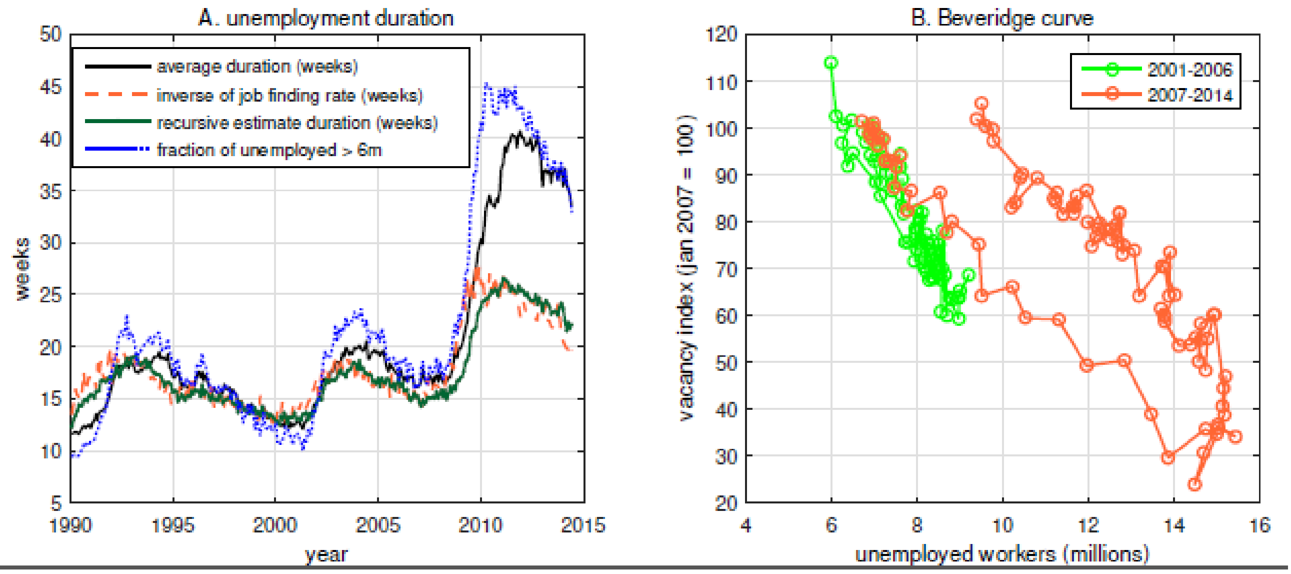

Figure 2: Labor Market Indicators

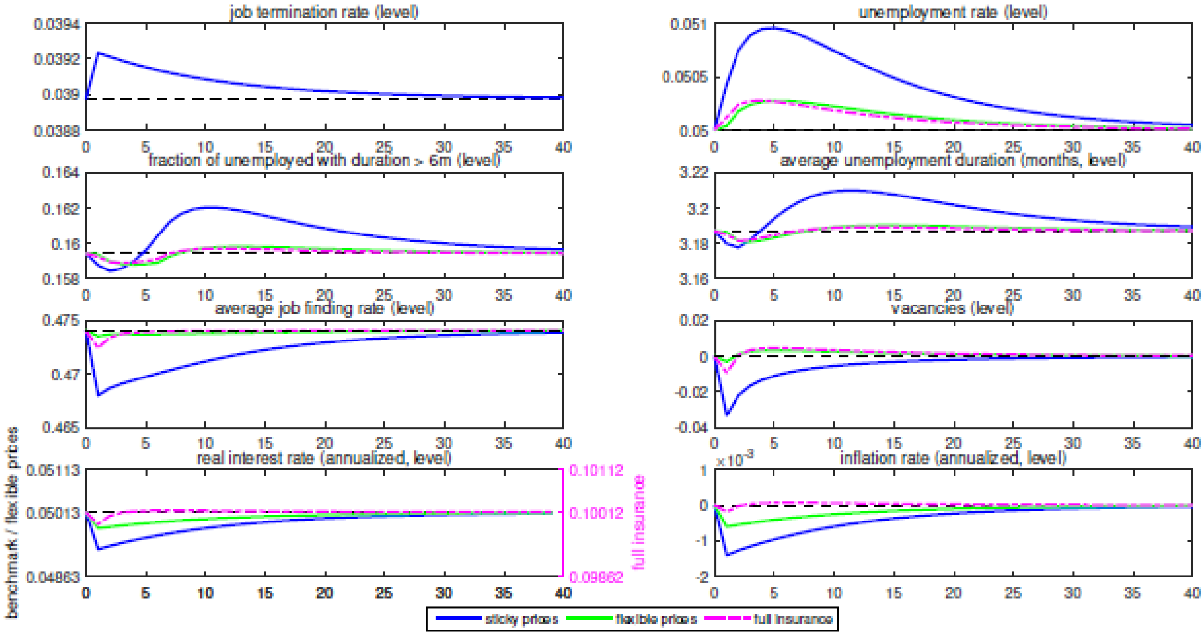

Figure 3: The Impact of Job Separation Shocks

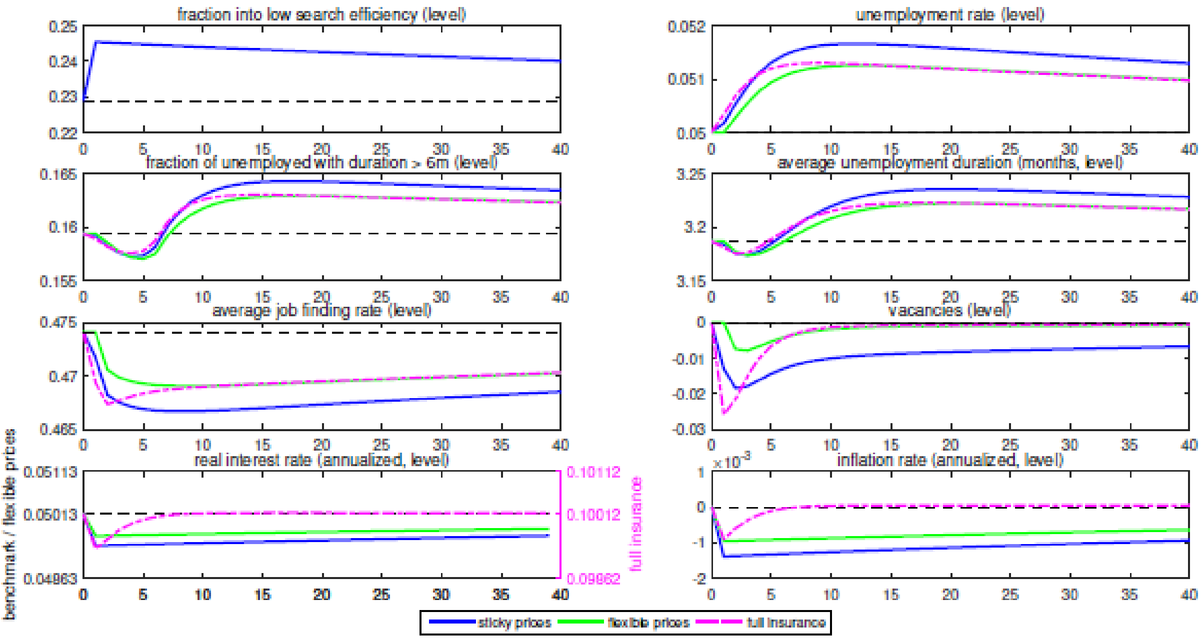

Figure 4: The Impact of Search Heterogeneity Shocks

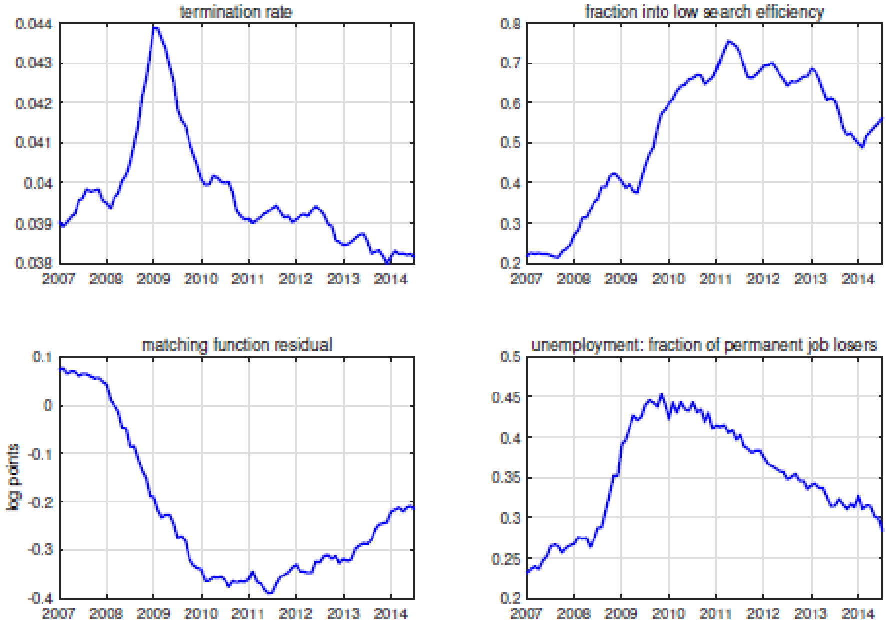

Figure 5: The Great Recession: Shocks

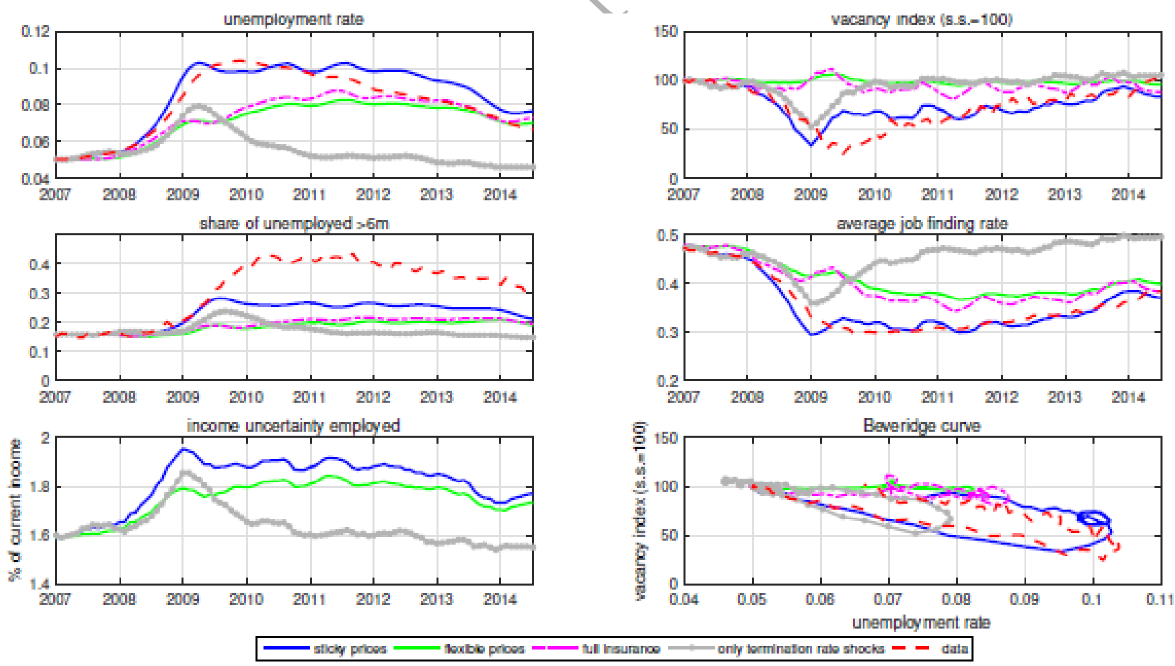

Figure 6: The Great Recession: Counterfactual

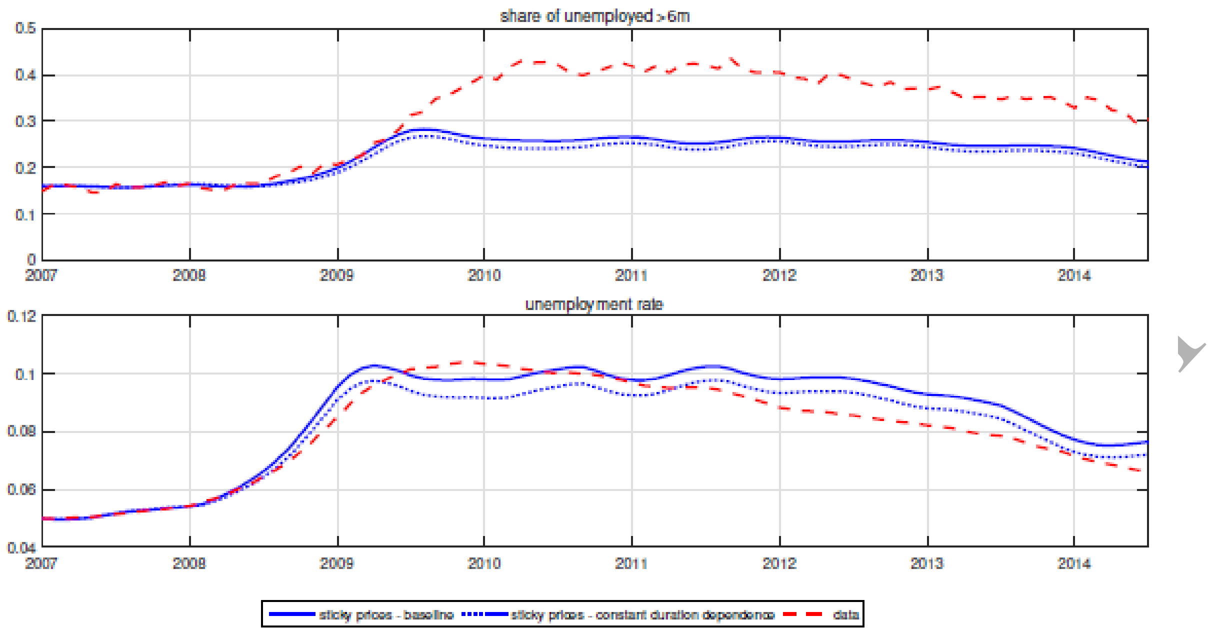

Figure 7: The Importance of Different Sources of Heterogeneity

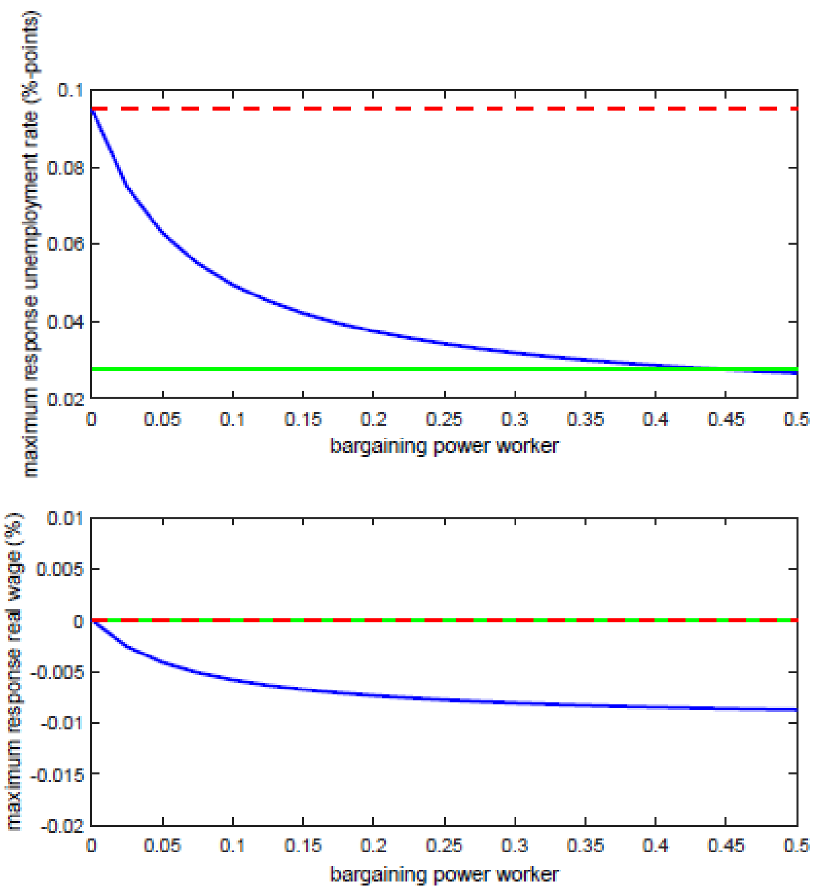

Figure 8: The Role of Wage Flexibility

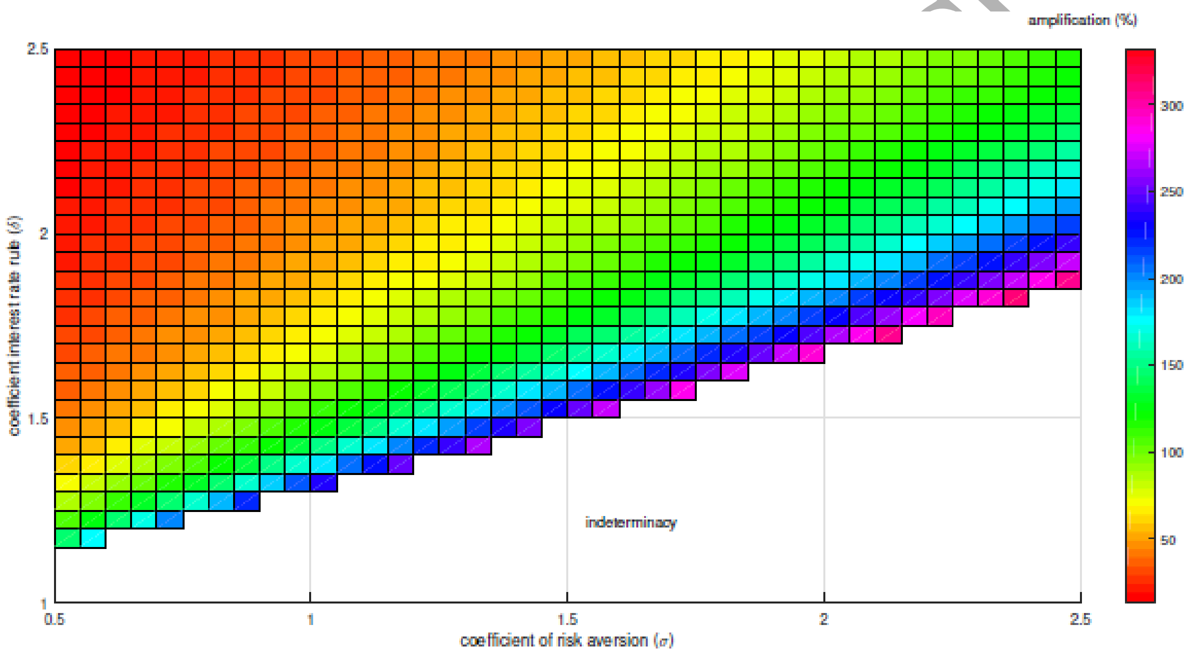

Figure 9: Monetary Policy and Amplification