Job Uncertainty and Deep Recessions*

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Abstract

This paper studies a heterogeneous agents model that combines frictions in the labor market with incomplete asset markets and nominal rigidities in price setting. Workers experience job terminations that can either send them into short term unemployment or into longer term unemployment. An increase in job uncertainty depresses aggregate demand which is transmitted to the supply side and produces a significant drop in job finding rates because firms cut back on vacancy postings. The amplification mechanism is small when asset markets are complete, prices are flexible or unemployment is predominantly short term. Applied to the Great Recession, the model can account for the sharp rise in the level of unemployment and for much of the shift and movement along the Beveridge curve observed during this recession. Job uncertainty also emerges as a plausible candidate for the shock that sent the US economy into a liquidity trap and we show that the zero lower bound on nominal interest rates can amplify the recession very significantly in this environment.

Keywords: job uncertainty, unemployment, incomplete markets, the zero lower bound

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1 Introduction

The U.S. labor market deteriorated dramatically during the Great Recession. The civilian unemployment rate increased from 4.7 percent in December 2007 to 9.9 percent by June 2009 and remained high thereafter for a long period. Moreover, the mean duration of unemployment shot up from 16.5 weeks in December 2007 to 29.7 weeks by June 2009 and subsequently reached hitherto unprecedented levels close to 40 weeks in late 2012. In this paper we develop a model in which such sluggish labor market conditions interact with frictions in goods and financial markets to produce a powerful amplification mechanism that we argue helps understanding the severity of the Great Recession.

The first tenant of our theory is that adverse labor market prospects can have a large impact on the demand side of the economy. We study a model in which households are risk averse and need to self-insure against unemployment due to an absence of unemployment insurance contracts. In such a setting increasing risk of job losses and uncertain prospects for finding a new job during unemployment triggers a precautionary savings motive. Such a precautionary savings can produce a decline in aggregate demand in response to increased job loss risk which goes significantly beyond the decrease in the income of workers that experience a job loss, see also Carroll and Dunn (1997) and Carroll, Dynan and Krane (2004).[1] Another important feature of our theory is that we allow for differences across unemployed workers in their prospects for finding jobs. This aspect is motivated with reference to the increase in the average duration of unemployment observed in the US during the Great Recession. Under the assumption that all unemployed workers face identical job market prospects, the average unemployment duration can be approximated by the inverse of the instantaneous job finding rate. However, the actual increase in the average duration of unemployment observed in the US during the Great Recession was much larger than what implied by this approximation, see also Hornstein (2012). To address this, we introduce heterogeneity in 'search efficiency' and assume that some proportion of the unemployed are 'mismatched' and therefore less efficient searchers than 'normal' households, see also Krusell and Smith (1999) and Krusell et al (2009).[2] Such mismatch can interact with the precautionary savings motive to produce a large

[1] The idiosyncratic uncertainty shock that we highlight is very different in nature to aggregate uncertainty shocks due changes in the second moments of productivity and policy shocks highlighted by e.g. Baker et al (2012) and Stock and Watson (2012).

[2] Our notion of mismatch is different from the one proposed by e.g. Shimer (2007) who defines mismatch in terms of imbalances between vacancies and unemployment across (local) labor markets.

decline in aggregate demand when it occurs at the same time as an increase in the risk of a job loss, a feature that we will argue is relevant for the Great Recession.

We model these features by combining a model with matching frictions in the labor market and differences across workers in search efficiency with an incomplete markets model in which households cannot purchase unemployment insurance contracts but can partially self-insure through savings. We add two further important ingredients. First, firms are faced with nominal rigidities in price setting. This feature is central to our theory because it allows changes in aggregate demand to be transmitted to the supply side. Secondly, real wages are assumed to be rigid so that wage cuts do not insulate new job hires from deteriorating economic conditions.[3] Monetary policy is described by a Taylor rule for the short-term nominal interest rate. The model is calibrated to match statistics for the US economy prior to the Great Recession assuming moderate degrees of risk aversion and of nominal rigidities. We impose a zero borrowing limit which implies that the consumption loss due to unemployment shocks – which we calibrate to 11 percent following Hurd and Rohwedder (2011) – is a key determinant of the precautionary savings motive.

We simulate the model in response to the short burst in job separations observed in the US at the onset of the Great Recession[4] and a mismatch shock which determines the share of job losers that become low search efficiency unemployed workers. The latter is calibrated so that the model matches the share of workers who have been unemployed for 6 months or more and we find an important increase in mismatch from mid-2009 onwards just as job separations level out. In response to these shocks, our theory imply a rise in the unemployment rate and a drop in vacancy postings that are very similar to the empirical counterparts observed during the Great Recession. Thus, the model also reproduces the much-discussed movements along and the outward shift of the Beveridge curve. Importantly, when we either neutralize the transmission from the demand side to the supply side by assuming flexible prices or eliminate the precautionary savings motive against idiosyncratic shocks by assuming large families, the labor market shocks have only limited impact on unemployment and the model fails to reproduce the Beveridge curve. In either case, we find that the labor market shocks have little impact on the job finding rate and that the model therefore lacks amplification. Thus, it is the combination of frictions in goods and financial markets that

[3] We adopt this last friction since there seems to have been little downward real wage flexibility in the US during the Great Recession, see also Shimer (2012).

[4] We take no view on the underlying sources of the job separation shock but the financial crisis of 2007/08 would be a likely and very plausible candidate.

produces amplification. We contrast our results also with those of the early 1990's recession. We show that the labor market shocks were much smaller in that recession but that the amplification mechanism of our model still matters for understanding the increase in unemployment and the decrease in vacancies observed in this recession.

Mismatch shocks are central to our ability to account for the Great Recession. When we eliminate these shocks we find an outward shift of the Beveridge curve but little movement along it. While we refrain from modeling the roots of this shock, one might speculate about structural interpretations. An appealing interpretation rests on disparity between the supply and demand for jobs across industries, occupations and skill groups. Such imbalances imply that workers who lose their jobs find it difficult to find jobs because of a lack of demand for workers in the 'local' labor market segment. Şahin et al (2012), however, find limited empirical relevance of this source of mismatch during the Great Recession. A decrease in search efficiency could also derive from financial constraints which make unemployed workers in negative equity (or with large potential capital losses on their housing stock) unwilling to move in their pursuit of new job opportunities, see eg. Sterk (2011). Such constraints on geographical mobility are also likely for households with multiple labor market participants in which one of the household members loses their job. Finally, as in Pissarides (1992), long unemployment spells may lead to human capital depreciation making the supply of suitable jobs more limited.[5]

Our analysis has implications for monetary policy design. 'Standard' New Keynesian models typically rest on representative agents settings with insurance against unemployment within large diversified households. In such settings, monetary policy should be aimed at addressing the inefficiencies imposed by nominal rigidities which typically can be implemented by letting interest rates react very aggressively to deviations of inflation from its target. We show that very aggressive monetary responses similarly can facilitate stabilization of the economy in response to labor market shocks by implementing the outcome observed under flexible prices while weak monetary policy responses to inflation can easily generate local indeterminacy. We further consider the impact of imposing a zero lower (ZLB) bound on short term nominal interest rates. We find that the labor market shocks during the Great Recession were sufficiently large to take the economy into a liquidity trap. When the ZLB binds, not only does job uncertainty hold back goods demand for

[5] Such a theory would be more consistent with a three state model in which job losers initially enter the high search efficeincy state and thereafter may experience a transition to the low search efficiency state. This model has very similar implications to the one we analyze.

precautionary savings reasons, but the lack of interest rate responds produces a further drop in output required to clear the savings market. Quantitatively, we find that the model with a ZLB produces an even larger recession than observed in the US which we interpret as indicating that policy interventions may have softened the recession.

Our work is closely related to a number of other contributions to the literature. Gomes, Greenwood and Rebelo (2001) and Krusell, Mukoyama, and Şahin (2011) investigate the impact of self-insurance in incomplete markets settings with frictional labor markets. Krusell and Smith (1999) and Krusell et al (2009) study a self-insurance model with risk of both short-term and long-term unemployment.[6] We add goods market frictions and find this aspect to be important. Challe and Ragot (2012) and Bayer et al (2013) study the impact of precautionary savings in an incomplete markets setting. The latter of these papers also introduces nominal rigidities and allows for time-varying variance of idiosyncratic earnings shocks while we model uncertainty through unemployment risk and the impact of mismatch.[7] Guerrieri and Lorenzoni (2012) also examine an incomplete markets setting with nominal rigidities focusing upon the impact of tightening borrowing constraints. Leduc and Liu (2013) present time-series evidence that increases in 'uncertainty' impacts negatively on aggregate demand and argue that labor market frictions and nominal rigidities are essential for accounting for this relationship. Most similar to our analysis are the recent contributions of Gornemann, Kuester and Nakajima (2012) and McKay and Reis (2012) who 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 (2012) focus upon the impact of automatic fiscal stabilizers. Unlike us, none of these contributions examine the consequences of allowing for longer-term unemployment.

The remainder of this paper is structured as follows. Section 2 reviews the labor market impact of the Great Recession. In Section 3 we present the model. Section 4 examines the quantitative properties of the model and provides an analysis of the Great Recession. Section 5 extends the

[6] A key difference between their analysis and ours is that agents in their economy are able approximately to self-insure against unemployment shocks while we calibrate towards empirical estimates of the impact of unemployment transitions on consumption.

[7] Basu and Bundick (2012), Rendahl (2012), and Schaal (2012) also investigate the impact of uncertainty or news shocks in models with labor market frictions. Caggese and Perez (2012) look at precautionary behavior in a model that combines labor market and financial market frictions.

analysis to the ZLB and provides some robustness analysis. Section 6 summarizes and concludes.

2 The Great Recession and the Labor Market

The financial crisis produced one of the longest and deepest recessions in US history. According to the NBER, the contraction lasted 18 months (December 2007 - June 2009), the longest since the Great Depression. The Great Recession also triggered a major deterioration of labor market conditions.[8] Unemployment rose from 4.7 percent in July 2007 to 10 percent by October 2009, and has subsequently remained stubbornly high, see Figure 1.

The flows in and out of unemployment provide a useful way to gain some further insight into the determinants of the change in unemployment. We compute the average instantaneous job finding rate, $\boldsymbol{\lambda}_t$, and the average job separation rate, $\boldsymbol{\rho}_t$ as:

$$\begin{aligned} \boldsymbol{\lambda}_t &= \frac{\mathbf{m}_t}{\mathbf{u}_{t-1}} \\ \boldsymbol{\rho}_t &= \frac{\mathbf{e}_t}{\mathbf{n}_{t-1}} \end{aligned}$$

where $\mathbf{u}_t$ 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 (permanent) job separations. All data were obtained from the Current Population Study (CPS) apart from $\mathbf{e}_t$ which we got from the Bureau of Labor Statistics. The appendix contains precise data sources.

Figure 2 illustrates the estimates of $\boldsymbol{\lambda}_t$ and $\boldsymbol{\rho}_t$. The initial rise in unemployment was triggered by a temporary increase in the inflow rate into unemployment but its persistence derives from a stubborn decline in the outflow rate (the job finding rate), a pattern that is not unusual for US recessions. Thus, any theory meant to address the labor market slump during the Great Recession has to say something about why the outflow rate - the rate at which unemployed workers have found jobs - has persisted at such low levels since the onset of the recession.

An important observation is that while the peak of the unemployment rate during the Great Recession does not stand out as particularly high relative to previous recessions, the impact on the duration of unemployment is very different from previous recessions, see Figure 3. The duration of unemployment usually increases during recessions but only to moderate levels. For example, in the early 1980's recession, the mean duration of unemployment went up from 13 weeks in 1981

[8] See Daly et al (2011), Elsby, Hobijn and Sahin (2010), Hall (2011), Katz (2010), and Rothstein (2011) for excellent discussions of the labor market during the Great Recession.

to 21 weeks by the summer of 1983. In contrast, during the Great Recession the duration of unemployment sky rocketed from 17.2 weeks in July 2007 to 40 weeks in late 2012, almost twice its previous peak value in the post-WWII sample, see also Rothstein (2011) and Wiczer (2013).[9]

The extended period of high unemployment provides one mechanical reason for the increase in longer term unemployment during the Great Recession but by itself it cannot account for size of the rise in the average spell of unemployment. To appreciate this, consider the following computation of the mean duration. Assume that all unemployed workers face identical job prospects so that the mean unemployment duration can be approximated by the inverse of the instantaneous job finding rate, $1/\boldsymbol{\lambda}_t$.[10] Figure 3 shows $1/\boldsymbol{\lambda}_t$ along with CPS estimates of the mean duration of unemployment. According to the actual CPS estimates, the mean duration of unemployment peaked at 40.4 weeks in July 2011, an increase of 25.8 weeks relative to the duration of unemployment in December 2007 prior to the contraction. In comparison, the counterfactual estimates indicate a peak increase in the duration of unemployment of only 11.3 weeks. Thus, the assumption of homogeneous job opportunities generates a far smaller increase in the duration of unemployment than can be observed in the data, see also Barnichon and Figura (2011) and Hornstein (2012). Our theoretical analysis addresses this issue by deviating from the assumption of a homogeneous labor market outlook for the stock of unemployed workers.

Another much discussed feature of the Great Recession is its impact on the Beveridge curve. Figure 4 illustrates the relationship between vacancies and unemployment using CPS estimates of unemployment and JOLTS estimates of the number of vacancies. We discriminate between the pre-Great Recession period and the period thereafter (from 2007:12). During the early parts of the recession, unemployment approximately doubled while the number of vacancies fell by around 50 percent in combination producing a striking movement down the Beveridge curve. In the course of the initial part of the recession, the labor market conditions worsened considerably but the dynamics of unemployment and vacancies appear consistent with the pre-crisis Beveridge curve. From late 2009 there is instead evidence that the Beveridge curve shifted outwards indicating a

[9] Similar dramatic increases can be observed in the median duration of unemployment (which peaked at 24.8 weeks in late June 2010, the double of its previous high in the post-WWII sample of 12.3 weeks in May 1983) and in the share of unemployed workers who have been out of work for more 6 months of more which peaked at 45.3 percent in March 2011, up from 16-18 percent prior to the contraction.

[10] Alternatively, when unemployed workers find job with the same probability, one can compute mean duration recursively from $d_t \simeq (1-\lambda_t)(d_{t-1}+1)(u_t/u_{t-1}) + e_t/u_t$. This approximation produces almost the same counterfactual estimate of mean duration as the inverse of the job finding rate.

less efficient matching between workers looking for employment and firms looking for new hires, see also Barlevy (2011).

3 Model

We construct a model in which a menu of frictions comes together and investigate how labor market shocks may be amplified endogenously.

Households. There is a continuum of mass 1 of households indexed by $i \in (0,1)$. Households are risk-averse, infinitely lived, have rational expectations and maximize the expected present value of their utility streams. A household is either working or unemployed. When employed, the household earns a real wage $\mathbf{w}_t$. A household that is employed at the beginning of the period may lose the job at the end of the period, an event that occurs with probability $\boldsymbol{\rho}_{x,t} \in [0,1]$. During unemployment the household searches for jobs and receives benefits $\boldsymbol{\xi} < \mathbf{w}_t$.

A household that experiences a job loss is randomly assigned to either a 'short-term' (indexed by $r = s$) unemployment pool or a 'long-term' unemployment ($r = l$) pool. We let $\boldsymbol{\rho}_{r,t} \in [0,1]$, $\boldsymbol{\rho}_{s,t} + \boldsymbol{\rho}_{l,t} = 1$, be the probability that a household which experiences a job loss in period t becomes state $r = s, l$ unemployed. The two unemployment states differ in the probability that the household finds a new job. We assume that the job finding probabilities, $\boldsymbol{\eta}_{r,t}$, are such that $0 \leq \boldsymbol{\eta}_{l,t} \leq \boldsymbol{\eta}_{s,t} \leq 1$ so that a short-term unemployed worker is at least as likely to receive a job offer as a long-term unemployed worker. This feature produces heterogeneity across unemployed workers in the *expected* duration of unemployment spells, see also Barnichon and Figura (2011), Hornstein (2012), Krusell and Smith (1999) and Krusell et al (2009).

The timing is as follows. At the beginning of the period, the aggregate labor market shocks are realized. After this, unemployed workers and firms match and new employment relationships are established. This is followed by production and consumption. At the end of the period, the job separations are effectuated. Thus, employed workers face idiosyncratic uncertainty within-period about the identity of job losers.[11]

Households cannot purchase unemployment insurance contracts but can self-insure by saving in a riskless nominal bond, $\mathbf{b}^h_{i,t}$. Asset choices are subject to a borrowing constraint that restricts

[11] Of course, households also face idiosyncratic uncertainty about the identity of future job losers.

households' real assets positions $\mathbf{b}_{i,t}^h \geq \mathbf{b}^{\min}$. They face a sequence of budget constraints:

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

where $\mathbf{c}_{i,t}$ denotes a consumption basket, $\mathbf{R}_{t-1}$ is the gross nominal interest rate paid out in period t on bonds purchased in period $t-1$, $\boldsymbol{\pi}_t$ denotes the net inflation rate in period t. $\mathbf{n}_{i,t}$ is an indicator variable for the household's employment state:

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

Let $\mathbf{V}_i^n\left(\mathbf{b}_i^h, \mathbf{S}\right)$ and $\mathbf{V}_i^{u,r}\left(\mathbf{b}_i^h, \mathbf{S}\right)$ be the expected present discounted utility of an employed household and an unemployed household in state $r = s, l$, respectively, given its bond position and the aggregate state vector, $\mathbf{S}$. $\mathbf{V}_i^n\left(\mathbf{b}_i^h, \mathbf{S}\right)$ is given as:

$$\begin{aligned} \mathbf{V}_i^n\left(\mathbf{b}_i^h, \mathbf{S}\right) &= \max_{\mathbf{c}_i, \mathbf{b}_i^{h\prime}} \{\mathbf{u}\left(\mathbf{c}_i^n\right) + \boldsymbol{\beta}\mathbb{E}\left(1 - \sum_{r=s,l} \boldsymbol{\rho}_x\boldsymbol{\rho}_r\left(1 - \boldsymbol{\eta}_r'\right)\right)\mathbf{V}_i^n\left(\mathbf{b}_i^{h\prime}, \mathbf{S}'\right) \\ &\quad + \boldsymbol{\beta}\mathbb{E}\sum_{r=s,l}\boldsymbol{\rho}_x\boldsymbol{\rho}_r\left(1 - \boldsymbol{\eta}_r'\right)\mathbf{V}_i^{u,r}\left(\mathbf{b}_i^{h\prime}, \mathbf{S}'\right)\} \end{aligned} \tag{2}$$

subject to the borrowing constraint and to the budget constraint in equation (1) setting $\mathbf{n}_i = 1$. $\mathbf{u}$ is a concave utility function. $\boldsymbol{\beta} \in (0,1)$ is the subjective discount factor, and $\mathbb{E}$ is the conditional expectations operator. $\boldsymbol{\rho}_x\boldsymbol{\rho}_r$ is the probability that a worker who is employed at the beginning of the period makes a transition to unemployment state r at the beginning of the next period.

The Bellman equation for a type r unemployed worker is:

$$\begin{aligned} \mathbf{V}_i^{u,r}\left(\mathbf{b}_i^h, \mathbf{S}\right) &= \max_{\mathbf{c}_i, \mathbf{b}_i^h} \{\mathbf{u}\left(\mathbf{c}_i^r\right) + \boldsymbol{\kappa} + \boldsymbol{\beta}\mathbb{E}\boldsymbol{\eta}_r'\mathbf{V}_i^n\left(\mathbf{b}_i', \mathbf{S}'\right) \\ &\quad + \boldsymbol{\beta}\mathbb{E}\left(1 - \boldsymbol{\eta}_r'\right)\mathbf{V}_i^{u,r}\left(\mathbf{b}_i', \mathbf{S}'\right)\},\ r = s, l \end{aligned} \tag{3}$$

subject to the borrowing constraint and the budget constraint in equation (1) setting $\mathbf{n}_i = 0$. $\boldsymbol{\kappa} > 0$ denotes the utility of leisure enjoyed by an unemployed household. As a matter of consistency, we assume that $\mathbf{V}_i^n\left(\mathbf{b}^h, \mathbf{S}\right) > \mathbf{V}_i^{u,s}\left(\mathbf{b}^h, \mathbf{S}\right)$ 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 $\boldsymbol{\eta}_s' > \boldsymbol{\eta}_l'$ the condition that $\mathbf{V}_i^n\left(\mathbf{b}^h, \mathbf{S}\right) > \mathbf{V}_i^{u,s}\left(\mathbf{b}^h, \mathbf{S}\right)$ for all $\mathbf{b}^h$ and $\mathbf{S}$ automatically implies that $\mathbf{V}_i^n\left(\mathbf{b}^h, \mathbf{S}\right) > \mathbf{V}_i^{u,l}\left(\mathbf{b}^h, \mathbf{S}\right)$ for all $\mathbf{b}$ and $\mathbf{S}$.[12]

[12] The formulation of the unemployed workers' problem in equation (3) assumes that there are no flows between the two unemployment states during unemployment. However, all workers face identical job prospects upon employment. The first of these assumptions is easily relaxed and immaterial for the results as long as the flow out of unemployment is sufficiently small for type l workers relative to type s workers.

The consumption index $\mathbf{c}_i$ is a basket of consumption goods varieties:

$$\mathbf{c}_i = \left(\int_j \left(\mathbf{c}_i^j \right)^{1-1/\gamma} dj \right)^{1/(1-1/\gamma)} \tag{4}$$

where $\mathbf{c}_i^j$ denotes household i's consumption of goods of variety j and $\gamma > 1$ is the elasticity of substitution between consumption goods. Variety j is purchased at the nominal price $\mathbf{P}_j$. It follows that household i's demand for variety j is given as:

$$\mathbf{c}_i^j = \left(\frac{\mathbf{P}_j}{\mathbf{P}} \right)^{-\gamma} \mathbf{c}_i \tag{5}$$

where $\mathbf{P}$ is the price index associated with the consumption basket defined in (4):

$$\mathbf{P} = \left(\int_j \mathbf{P}_j^{1-\gamma} dj \right)^{1/(1-\gamma)} \tag{6}$$

Entrepreneurs. Consumption goods are produced by a continuum of monopolistically competitive firms indexed by $j \in (0,1)$ which are owned by risk neutral entrepreneurs. $\Psi < 1$ denotes the measure of entrepreneurs. Entrepreneurs discount utility at the rate $\boldsymbol{\beta}$ and make decisions on the pricing of their goods, on vacancy postings, and on their consumption and savings policies. In return for managing (and owning) the firm, they are the sole claimants to its profits (but will also have to stand ready to cover losses). We assume that entrepreneurs can save but face a no-borrowing constraint. This no-borrowing constraint implies that the entrepreneur finances hiring costs through retained earnings.[13]

Output is produced according to a linear technology:

$$\mathbf{y}_{j,t} = \mathbf{n}_{j,t} \tag{7}$$

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

$$\mathbf{n}_{j,t} = \left(1 - \boldsymbol{\rho}_{x,t-1}\right) \mathbf{n}_{j,t-1} + \mathbf{h}_{j,t} \tag{8}$$

where $\mathbf{h}_{j,t}$ denotes hires made by firm j in period t. The number of hires in turn is given as:

$$\mathbf{h}_{j,t} = \boldsymbol{\rho}_{f,t} \mathbf{v}_{j,t} \tag{9}$$

where $\mathbf{v}_{j,t}$ is the number of vacancies posted by the firm and $\boldsymbol{\rho}_{f,t}$ is the job filling probability. Firms are assumed to be sufficiently large that $\boldsymbol{\rho}_{f,t}$ can be interpreted as the *fraction* of vacancies that

[13] In the stationary equilibrium, $\beta < 1/\left(R/\left((1+\pi)\right)\right)$ so entrepreneurs will be borrowing constrained.

lead to a hire.[14] The cost of posting a vacancy is given by $\boldsymbol{\mu} > 0$. Real marginal costs are therefore given as:

$$\mathbf{mc}_{j,t} = \frac{\mathbf{w}_t}{\mathbf{A}} + \frac{\boldsymbol{\mu}}{\boldsymbol{\rho}_{f,t}} - \boldsymbol{\beta}\mathbb{E}_t\left[\left(1-\boldsymbol{\rho}_{x,t}\right)\frac{\boldsymbol{\mu}}{\boldsymbol{\rho}_{f,t+1}}\right] \tag{10}$$

which incorporates the fact that hiring in period t impacts on future marginal costs through future hiring cost savings.

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

$$\mathbb{E}_t\sum_{s=0}^{\infty}\boldsymbol{\beta}^s\left(\left(\frac{\mathbf{P}_{j,t+s}}{\mathbf{P}_{t+s}} - \mathbf{mc}_{j,t+s}\right)\mathbf{y}_{j,t+s} - \frac{\phi}{2}\left(\frac{\mathbf{P}_{j,t+s}-\mathbf{P}_{j,t+s-1}}{\mathbf{P}_{j,t+s-1}}\right)^2\mathbf{y}\right) \tag{11}$$

subject to:

$$\mathbf{y}_{jt} = \left(\frac{\mathbf{P}_{jt}}{\mathbf{P}_t}\right)^{-\gamma}\mathbf{y}_t \tag{12}$$

Equation (12) is the demand for goods variety j. $\mathbf{y}_t$, can be interpreted as aggregate real income. In equation (11) $\phi \geq 0$ indicates the severity of nominal rigidities in price setting with $\phi = 0$ corresponding to flexible prices.[15] The first-order condition for this problem is given as:

$$\begin{aligned}\left((1-\gamma)+\gamma\mathbf{mc}_{j,t}\frac{\mathbf{P}_t}{\mathbf{P}_{j,t}}\right)\mathbf{y}_{j,t} &= \phi\frac{\mathbf{P}_t}{\mathbf{P}_{j,t-1}}\left(\frac{\mathbf{P}_{j,t}-\mathbf{P}_{j,t-1}}{\mathbf{P}_{j,t-1}}\right)\mathbf{y} \\ &\quad +\phi\boldsymbol{\beta}\mathbb{E}_t\left[\left(\frac{\mathbf{P}_{j,t+1}}{\mathbf{P}_{j,t}^2}\right)\left(\frac{\mathbf{P}_{j,t+1}-\mathbf{P}_{j,t}}{\mathbf{P}_{j,t}}\right)\mathbf{P}_t\mathbf{y}\right]\end{aligned} \tag{13}$$

In a symmetric equilibrium, which will be the focus of our analysis, this simplifies to:

$$(1-\gamma)+\gamma\mathbf{mc}_t = \phi\boldsymbol{\pi}_t\left(1+\boldsymbol{\pi}_t\right) - \phi\boldsymbol{\beta}\mathbb{E}_t\left[\boldsymbol{\pi}_{t+1}\left(1+\boldsymbol{\pi}_{t+1}\right)\right] \tag{14}$$

Given the entrepreneurs decisions as a producer and price setter, she solves the following dynamic programming problem:

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

[14] This assumption - which is equivalent to assuming that Ψ is sufficiently smaller than 1, can be relaxed which would produce ex-post heterogeneity across firms. The assumption also allows us to assume that there are no indivisibility problems associated with the full-time hours assumption and

[15] In equation (11) we scale the price adjustment costs with steady-state output. This assumption has no consequences for our results apart from when we introduce the zero lower bound on the nominal interest rate in the robustness analysis.

subject to the budget and borrowing constraints:

$$\mathbf{d}_j + \mathbf{b}_j^e + \mathbf{w}\mathbf{n}_j + \boldsymbol{\mu}\frac{\mathbf{h}_j}{\boldsymbol{\rho}_f} = \frac{\mathbf{P}_j}{\mathbf{P}}\mathbf{A}\mathbf{n}_j - \mathbf{T}^e + \frac{\mathbf{R}}{1+\boldsymbol{\pi}}\mathbf{b}_j^e \tag{16}$$

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

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 employer to cover the government provided unemployment benefits.

Labor Market. We assume that real wages are constant, $\mathbf{w}_t = \overline{\mathbf{w}}$, 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.[16] The constant real wage assumption serves as a useful benchmark and is consistent with the US experience during the Great Recession. We examine later whether the results are sensitive to assuming that wages are instead determined according to a Nash bargaining model.

The matching technology is given as:

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

where $\mathbf{m}_t$ denotes the measure of matches between firms with vacancies and unemployed workers at date t, $\mathbf{u}_{a,t}$ is the measure of 'active' searchers, and $\mathbf{v}_t$ is the measure of vacancies posted by the firms. $\psi > 0$, and $\alpha \in (0,1)$ are constant parameters. The number of active searchers, in turn, is given as:

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

where $\mathbf{u}_{r,t}$ is the measure of type r unemployed workers at date t. $\mathbf{q} \in (0,1]$ is the probability that a type l unemployed worker is searching for a job at date t. When $\mathbf{q} < 1$, type l workers are less likely to find a job than type s unemployed workers and face longer expected unemployment spells. The right hand side of this expression consists of the unemployed workers from last period plus the number of new job separations of each type corrected for the fact that type l unemployed workers search only with probability $\mathbf{q}$. $\mathbf{u}_{a,t}$ can therefore be thought of as the number of unemployed searchers measured in efficiency units at the beginning of the period prior to the current period's matching between firms and workers.

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

Given the matching technology, the job filling probability and the job finding probabilities are given as:

$$\boldsymbol{\rho}_{f,t} = \psi \boldsymbol{\theta}_t^{-\alpha} \tag{20}$$

$$\boldsymbol{\eta}_{s,t} = \psi \boldsymbol{\theta}_t^{1-\alpha} \tag{21}$$

$$\boldsymbol{\eta}_{l,t} = \mathbf{q}\boldsymbol{\eta}_{s,t} \tag{22}$$

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:

$$\mathbf{n}_t = \left(1 - \boldsymbol{\rho}_{x,t-1}\right) \mathbf{n}_{t-1} + \mathbf{m}_t \tag{23}$$

$$\mathbf{u}_{r,t} = \left(1 - \boldsymbol{\eta}_{r,t}\right) \left(\mathbf{u}_{r,t-1} + \boldsymbol{\rho}_{r,t-1}\boldsymbol{\rho}_{x,t-1}\mathbf{n}_{t-1}\right) \tag{24}$$

Government. The government is in charge of monetary and fiscal policies. We assume that the government balances the budget period by period which means that:

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

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

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

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.

Stochastic Shocks. We allow for shocks to the job separation rate, $\boldsymbol{\rho}_{x,t}$, and to $\boldsymbol{\rho}_{s,t}$, the stochastic variable which determines the share of workers affected by job terminations that become short-term unemployed. We assume that:

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

$$\boldsymbol{\rho}_{s,t} = \overline{\boldsymbol{\rho}_s} + \mathbf{z}_{s,t} \tag{28}$$

$$\mathbf{z}_{x,t} = \boldsymbol{\lambda}_x \mathbf{z}_{x,t-1} + \boldsymbol{\varepsilon}_{x,t} \tag{29}$$

$$\mathbf{z}_{s,t} = \boldsymbol{\lambda}_s \mathbf{z}_{s,t-1} + \boldsymbol{\varepsilon}_{s,t} \tag{30}$$

where $\overline{\boldsymbol{\rho}_x}, \overline{\boldsymbol{\rho}_s} \in (0,1)$ are the long-run levels of job termination and the share of short-term unemployed, respectively, while $\boldsymbol{\lambda}_x, \boldsymbol{\lambda}_s \in (-1,1)$ denote the persistence of shocks to the job termination rate and to the share of short-term unemployed. It is assumed that $\boldsymbol{\varepsilon}_t \sim N\left(0, \mathbf{V}_{\boldsymbol{\varepsilon}}\right)$ where $\boldsymbol{\varepsilon}_t = \left(\boldsymbol{\varepsilon}_{x,t}, \boldsymbol{\varepsilon}_{s,t}\right)'$.

Equilibrium. We focus upon a recursive equilibrium in which households 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 assumptions made earlier about the absence of idiosyncratic productivity shocks, state contingent pricing and the large firm assumption. We let $\mathbf{p}_{j,t} = \mathbf{P}_{j,t}/\mathbf{P}_t$ denote the relative price of firm j's product. Symmetry implies that this relative price equals 1 in equilibrium.

We impose that $\mathbf{b}^{\min} = 0$. Since no household is allowed to be in debt and there is no aggregate savings vehicle, this implies that, in equilibrium, all households consume their income and that the aggregate wealth distribution is degenerate and not relevant as a state variable. Due to this assumption, the aggregate state vector is $\mathbf{S}_t = \left(\mathbf{u}_{l,t}, \mathbf{u}_{s\,t}, \boldsymbol{\rho}_{x,t}, \boldsymbol{\rho}_{s,t}\right)$ which does not involve the wealth distribution and this simplifies the computationally aspects very considerably while it has only limited impact on the aggregate dynamics, see Ravn and Sterk (2012). We can now define the equilibrium formally:

Definition 1 *A recursive monopolistic competition equilibrium is defined as a state vector* $\mathbf{S}$*, pricing kernels* $(\mathbf{w}(\mathbf{S}), \boldsymbol{\pi}(\mathbf{S}))$*, decision rules* $\left(\mathbf{c}_i^h\left(\mathbf{b}_i^h, \mathbf{S}\right), \mathbf{b}_i^{h\prime}\left(\mathbf{b}_i^h, \mathbf{S}\right)\right)_{i=0}^1$ *and* $\left(\mathbf{p}_j\left(\mathbf{b}^e, \mathbf{S}\right)_{j=0}^J, \mathbf{n}\left(\mathbf{b}^e, \mathbf{S}\right), \mathbf{h}\left(\mathbf{b}^e, \mathbf{S}\right)\right)$*, value functions* $\left(\mathbf{V}_i^e\left(\mathbf{b}_i^h, \mathbf{S}\right), \mathbf{V}_i^{u,s}\left(\mathbf{b}_i^h, \mathbf{S}\right), \mathbf{V}_i^{u,l}\left(\mathbf{b}_i^h, \mathbf{S}\right)\right)_{i=1}^1$ *and* $\mathbf{W}\left(\mathbf{b}^e, S\right)$*, and government policies* $(\mathbf{T}(\mathbf{S}), \mathbf{R}(\mathbf{S}))$ *such that*

(i) given the pricing kernel, the government policies, and the aggregate and individual states, the household decision rules solve the households problem;

(ii) given the pricing kernel, government policies, and the aggregate state, the entrepreneur decision rules solve the entrepreneurs' problem and $\mathbf{p}_j\left(\mathbf{b}^e, \mathbf{S}\right)_{j=0}^J = 1$ *for all* j *and all* $\left(\mathbf{b}^e, \mathbf{S}\right)$*;*

(iii) asset, goods and labor markets clear:

$$\begin{aligned}
\int_i \mathbf{b}_i^{h\prime}\left(\mathbf{b}_i^h, \mathbf{S}\right) di + \Psi \int_j \mathbf{b}_j^{e\prime}\left(\mathbf{b}_j^e, \mathbf{S}\right) dj &= 0 \\
\int_i \mathbf{c}_i^h\left(\mathbf{b}_i^h, \mathbf{S}\right) d\boldsymbol{\Omega} + \Psi \int_j \mathbf{d}_j\left(\mathbf{b}_j^e, \mathbf{S}\right) dj &= \mathbf{y} \\
\int_i \mathbf{n}_i^h d\boldsymbol{\Omega} &= \mathbf{y}
\end{aligned}$$

(iv) the government budget constraint is satisfied and the nominal interest is given by the policy rule in equation (26)*;*

4 Quantitative Results

4.1 Calibration

We solve the model numerically using a standard pertubation approach (see the Appendix for details). The calibration targets and parameter values are summarized in Tables 1 and 2. One model period corresponds to a calendar month. The household utility function is assumed to be given as:

$$u\left(\mathbf{c}_{i,t}\right) = \frac{\mathbf{c}_{i,t}^{1-\sigma} - 1}{1-\sigma},\ \sigma \geq 0$$

σ determines the degree of risk aversion which matters for the household savings response to uncertainty and this is important in our model. 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 who have examined either household data or aggregate time series.

We assume an annual real interest rate of 4 percent in the steady state and set the subjective discount factor equal to 0.993 for both households and entrepreneurs. This value is low relative to standard representative agent models but because of idiosyncratic risk and incomplete markets, agents have a strong incentive to engage in precautionary savings and a low real interest rate is required to induce zero savings in equilibrium.

We target an unemployment rate of 5 percent and a 15 percent share of unemployed workers who have been out of work for 6 months or more in the stationary equilibrium, values that correspond to the mean values observed in the United States in the post-1970 period. Following Rothstein (2011), we target a monthly hazard rate from unemployment to employment for a newly unemployed worker of 43 percent and a 31 percent monthly hazard rate for workers who have been unemployed for 26 weeks or more. It follows from this that the steady-state job loss probability ($\overline{\boldsymbol{\rho}_x}$) is 3.47 percent per month, that the share of workers who experience a job loss that enter the pool of high search efficiency unemployment ($\overline{\boldsymbol{\rho}_s}$) equals 35 percent, and that the relative search efficiency of the longer term unemployed ($\mathbf{q}$) is 65.4 percent.[17]

Using the estimates of Hurd and Rohwedder (2010), we calibrate the benefit level $\boldsymbol{\xi}$ by targeting a consumption loss upon job loss of 11 percent.[18] We assume that the matching function elasticity

[17] It is important to notice that the share of mismatched workers does not correspond directly to the share of long term unemployed workers because some of the mismatched workers find jobs quickly while some of the high search efficiency workers take a long time to find a job.

[18] See http://www.nber.org/papers/w16407.pdf?new_window=1; Table 21. Browning and Crossley (2001) estimate

to unemployment is equal to 50 percent ($\alpha = 0.5$), and normalize $\psi = 1$. $\boldsymbol{\mu}$, the vacancy cost parameter, is calibrated by targeting an average hiring cost of 4.5 percent of the quarterly wage bill per worker. Given other parameters, this implies that $\boldsymbol{\mu} = 0.13$.

We set the average mark-up equal to 20 percent which implies that γ, the elasticity of substitution between goods, is equal to 6. ϕ, the parameter that determines the importance of price adjustment costs, is calibrated to match a price adjustment frequency of 5 months. This value is conservative but close to the value estimated by Bils and Klenow (2004).[19] This implies that $\phi = 97.42$. We assume that the government's inflation target $\overline{\pi} = 1$ so that it 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 that determine the persistence and volatility of the job separation rate and of the share of high search efficiency unemployed workers from time-series data for the employment-to-unemployment flow rate and the share of workers who have been unemployed for 6 months or more, both from the period 1980-2006.[20] For the autocorrelation coefficients, we find estimates of $\lambda_x = 0.991$ and $\lambda_s = 0.881$. This implies a half-life of job separation shocks of 77 months while shocks to the share of short term unemployed die out much faster. For the volatility parameters, we find $\nu_x = 4.7 \cdot 10^{-4}$ and $\nu_s = 0.0513$.

4.2 Results

The Impact of Labor Market Shocks. We first examine the impact of job separation and mismatch shocks. We compare the benchmark economy with two alternative economies. In the first we assume that prices are flexible ($\phi = 0$) but retain the incomplete markets assumption. Comparing this economy with the benchmark model gives insights into whether the transmission of 'demand side' shocks to the 'supply side' due to nominal rigidities matters for our results. In the second alternative economy, we retain nominal rigidities in price setting but assume that households belong to large diversified families and that families share the idiosyncratic employment risk. In the cooperative (risk sharing) outcome, consumption is equalized across household members independently of their labor market status and the family maximizes utility subject to the single

a similar average consumption loss due to unemployment shocks in Canadian household data.

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

[20] We use monthly data from the BLS, detrended using the HP filter with smoothing coefficient 10^9.

budget constraint:

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

where $\mathbf{n}_t$ is the fraction of the household members that is employed in period t. In this economy, insurance neutralizes the precautionary savings motive deriving from idiosyncratic employment risk. Comparing this economy with the benchmark mode therefore allows us to see how labor market risks impacts on the equilibrium outcome.

Figure 5 illustrates the impact of a one standard deviation increase in job terminations. This shock sets off a persistent rise in unemployment which peaks 10-12 months after the initial increase in job separations. It is noticeable that the peak increase in unemployment is much larger than the initial impact of the shock because of an amplification mechanism that we discuss below. We also find that the fraction of longer term unemployed workers and the average duration of unemployment both increase significantly.[21] Importantly, vacancy postings drop persistently and therefore, in combination with the higher level of unemployment, implies a long-lived decrease in the job finding rate. This finding is interesting since, as we discussed in Section 2, the Great Recession involved an initial spur of job separations that was followed by a prolonged period of low job finding prospects. From a more general perspective, the results are also important because much of the macro-labor literature has concluded that variations in job separations are of little consequence for understanding fluctuations in unemployment since there is a strong incentive for firms to post more vacancies in periods of high unemployment when hiring is relatively cheap. In our economy, there are other forces which lead firms to cut back on hiring as we discuss below.

Figure 6 repeats the analysis for an increase in the share of job losers that flow into the unemployment state with low search efficiency (keeping the overall job termination rate constant). We find that unemployment increases stubbornly in response to this shock and so does the average duration of unemployment. Again, the persistence of the increases in the level and duration of unemployment derives from a stubborn drop in vacancy postings that produces a large decline in the job finding rate.

It is instructive to consider the following two key relationships in order to comprehend the

[21] Initially the increase in job separations produces a drop in average unemployment duration and in the fraction of long-term unemployed workers because of the inflow of newly unemployed workers. This is, however, quickly reversed.

results:

$$\partial \mathbf{u}\left(c^{n}\right)/\partial c^{n} = \boldsymbol{\beta}\mathbb{E}\frac{\mathbf{R}}{1+\boldsymbol{\pi}'}\{\left(1-\sum_{r=s,l}\boldsymbol{\rho}_{x}\boldsymbol{\rho}_{r}\left(1-\boldsymbol{\eta}_{r}'\right)\right)\partial \mathbf{u}\left(c^{n\prime}\right)/\partial c^{n\prime}$$
$$+\boldsymbol{\rho}_{x}\boldsymbol{\rho}_{s}\left(1-\boldsymbol{\eta}_{s}'\right)\partial \mathbf{u}\left(c^{u,s\prime}\right)/\partial c^{u,s\prime}+\boldsymbol{\rho}_{x}\boldsymbol{\rho}_{l}\left(1-\boldsymbol{\eta}_{l}'\right)\partial \mathbf{u}\left(c^{u,l\prime}\right)/\partial c^{u,l\prime}\} \quad (31)$$

$$(1-\gamma)+\gamma\left(\mathbf{w}+\frac{\boldsymbol{\mu}}{\boldsymbol{\rho}_{f}}-\boldsymbol{\beta}\mathbb{E}\left(1-\boldsymbol{\rho}_{x}\right)\frac{\boldsymbol{\mu}}{\boldsymbol{\rho}_{f}'}\right)=\phi\left(1+\boldsymbol{\pi}\right)\boldsymbol{\pi}+\boldsymbol{\beta}\phi\mathbb{E}\left(1+\boldsymbol{\pi}'\right)\boldsymbol{\pi}' \quad (32)$$

Equations (31) is the Euler equation for employed households and (32) is the first order condition for price setting. From the Euler equation it follows that higher job terminations produces an increase in expected future marginal utility of consumption for employed workers because of the drop in expected future income which implies a precautionary savings motive. An increase in the share of job losers that become mismatched implies longer expected unemployment duration which also triggers a precautionary savings motive. In equilibrium, asset market clearing requires that the real interest rate must fall which, in turn, produces a drop in inflation due to the monetary policy rule. Lower inflation has to be accompanied by a decrease in marginal costs of production, see (32), which in equilibrium means lower vacancy postings. It is this transmission of demand to the supply side that produces the amplification mechanism occurs because lower vacancy postings implies even worse job finding prospects therefore introducing an even stronger precautionary savings motive which in turn lowers aggregate demand.

The results can be further understood by considering the two alternative economies described above. When prices are flexible (but agents are exposed to idiosyncratic risk), job separations shocks impact much less on unemployment and lead to a much smaller increase in the mean duration of unemployment than in the benchmark economy. In this economy, the increase in job separations have little impact on vacancy postings beyond the first period because firms take advantage of low hiring costs in response to the initial increase in unemployment. The lack of amplification in the flexible price economy is even starker when considering the mismatch shock which is largely neutralized when prices are flexible. In the flexible price economy is that there is very little transmission from the demand side to equilibrium quantities in this economy because firm cut prices in response to declining demand. Thus, while households still increase precautionary savings in response to either of the labor market shocks, there is little need to cut back on vacancy postings in equilibrium.

In the economy with insurance within the family, the main impact of increases in either job separations or in the incidence of mismatch is to decrease expected future family income which

spurns an intertemporal savings motive while the uncertainty effect no longer is relevant. The intertemporal savings motive is very small in the case of mismatch shocks which accordingly have very minor effects in this alternative economy. Job separations have a large effect in the short run but thereafter leads to a muted response of the economy that is very similar to what we found for the flexible price economy.

We conclude from this analysis that the combination of idiosyncratic employment risk, incomplete asset markets and nominal rigidities provide a powerful mechanism through which labor market shocks are amplified.

A Great Recession Experiment. We now consider the extent to which the mechanisms of the model may be useful for thinking about the features of the Great Recession discussed in Section 2. We derive estimates of the sequences of innovations to job termination and to the fraction of workers that flow into mismatch unemployment, $(\varepsilon_{x,t}, \varepsilon_{s,t})_{t=2007:1}^{2012:1}$ by matching the observed US time-series on employment-to-unemployment transition rate and the number of unemployed workers who have been out of work for 6 months or more relative to the labor force. In order to avoid having too erratic shocks, we smooth both data series with a 6 months moving average filter. We then feed the resulting shock processes into the model economy and simulate the economy in response to this particular sequence of shocks.

Figure 7a illustrates the shocks that we estimate for the Great Recession and their impact on the level and average duration unemployment, the number unemployed worker out of work for 6 months or more (relative to the labor force), and on vacancies. As discussed in Section 2, the Great Recession witnessed a spur of job separations which peaked in early 2009. Conditional upon this shock, our estimates imply that the fraction of mismatched workers remained flat until 2009 and then increased 25 percentage points from 65 percent in the steady-state to 90 percent in mid-2010. Thus, according to our estimates, the mismatch shock reinforced the negative labor market conditions as the job separation shock starts leveling out.

In response to the labor market shocks, the benchmark model implies a large and persistent rise in unemployment that is very similar to what was observed in the US economy in the aftermath of the financial crisis. By comparing with the effects that we obtain when assuming no mismatch shocks, we see that the initial increase in unemployment derives from the increase in job separations in the early part of the crisis but the mismatch shock is responsible for both the high level of unemployment and its persistence from mid-2009 onwards. We also find that the model can account

for a large fraction of the fall in vacancies that occurred during the Great Recession even if it misses the full extent of the vacancy decline in mid-2009. The mismatch shock is even more important for accounting for the drop in vacancies. Eliminating this shock, we find only a modest initial decline in vacancies.

The uncertainty channel is key for understanding why the depressed labor market conditions triggered the large increase in unemployment and the decline in vacancies. When we eliminate the idiosyncratic risk mechanism, we find a very muted increase in unemployment because firms respond to higher unemployment levels by increasing vacancy postings. As a result, this economy also predicts a very modest increase in the share of long term unemployed. Nominal rigidities also have an important role to play. Assuming perfectly flexible prices, the model predicts that vacancies remain approximately constant over the duration of the Great Recession and therefore a much smaller increase in unemployment than what was observed in the US.

Figure 7b illustrates the Beveridge curve observed in the US data and the counterfactual combinations of unemployment and vacancies implied by the model. One might suspect that the mismatch shock introduces a too large outward shift of the Beveridge curve relative to what is observed in US data but we find that the benchmark model provides a surprisingly good fit to actual data. Similarly to what can be observed in the US data, the model economy experiences a large slide down the Beveridge curve during the early part of the recession and an outward shift of this curve in the latter part of the recession. Interestingly, when we eliminate the mismatch shock, the model implies a very modest slide down the Beveridge curve but a sizeable outward shift of this relationship. Thus, the decline in search efficiency that we estimate is mainly responsible for generating the large increase in unemployment and a decline in vacancies that can be observed in the US during the Great Recession.[22] When we assume flexible prices or insurance within the family, the model fails to generate a Beveridge curve and implies either a flat relationship between unemployment (when prices are flexible) and vacancies or a positive sloped Beveridge curve (when households can insure).

The Role of Monetary Policy: It is standard intuition in the monetary economics literature that sufficiently aggressive monetary policy responses to inflation may neutralize much of the inefficiencies that derive from nominal rigidities while too weak responses to inflation produce locally

[22] This may be surprising since a standard approach to estimating mismatch is to base this on the shifts in the Beveridge curve (see e.g. Barlevy, 2011).

indeterminate equilibria. In our setting, these issues are more complicated because of the combination of incomplete markets and nominal rigidities, but the policy relevance is obviously just as pertinent. To examine this, we now investigate how the specification of the interest rate rule impacts on the allocation in the benchmark model.

Figure 8 reports how mismatch shocks (panel a) and job separation rate shocks (panel b) impact on unemployment in the benchmark economy 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 while σ determines the extent to which households 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 following one of the two shocks 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.

We find that sufficiently aggressive monetary policy rule succeeds in neutralizing the amplification mechanism in the benchmark model while interest rate rules similar to those typically assumed in the New Keynesian literature instead produce a large amount of amplification. In our calibration ($\delta = \sigma = 1.5$), both shocks are significantly amplified but increasing δ to around 3 would succeed in neutralizing much of the amplification relative to the flexible price allocation. 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.

It is interesting to notice that higher degrees of risk aversion demand more aggressive policy rules because more risk averse households react more strongly to labor market uncertainty so that the policy maker needs to be even more inflation averse in order to stabilize expectations. The dependence of the strength of the amplification mechanism on the degree of risk aversion also means the amount of idiosyncratic risk and household responses to risk is key for determining whether the equilibrium is locally determinate.[23] Furthermore, the higher is the degree of risk aversion, the more aggressive an interest rate rule is required to rule out local indeterminacy of the intended equilibrium. This feature derives from the interaction between incomplete markets and nominal

[23] σ also impacts on the determinacy region in standard New Keynesian models, see e.g. Gali (2008), but only because it impacts on the response of consumption to real interest rates. In our model, a more important source of impact is through precautionary savings.

rigidities. A too weak monetary policy response to inflation fails to rule out indeterminacy when households are very risk averse because concerns about job uncertainty can lead to a self-fulfilling equilibrium in which household expectations about low vacancy postings and firm expectations about weak goods demand can generate expectations driven equilibria.

5 Extensions and Robustness Analysis

In this section we will extend our analysis to investigate three further issues. First we examine the importance of the monetary policy in the benchmark model. We then consider the impact of imposing the ZLB on nominal interest rates. Third, we explore the performance of our model in accounting for the early 1990's recession. Finally, we examine the importance of the assumption regarding a fixed real wage.

The Zero Lower Bound: At the early stages of the Great Recession the Federal Reserve cut nominal interest rates aggressively and the ZLB on nominal interest rates has been binding since late 2008. This aspect of the recession has been widely discussed in the monetary and fiscal policy literatures as a distinguishing feature of the recession and may also be interesting for our analysis. As discussed above, job uncertainty shocks provide a precautionary savings motive which puts downward pressure on nominal interest rates in an interest rate rule environment. Moreover, the ZLB may have interacted with the mechanisms that we have stressed to further amplify the impact of labor market uncertainties.

We modify the monetary policy rule by imposing the ZLB:

$$\mathbf{R}_t = \max\left[\overline{\mathbf{R}}\left(\frac{1+\boldsymbol{\pi}_t}{1+\overline{\boldsymbol{\pi}}}\right)^{\delta}, \mathbf{1}\right] \tag{33}$$

We make two further modifications to the model in order to accommodate dynamics at the ZLB. At the ZLB, the nominal interest rate can no longer fall and an equilibrium with positive vacancy posting may then fail to exist. In this case, the real wage no longer belongs to the bargaining set.[24]

[24] To appreciate this point, recall that the equilibrium must satisfy the subsystem comprised by Equations (29) and (30). No endogenous state variable enters this system, so its solution is a function of the exogenous state only. When $\mathbf{R} = 1$ and real wages are fixed, there is no current-period variable that can adjust to ensure that Equation (29) holds in any state of the world. It is straightforward to show that in a perfect-foresight version of the model without persistence in the exogenous variables, the Euler equation generally has no solution at the ZLB if real wages are fixed. Expectedly, we were also unable to find a numerical solution more general versions of the model with the ZLB and a fixed real wage.

For that reason we allow the real wage to fall temporarily as long as the ZLB binds.[25] We assume the following wage rule:

$$\mathbf{w} = \min\left(\overline{\mathbf{w}}, \overline{\mathbf{w}} + \xi\left(\boldsymbol{\eta}_{s,t} - \widetilde{\boldsymbol{\eta}}\right)\right) \tag{34}$$

where $\xi,\ \widetilde{\boldsymbol{\eta}} \geq 0$ are constant parameters. This specification implies that wages drop once the job finding rate amongst searchers falls below a certain threshold, $\widetilde{\boldsymbol{\eta}}$.

Second, we assume that a certain fraction of the active job searchers can find employment through informal channels even in the absence of any vacancy postings. We make this assumption in order to avoid having too drastic implications arising from the matching framework since a total freeze in vacancy postings (which would occur in the absence of this extension of the model) would lead to extreme levels of unemployment.

We solve the nonlinear model using a time iteration projection method, approximating the equilibrium laws of motion for inflation and the job finding rate among active searchers using third-order polynomials of the exogenous state variables on a grid with 225 nodes (15 in each of the two dimensions). To approximate conditional expectations, we use the Gauss-Hermite method with 25 nodes (five in each dimension). We follow the same steady-state calibration strategy as for our benchmark model and choose the same values for the same persistence parameters of the shock processes. Given the larger degree of amplification in the model with ZLB, we reduce the volatility parameters by fifty percent relative to the benchmark.[26]

The results are reported in Figure 9 where we show the joint impact of the job separation shock and the mismatch shock. We illustrate the paths of nominal interest rates, the unemployment rate, the job finding rate and the real wage.[27] The precautionary savings effects generated in response to the labor market shocks are sufficiently important that the economy the ZLB becomes binding and remains so for 18 months. The extended duration of the liquidity trap is interesting since we only feed in unanticipated shocks at the start of the recession. Typically, to generate lasting liquidity traps, it is necessary to allow for sequences of surprise shocks, see e.g. Gust, Lopez-Salido and Smith (2012).

[25] At the ZLB, we find the equilibrium wage from the employed households' Euler equation.

[26] The solution to the benchmark model does not depend on the volatility of the shock parameters, due to the certainty equivalence property implied by the first-order perturbation technique. The non-linear solution to the model with zero lower bound does depend on shock volatilities.

[27] We report the real wage because we found that it needs to adjust slightly downwards in response to the shocks that we simulate in order for the job match surplus to be positive.

We find that the introduction of the ZLB produces a severe recession in which the economy experiences a very large increase in unemployment. Once the economy exits the ZLB, it makes a relative swift recovery. The further amplification of the labor market shocks produced by the ZLB derive from two mechanisms. First, real wages have to fall to ensure that the solution is consistent with the real wage belonging to the bargaining set. This in itself implies a drop in demand. Moreover, at the ZLB, equilibrium output has to fall even further in order to clear the asset market[28] and this produces even more job uncertainty – and therefore precautionary savings – as firms cut back on hiring until only the frictionless jobs are filled.

Given these results, Figure 10 repeats the Great Recession exercise that we discussed in the previous exercise. As above, we feed in the observed job termination process and we calibrate the mismatch shock so that we reproduce the observed US time-series for long-term unemployment as a fraction of unemployment. The resulting process for the mismatch shock which is very similar to what we showed in figure 7. With these shocks, the model reproduced to a surprisingly good extent the observed path of the nominal interest rate and we find that the ZLB binds from late 2008 until the end of the sample. Given these shocks, we find that the real wage must fall but only very marginally(the largest decline in the real wage is less than 1 percent in our simulation). In response to the labor market shocks, we find a large increase in unemployment which in our simulation peaks at 12 percent in early 2010. Clearly, the implied increase in unemployment is larger than what has been observed in the US economy during the Great Recession. One interpretation of this result that there were other shocks affecting the economy or that other policy interventions such as unconventional monetary policies or fiscal policies may have had a stabilizing effect.

Flexible wages: Our analysis in Section 4 assumes that the real wage is fixed. Much of the macro literature instead assumes that wages are flexible and determined by Nash bargaining. In incomplete markets settings this typically leads to very complicated outcomes because wages become wealth dependent as more wealthy unemployed workers have a better outside option. In our setting, the borrowing constraint implies that there is no wealth inequality in equilibrium and this makes it attractive to analyze the outcome under Nash bargaining.

We assume that workers and firms have equal bargaining power. We also assume that once workers and firms have been matched, a worker flows to the two unemployment pools with the same probability as newly unemployed workers so that the past unemployment state is irrelevant

[28] See also Christiano, Eichenbaum and Rebelo (2011).

for the outside option. Figure 10 reports the impact of job separation shock (top panel) and of the mismatch shock (bottom panel) comparing the benchmark model with Nash bargaining model assuming that prices are either flexible or sticky. We find that the real wage falls only moderately in response to the increase in job separations but this fall in the real wage is nonetheless sufficient to moderate the impact on the level of unemployment very significantly. Similarly, real wages fall only marginally in response to the mismatch shock but much of the impact of the shock on unemployment is neutralized. Interestingly, when real wages are flexible, we find that nominal rigidities in prices setting appear immaterial for the unemployment response to labor market shocks.

Thus, it follows that our assumption regarding real wage inflexibility is important quantitatively. Nonetheless, as we have shown above, much of this sensitivity to the determination of the real wage appear less important when allowing also for the ZLB indicating that this assumption matters less in more general settings.

The Early 1990's Recession: An important check on our analysis is its applicability to other recessions. We now study the early 1990's recession which was much milder than the Great Recession. As above we feed in the observed US time-series for job separations and estimate the mismatch shock to match the US time-series for the fraction of workers who have been out of work for 6 months more. The resulting series for the job separation rate and the mismatch shock are shown in the top part of Figure 11a. We note that a main difference between the early 1990's recession and the Great Recession is that the shocks that hit the economy were much smaller in the former of these recessions. On the other hand, similarly to the Great Recession, we find that the mismatch shock sets in late after the trough of the contraction thus providing an important source of persistence of the labor market impact of the downturn.

The model can account for much of the rise in unemployment during the early 1990's recession as well and for the decline in vacancies in the last part of the recession, see Figure 11b. As in the Great Recession considered earlier we find that the benchmark model generates a much better account of the dynamics of unemployment and vacancies that the flexible price model and the model with insurance against idiosyncratic shocks. Moreover, we also find that the mismatch shock has important quantitative implications. Hence, the mechanisms we have stressed above appear to be relevant also in the early 1990's recession.

This insight is reinforced when inspecting the Beveridge curve. Similarly to the Great Recession, the early 1990's recession witnessed a slide down and an outward shift of the Beveridge curve which

the benchmark model can account for although it implies a somewhat erratic relationship between unemployment and vacancies. In contrast, in the absence of job uncertainty or nominal rigidities in price setting, we once again find a positively sloped Beveridge curve. Thus, the central mechanisms of the model appear important also for other recessions even if the uncertainty effect appears much more prominent in the Great Recession due to the scale of the shocks that affected the US economy.

6 Conclusions and Summary

We have developed a model that combines multiple sources of frictions in asset, labor and goods market and applied it to tell a story of the Great Recession. At the heart of our theory is the idea that job uncertainty can trigger households to engage in precautionary savings which we have shown can have large effects when firms are subject to nominal rigidities. The precautionary motive derives from the assumption that consumers cannot perfectly insure against unemployment so that they are exposed to idiosyncratic unemployment risk. We combined these aspects with a model in which households face the risk of becoming long-term unemployed due to mismatch. We showed how this model can account not only for the increase in unemployment observed in the US during Great Recession but also for much of the movements along the Beveridge curve and for the large increase in the share of longer term unemployed that occurred during this recession. It is the transmission of job uncertainty which impacts on aggregate demand to aggregate supply that produces these results because firms are reluctant to post vacancies due to the combination of weak demand and nominal rigidities.

Our emphasis on job uncertainty that derive from idiosyncratic employment risk is different from much of the recent literature which has examined uncertainty shocks modelled as changes in volatility of aggregate variables such as TFP or policy related variables. We believe that it would be interesting to provide further empirical analysis contrasting these two views as they have potentially conflicting implications for optimal policy responses. We also showed that the job uncertainty that forms the basis of the precautionary savings motive in our story may be a candidate for the shock that took the US economy into a liquidity trap from which it is yet to escape.

We argued that the shocks that impacted on job separations and on mismatch during the Great Recession were unusually large. This triggers two important questions. First, how come job separations increased by an unusual large amount during this episode? We have provided no theory of the underlying determinants of this shock but we hypothesize that the financial market crisis

may have be one plausible source as it tightened credit access for firms. Secondly, is it possible to provide some foundation for the mismatch shock that we argued was an important element of the shocks impacting on the US labor market? One plausible hypothesis is that the drop in housing prices prevented unemployed households to engage in other than local labor market search, see e.g. Sterk (2011). Another hypothesis is that unemployed workers searched less hard for jobs because of the gloomy outlook for a quick recovery. A third possibility, is that the mismatch shock is related to the traditional notion of imbalances across local labor markets defined by skill, occupation or industry (see e.g. Şahin et al, 2012). We leave it to future research to examine these issues in further details.

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7.1 Appendix 1: Solving the model

Given the borrowing constraint that we impose, it follows that in equilibrium, the individual workers' consumption levels are given as:

$$\begin{aligned} \mathbf{c}^{u_l} &= \mathbf{c}^{u_s} = \boldsymbol{\xi} \\ \mathbf{c}^{n} &= \mathbf{w} \end{aligned}$$

Given the equilibrium definition, we can reduce the model down to the following two equations:

$$\begin{aligned} \partial \mathbf{u}\left(c^{n}\right)/\partial c^{n} &= \boldsymbol{\beta}\mathbb{E}\frac{\mathbf{R}}{1+\boldsymbol{\pi}'}\{\left(1-\sum_{r=s,l}\boldsymbol{\rho}_x\boldsymbol{\rho}_r\left(1-\boldsymbol{\eta}_r'\right)\right)\partial \mathbf{u}\left(c^{n\prime}\right)/\partial c^{n\prime} \\ &\quad +\boldsymbol{\rho}_x\boldsymbol{\rho}_s\left(1-\boldsymbol{\eta}_r'\right)\partial \mathbf{u}\left(c^{u,s\prime}\right)/\partial c^{u,s\prime}+\boldsymbol{\rho}_x\boldsymbol{\rho}_l\left(1-\boldsymbol{\eta}_l'\right)\partial \mathbf{u}\left(c^{u,l\prime}\right)/\partial c^{u,l\prime}\} \end{aligned} \tag{35}$$

$$(1-\gamma)+\gamma\left(\mathbf{w}+\frac{\boldsymbol{\mu}}{\boldsymbol{\rho}_f}-\boldsymbol{\beta}\mathbb{E}\left(1-\boldsymbol{\rho}_x\right)\frac{\boldsymbol{\mu}}{\boldsymbol{\rho}_f'}\right)=\phi\left(1+\boldsymbol{\pi}\right)\boldsymbol{\pi}+\boldsymbol{\beta}\phi\mathbb{E}\left(1+\boldsymbol{\pi}'\right)\boldsymbol{\pi}' \tag{36}$$

plus the laws of motion for the stocks of unemployment and the monetary policy rule. This system can be further simplified using the expression for consumption above and realizing that $\boldsymbol{\eta}_s=\mathbf{q}\boldsymbol{\eta}_l=\psi^{1/\alpha}\boldsymbol{\rho}_f^{(\alpha-1)/\alpha}$. We solve this system of equations using a standard pertubation approach. All other endogenous variables can be derived from the remaining equilibrium conditions of the model.

7.2 Tables and Figures

Table 1: Targets and Parameter Values

Targets	
0.05	unemployment rate
0.4	average job finding rate among newly unemployed
0.3	average job finding rate among unemployed > 6m
0.045	hiring cost as a fraction of the quarterly wage
0.15	fraction of long-term unemployed
0.11	consumption loss upon unemployment $(\frac{\boldsymbol{\xi}_s}{\overline{\mathbf{w}}}, \frac{\boldsymbol{\xi}_l}{\overline{\mathbf{w}}})$
0	net inflation rate
Parameters	
0.035	s.s. job termination rate $(\overline{\boldsymbol{\rho}}_x)$
0.65	s.s. fraction into mismatch $(\overline{\boldsymbol{\rho}}_l)$
0.13	$\frac{\boldsymbol{\mu}}{\psi}$ ratio of vacancy cost over matching efficiency parameter
0.37	prob. of search mismatched $(\mathbf{q})$
0.83	real wage $(\overline{\mathbf{w}})$
0.74	unemployment benefit $(\boldsymbol{\xi}_s, \boldsymbol{\xi}_l)$
0.0033	s.s. nominal interest rate$(\overline{\mathbf{r}})$

Table 2: Stationary State Values

Parameter	Value	Meaning
$\mathbf{c}_e$	0.829	consumption employed
$\mathbf{c}_{u,s}$	0.737	consumption regular unemployed
$\mathbf{c}_{u,l}$	0.737	consumption mismatch unemployed
$\boldsymbol{\eta}_s$	0.848	job finding rate searchers
$\boldsymbol{\eta}_l$	0.310	job finding rate mismatched
$\mathbf{u}_s$	0.0020523	mass of regular unemployed
$\mathbf{u}_l$	0.0226742	mass of mismatch unemployed

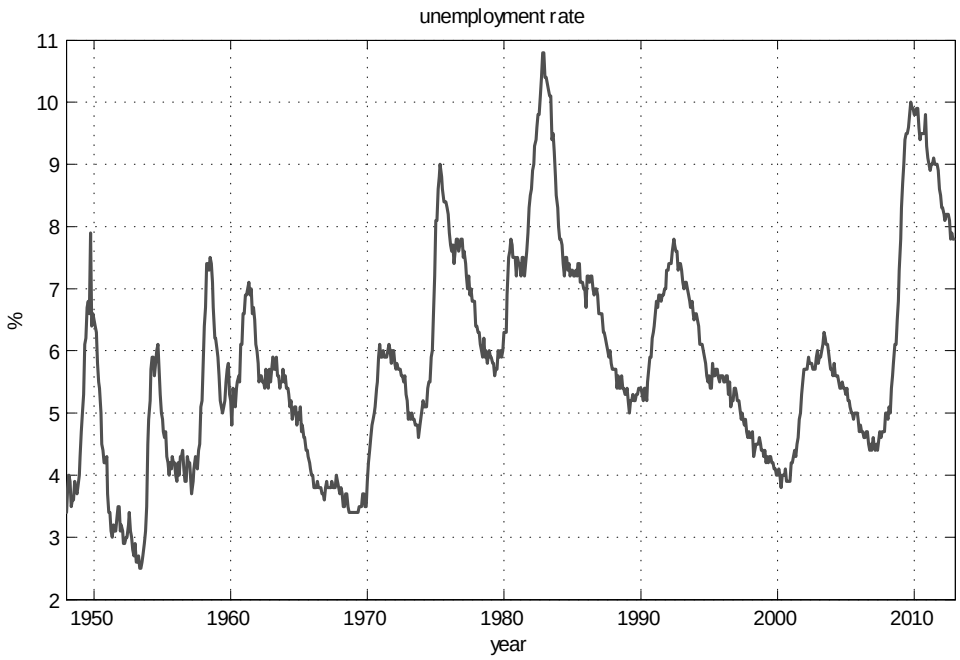

Figure 1: The US Civilian Unemployment Rate

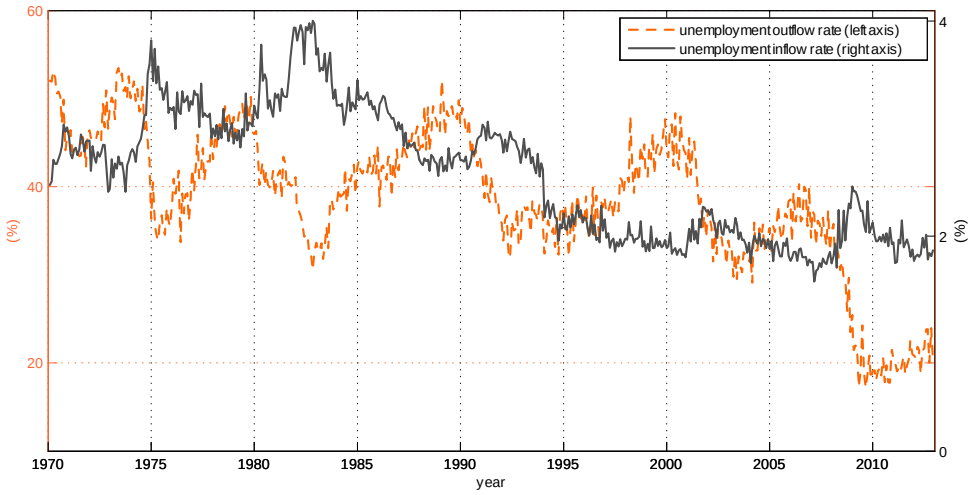

Figure 2: Estimates of Job Separation and Job Finding Rates

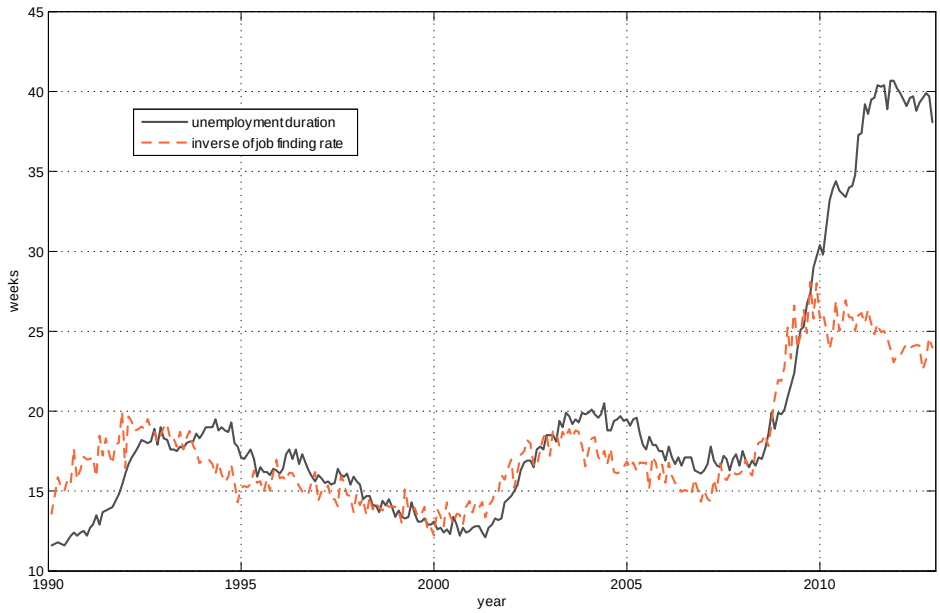

Figure 3: The Inverse Instantaneous Job Finding Rate and Mean Unemployment Duration

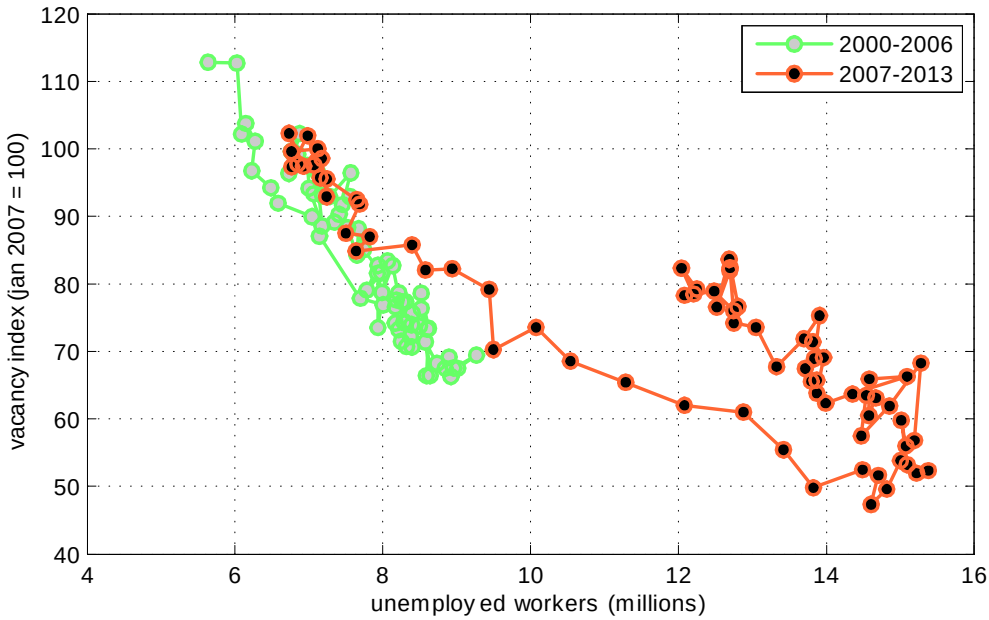

Figure 4: The Beveridge Cruve

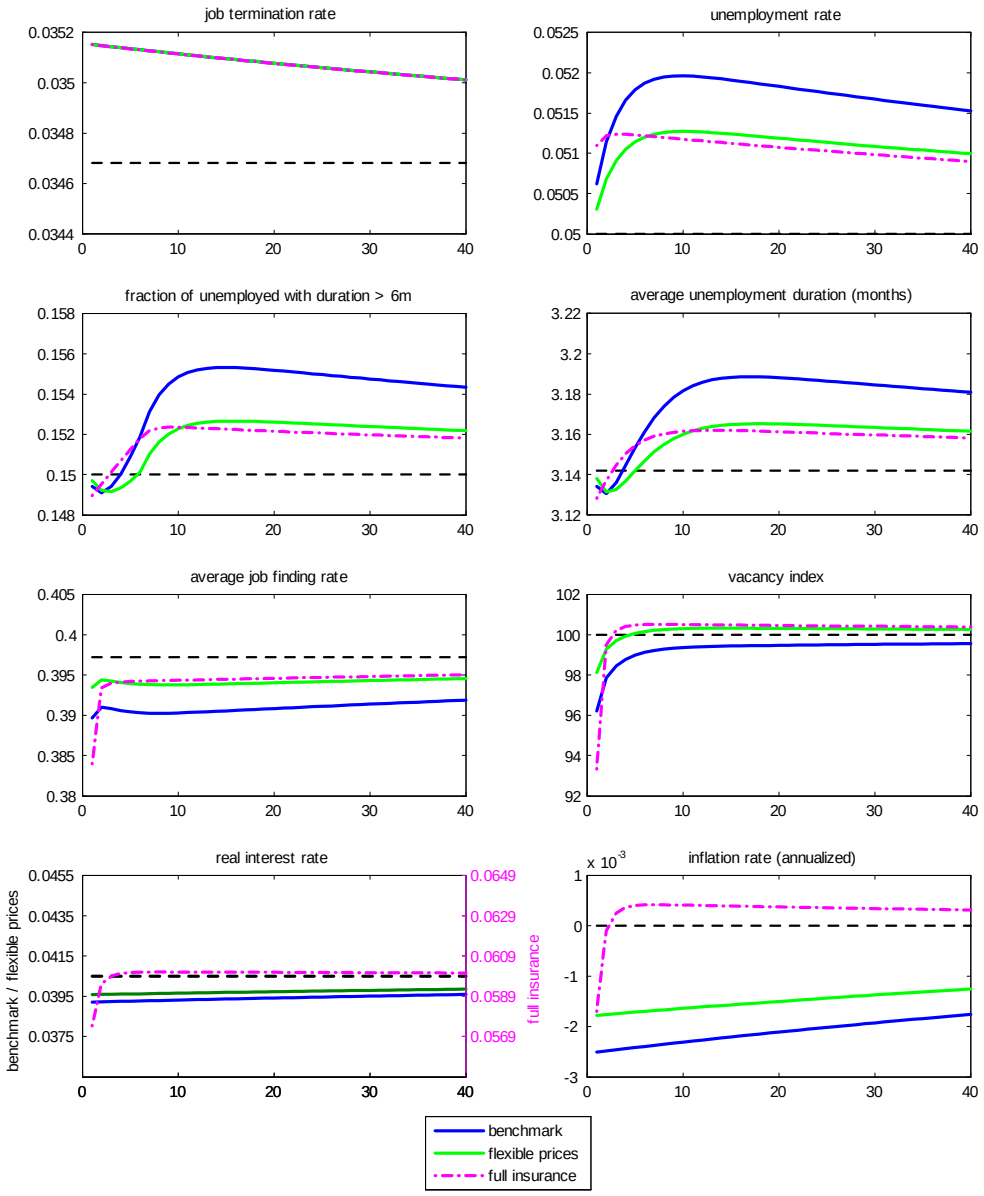

Figure 5: The Impact of Job Separation Shocks

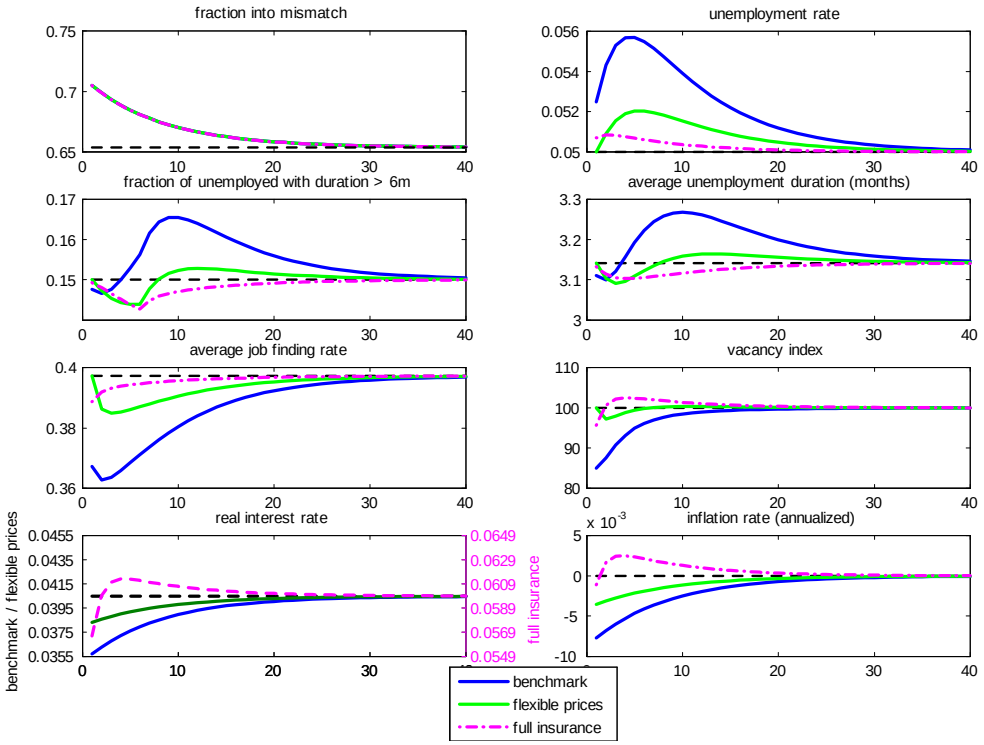

Figure 6: The Impact of Mismatch Shocks

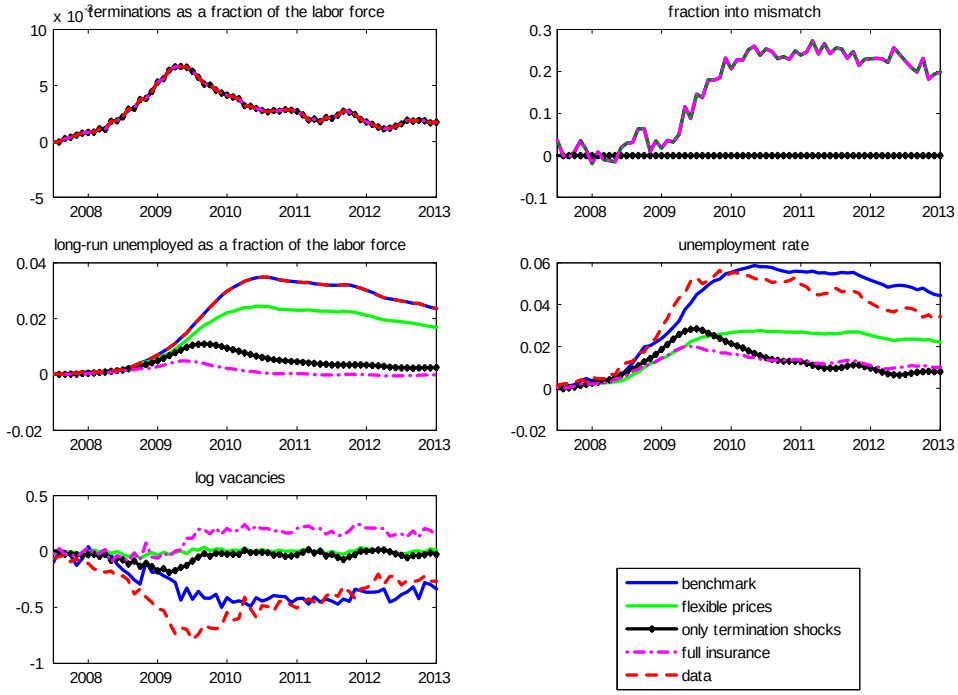

Figure 7A: The Great Recession

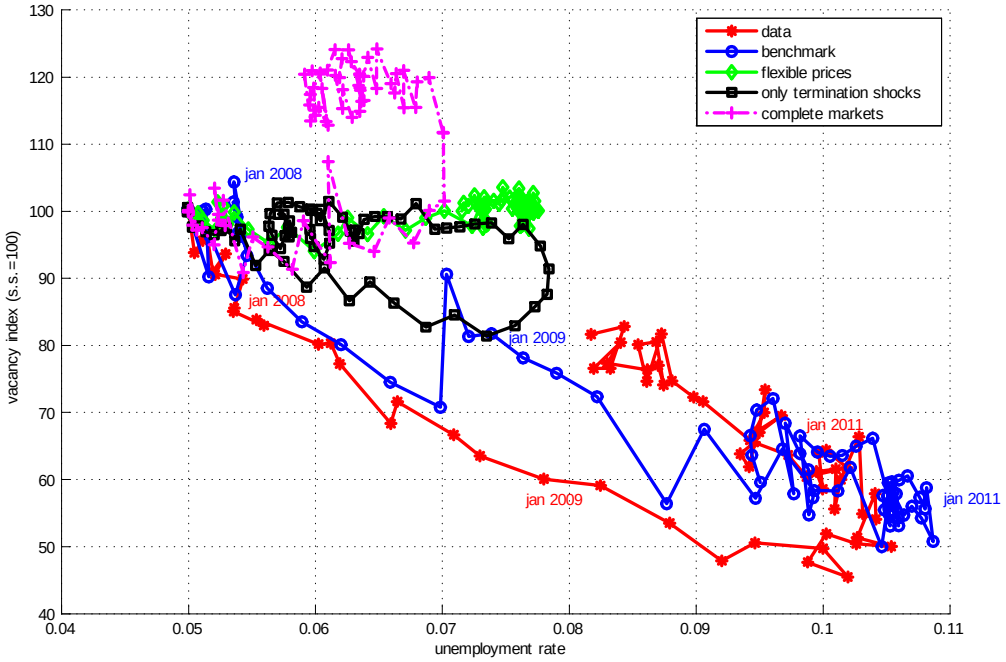

Figure 7b: Actual and Counterfactual Beveridge Curves

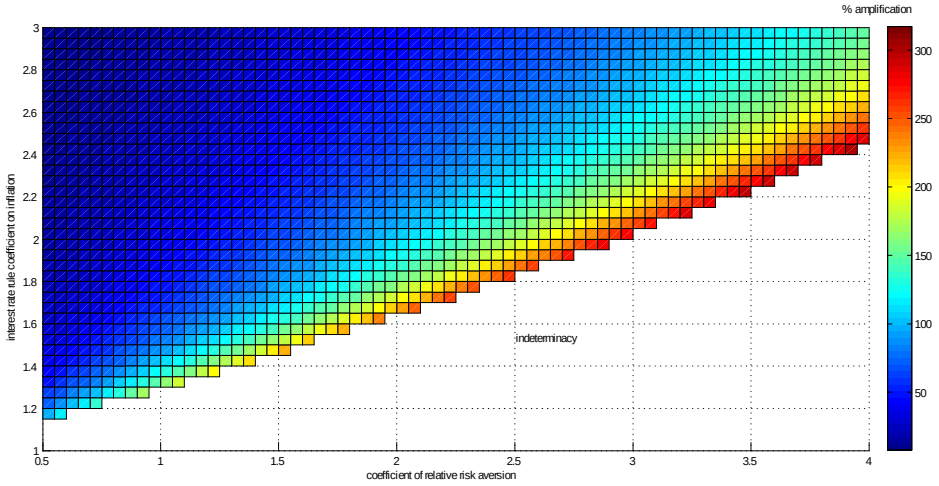

Figure 8: Amplification and the Monetary Policy Rule

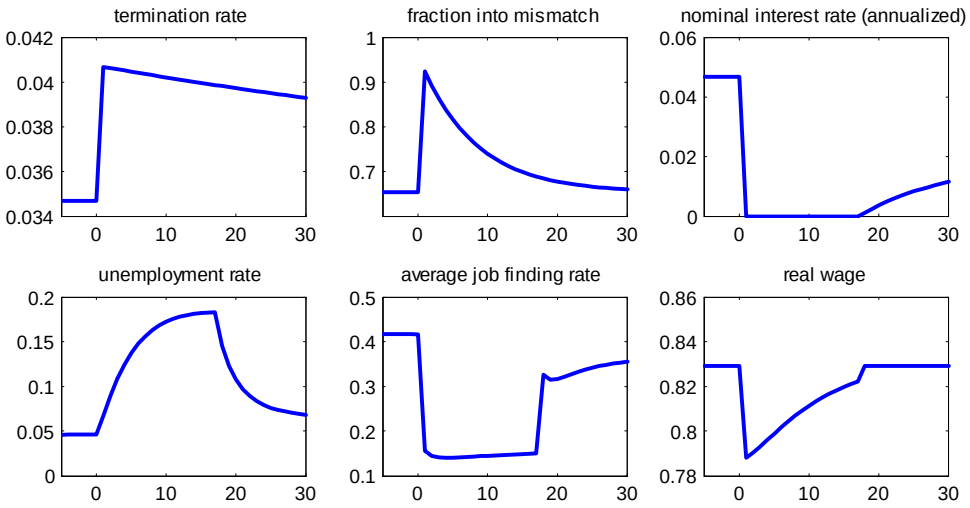

Figure 9: The Impact of Labor Market Shocks when Imposing the ZLB

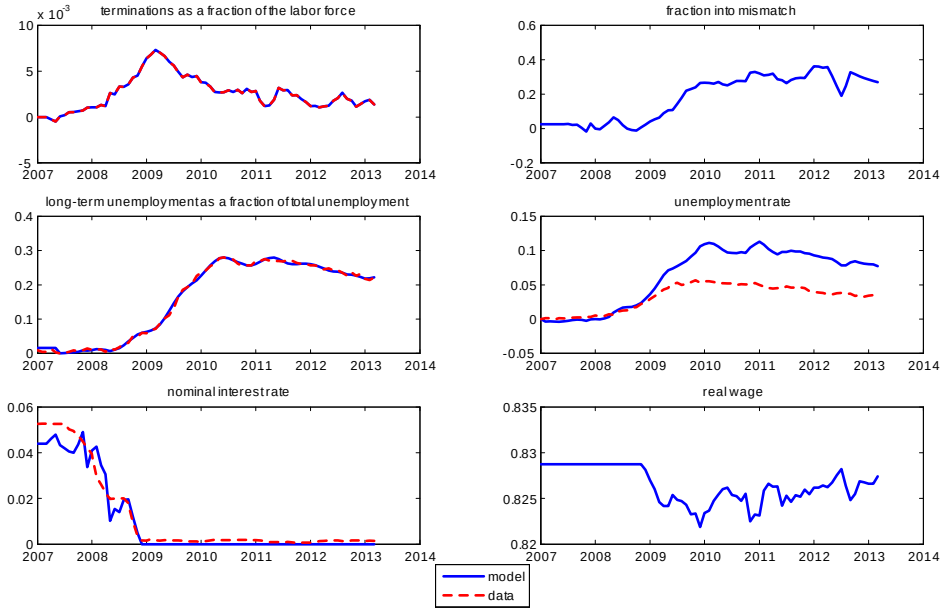

Figure 10: The Great Recession Imposing the ZLB

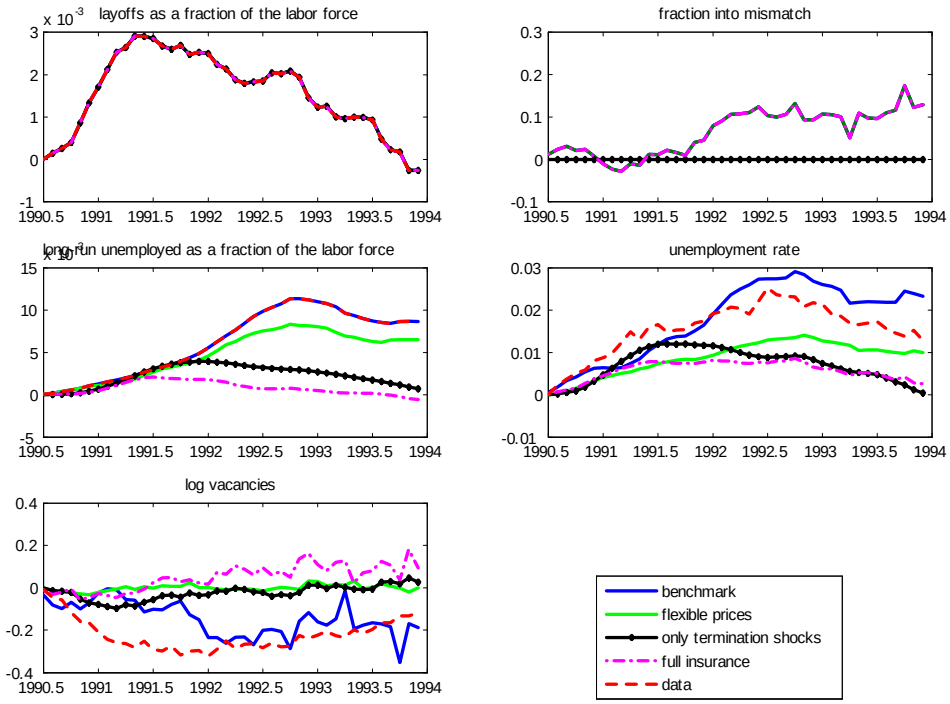

Figure 11a: The Early 1990's Recession

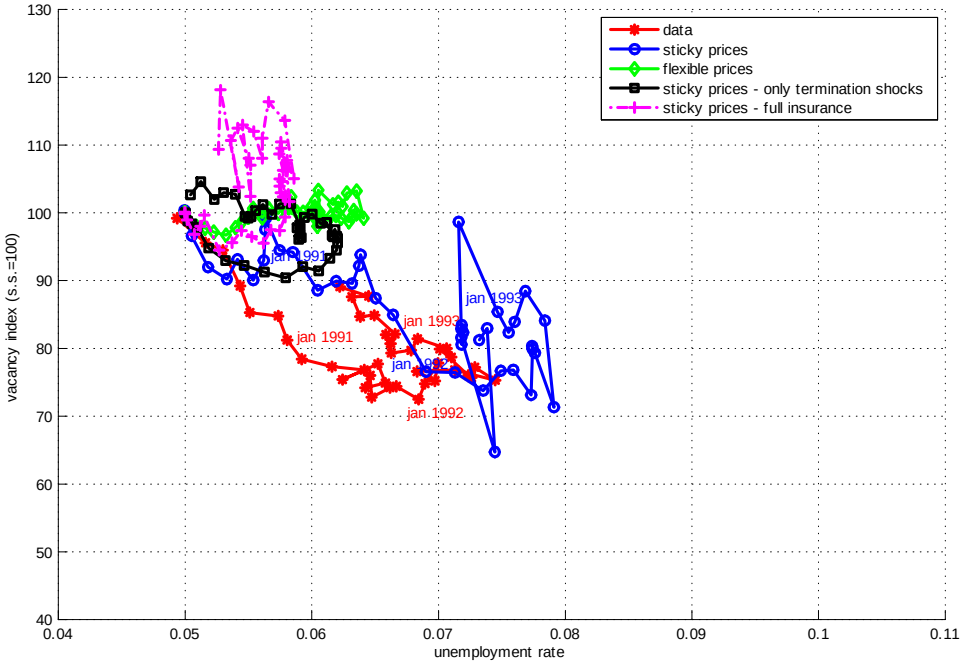

Figure 11b: The Beveridge Curve in the Early 1990's Recession