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The labor market channel of macroeconomic uncertainty

by Elisa Guglielminetti

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THE LABOR MARKET CHANNEL OF MACROECONOMIC UNCERTAINTY

by Elisa Guglielminetti*

Abstract

Uncertainty has recently become a major concern for policymakers and academics. Spikes in uncertainty are often associated with recessions and have detrimental effects on the aggregate economy. This paper analyzes the effects of uncertainty on firms' hiring and investment decisions, both empirically and theoretically. Empirically, VAR estimates show the negative effects of uncertainty on economic performance and in particular on the labor market. Counterfactual experiments highlight the significant role of hiring decisions as a transmission channel for uncertainty. The empirical findings are rationalized through a DSGE model with search and matching frictions in the labor market and stochastic volatility. The model is able to replicate the observed co-movement among consumption, investment, output and labor market outcomes generated by an uncertainty shock. Price stickiness greatly amplifies the reaction of the economy. Simulations show that monetary policy can mitigate the adverse effects of uncertainty by adopting a strong anti-inflationary policy.

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* Bank of Italy, Economic Outlook and Monetary Policy Directorate.

1 Introduction

After the 2008 Great Recession, economic agents, policymakers and academics are increasingly concerned about uncertainty and its potentially detrimental effects on the aggregate economy.

The October 2012 IMF World Economic Outlook documents that uncertainty surged at the onset of the Great Recession and remained high ever since. At the same time, small businesses in the US ranked uncertain economic conditions as the second most severe problem¹ and the vast majority of the respondents to a survey administered by the National Association for Business Economics agreed that uncertainty about fiscal policy was holding back economic recovery².

The negative correlation between uncertainty and economic performance is a well established stylized fact. Empirical works in the fields generally find that uncertainty has a negative and significant effect on real economic activity³. However, the transmission mechanism of uncertainty to the real economy represents a more controversial issue and motivates a newly blossoming area of research. Indeed, reproducing the co-movement of output, consumption, investment and labor market variables which follows a spike in uncertainty is not straightforward. In a competitive environment, uncertainty shocks determine a decline in consumption and a contemporaneous rise in investment, output and employment, in sharp contrast with the empirical evidence⁴. The macroeconomic effects of uncertainty can be only explained by the presence of some friction. In this paper, I propose an explanation which hinges on the presence of frictional labor markets. Previous works have mainly explored different (but not self-excluding) mechanisms.

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¹See NFIB (2012).

²See NABE (2012).

³Alexopoulos and Cohen (2009) show that uncertainty shocks are able to explain a non-trivial fraction of the total variance of industrial production, output, employment, consumption and investment, whereas Knotek II and Khan (2011) estimate a modest impact on households' consumption. Bachmann, Elstner, and Sims (2013) compare the effects of uncertainty on the German and US economy, finding that an increase in uncertainty causes a negative response of output.

⁴See Wang (2012) and Cesa-Bianchi and Fernandez-Corugedo (2014) for a discussion about the co-movement problem and the crucial importance of the labor block.

Starting from the seminal contribution by Bloom (2009), some works focus on the relationship between uncertainty and investment (see Bloom et al. (2012); Bachmann and Bayer (2013)). When physical investment is irreversible, agents must trade off the extra returns from early commitment against the benefits from waiting for more information. Increased uncertainty about future returns increase the value of waiting for more information, thus dampening investment and economic activity.

Other authors underly the role of financial frictions. Christiano, Motto, and Rostagno (2010) and Christiano, Motto, and Rostagno (2014) estimate a large-scale DSGE model where financial frictions combine with shocks to the dispersion of idiosyncratic returns on investment, defined as risk shocks, finding that they are one of the major business cycle driving force. In Arellano, Bai, and Kehoe (2012), firms cannot issue state-contingent bonds to insure themselves against the risk of default. As a consequence, hiring labor is a risky activity and shocks to the volatility of idiosyncratic demand make firms more reluctant to hire workers. In Gilchrist, Sim, and Zakrajsek (2014) financial frictions represent an amplification device of fluctuations caused by the partial irreversibility of investment.

The effects of nominal rigidity are analyzed by Basu and Bundick (2014), whereas other papers find that idiosyncratic volatility represents a relevant dimension of macroeconomic fluctuations (see Fernandez-Villaverde and Ramirez (2011) and Justiniano and Primiceri (2008)). Finally, policy uncertainty is the focus of ongoing research^{5,6}.

This paper contributes to the literature by proposing a different explanation about the effects of uncertainty shocks where the labor market plays a key role. The mechanism recalls the traditional argument of irreversibility put forward by Bloom (2009). When labor markets are frictional, the hiring process is costly and resembles an irreversible investment decision. I show that this mechanism is consistent with the data⁷ and it is sufficient to

⁵See Fernández-Villaverde et al. (2015), Baker, Bloom, and Davis (2015) and Born and Pfeifer (2014).

⁶The literature mentioned so far assumes that changes in uncertainty are exogenous to the economic environment. Even if the counter-cyclical behavior of both micro and macro uncertainty measures seems to be robust, there is less consensus on the direction of causality. Bloom et al. (2012) addresses this point: they find no evidence that first-moment shocks drive microeconomic uncertainty but rather argues that higher uncertainty leads to a TFP slowdown. Other authors have thus take another route, explaining how uncertainty can endogenously arise from more conventional first-moment shocks (the so called "by-product hypothesis", since uncertainty is a by-product of the cycle). Prominent examples are van Nieuwerburgh and Veldkamp (2006), Bachmann, Elstner, and Sims (2013), D'Erasmus and Boedo (2013) and Fajgelbaum, Schaal, and Tascherau-Dumouchel (2015).

⁷The empirical analysis is conducted on US data. The results are likely to be even stronger for Europe, where frictions are more pronounced.

generate the observed co-movement in a general equilibrium model. In the final part of the paper I use the model to explore the linkages with price stickiness and the implications of different monetary policy rules.

I use a SVAR model to study the significance and the quantitative implications of increases in uncertainty once TFP shocks are taken into account. I find that a 1 SD increase in uncertainty does have significant negative effects on employment, the number of vacancies posted by firms and the job finding rate. Further, it reduces output, consumption and investment. Building on these estimates, I then perform a counterfactual analysis to gauge the relevance of the labor market in the transmission of uncertainty shocks to the whole economy. I find that if uncertainty shocks had not a direct impact on vacancies, the detrimental effect on aggregate economic activity would be much weaker. Other transmission channels (like investment or financial markets) do not seem to be as important.

Motivated by the empirical findings, I build a theoretical setup to analyze the effect of exogenous spikes in uncertainty on the aggregate economic activity, focusing on frictional labor markets as the main transmission channel. I adopt a dynamic general equilibrium framework: some previous contributions, including the seminal paper by Bloom (Bloom (2009)) have partial equilibrium models, which neglect price dynamics that can potentially offset the real effects. In a frictional environment, firms cannot perfectly adjust employment to their needs and the value of a job depends on the present discounted value of the expected stream of profits generated by the match. When future returns are more uncertain, firms prefer to wait hiring more workers before engaging in costly vacancy posting activities. Hence, the model with search and matching frictions is able to match the empirical co-movement among consumption, output, investment, employment, vacancies, the labor market tightness and the job finding rate triggered by an uncertainty shock.

By the best of my knowledge, four other independent works explore the effects of uncertainty shocks in a model with search. Riegler (2014) and Schaal (2015) analyze the effects of volatility shocks in partial equilibrium search models with heterogeneous firms. Differently from this paper, they consider uncertainty at the micro level. Closer to my work, Leduc and Liu (2012) and Cacciatore and Ravenna (2015) embed aggregate stochastic volatility in macro models with frictional labor markets. However, I add to them by taking into account capital accumulation with variable utilization rate, which can crucially alter the transmission of uncertainty shocks to the whole economy. I also consider the monetary policy implications of my framework; while Leduc and Liu (2012) claim that uncertainty shocks act like aggregate negative demand shocks, I show that their

results crucially hinge on a linear specification of the production function. Cacciatore and Ravenna (2015) investigate the role of downward wage rigidity in transmitting uncertainty shocks, a feature which is not present in my model. Despite the differences, we all argue that the presence of search frictions in the labor market can explain the negative impact of uncertainty on economic activity.

The rest of the paper is structured as follows. Section 2 presents the empirical evidence; Section 3 provides the economic intuition of the effects of uncertainty in different settings; Section 4 introduces the model; Section 5 outlines the solution method and the calibration strategy; Section 6 presents the results; Section 7 concludes.

2 Empirical evidence

In this Section I present some empirical evidence on the effect of uncertainty on the aggregate economy and more specifically on the labor market. As uncertainty indicator I use a measure of disagreement drawn by the Survey of Professional Forecasters (SPF). The SPF is a quarterly survey administered by the Philadelphia FED, starting in 1968Q4 and still conducted roughly in the same format. Professional forecasters are asked to disclose their best predictions about several macroeconomics indicators at different horizons. The Philadelphia FED itself computes a measure of forecast dispersion, which consists of the difference between the 75th and the 25th percentiles of the forecasts⁸. I use this measure computed for the forecast on nominal GDP for the quarter immediately following the survey date. This measures the ex-ante disagreement among professionals and thus captures the uncertainty surrounding future economic conditions⁹. As a robustness test, I also consider other measures of uncertainty which are discussed in Appendix A.

Before discussing the SVAR specification and the empirical results, one caveat is worth taking. Both theoretically and empirically, it is not straightforward to establish the direction of causality between uncertainty and the business cycle. In principle, uncertainty can be either an impulse or a consequence of recessions. Evidence on this is sparse and

⁸More details about the SPF are contained in Appendix A.1.

⁹In the context of future inflation uncertainty, Bomberger (1996) indicates a clear relationship among forecasters disagreement and conditional variance of ex-post forecast errors. He thus concludes that the survey-based measure based on Livingston data are a good proxy for uncertainty. Giordani and Soderlind (2003) reach the same conclusion on SPF data. More recently, Lahiri and Sheng (2010) find that disagreement tracks well uncertainty during stable periods and for short forecast horizons.

Table 1. Correlations with GDP at different leads and lags (HP-filtered series)

	$t-3$	$t-2$	$t-1$	t	$t+1$	$t+2$	$t+3$
Forecast disp.^a	-0.36***	-0.38***	-0.32***	-0.27***	-0.20 ***	0.00	0.12
Stock market vol.^b	-0.36 ***	-0.38***	-0.34***	-0.21***	-0.04	0.11	0.19***
EPU^c	-0.50***	-0.52***	-0.51***	-0.42***	-0.24**	-0.09	-0.04
Δ TFP vol.^d	-0.23***	-0.24***	-0.23***	-0.24***	-0.25***	-0.25***	-0.22***

Correlation between x_{t+k} and y_t , where x is the row variable, y is GDP and $k \in [-3, 3]$ are the different leads and lags.

^a Cross-sectional dispersion of forecasts on nominal GDP in the next quarter from the Philadelphia FED's SPF.

^b Stock market volatility (VIX index).

^c Economic Policy Uncertainty index (cfr. Baker, Bloom, and Davis (2015)).

^d Variance of the TFP growth rate (cfr. Fernald (2012)).

* Statistically significant at the 10 percent level. ** Statistically significant at the 5 percent level. *** Statistically significant at the 1 percent level.

far from conclusive¹⁰. Table 1 shows weak evidence that different measures of uncertainty lead the cycle rather than lagging it. On the contrary, the time correlation pattern of a realized measure of dispersion like the variance of the TFP growth rate displays noticeable differences. Even if causality cannot be inferred by simple correlations, the table suggests that it is unlikely that spikes in uncertainty are determined by bad economic performance.

2.1 Baseline VAR estimates

Despite of the wider use of stochastic volatility as a proxy for macroeconomic uncertainty I take forecast dispersion as favorite measure, since it is the closest concept to the specifi-

¹⁰Bachmann, Elstner, and Sims (2013) argue that the direction of causality runs from recessions to increased observed cross-sectional dispersion. In contrast, Bloom et al. (2012) find that TFP shocks seem not to drive countercyclical uncertainty at the micro level.

As for this paper, I have conducted Granger causality tests which do not exclude neither the possibility of uncertainty Granger-causing GDP (or other economic variables) nor the opposite.

cation of time-varying volatility I adopt in the model.

I present estimates for tri-variate VARs, including GDP, my measure of uncertainty (forecast dispersion in the preferred specification) and a further measure of economic activity. VAR estimates are based on United States data at quarterly frequency, spanning from 1968q4 (the first available date for the SPF) to 2015q3¹¹. Each series is logged and expressed as percentage deviations from an HP trend with smoothing parameter 1600.

Like other contributions in the field, I adopt a recursive identification scheme: I assume that uncertainty is not contemporaneously affected by the state of the economy¹². This assumption explicitly exploits the survey design: respondents are asked to report their best forecast before the data on the state of the economy in the current quarter are released¹³. However, results are robust to alternative recursive orderings and uncertainty measures.

The tri-variate specification allows me to take into account shocks to the technological level, and provide more conservative estimates with respect to the bi-variate case (i.e. only with the uncertainty and the economic measure). The variables enter in the following order: GDP as a proxy for technology, the uncertainty indicator, and one measure of economic activity. This ordering implies that the IRFs to uncertainty shocks have already been purged from the effects of TFP shocks. I also verified that the effect of uncertainty remains significant once including in the VAR a measure of financial distress like the spread between Baa and Aaa rated US corporate bonds or the excess bond premium computed by Gilchrist and Zakrajšek (2012)¹⁴.

Figures 1 and 2 plot the impulse response functions of different economic outcomes to a 1 SD uncertainty shock. Uncertainty has a significant negative impact on economic activity

¹¹However, the proxy for vacancies (the composite help-wanted index computed by Regis Barnichons) is available only up to 2014q3 and the job finding rate (computed by Robert Shimer) only until 2007.

¹²The estimates are obtained using the code of Binning (2013). This code is an extension of the algorithm elaborated by Rubio-Ramirez, Waggoner, and Zha (2010) and has a high degree of flexibility in allowing for different types of restrictions. The codes for bootstrapping are taken from Ambrogio Cesa Bianchi.

¹³One caveat has to be made regarding labor market outcomes. Before the deadline to return the questionnaires, the BLS releases the Employment Situations Reports, which contains informations about employment trends in the first month of the current quarter. This implies that, as far as labor market variables are concerned, the possibility that forecasters can be influenced by the contemporaneous state of the labor market cannot be ruled out. In a previous version of this paper, I have tackled this issue by showing that results are robust to a novel identification strategy based on long-run restrictions (assuming that forecast dispersion is not affected by economic activity in the long run). Results are available upon request.

¹⁴Caldara et al. (2016) argue that it is hard to jointly identify financial and uncertainty shocks. However, among the various uncertainty measures they consider, forecasters' disagreement has the highest predictive power of real economic activity.

and the labor market. The estimates imply that uncertainty causes a drop of industrial production by 0.1% after three quarters, and has even stronger effects on investment and unemployment, which increases by 0.4% at its peak. Focusing of labor market outcomes, uncertainty also causes a drop in two variables most studied in the search literature, namely vacancies (i.e. the composite help-wanted advertising index computed by Regis Barnichon) and the job finding rate (computed by Robert Shimer). Forecast dispersion also has a negative impact on hours worked (not shown in the figure). The major effects show up between three and five quarters, with the economy then reverting back to the previous state and eventually overshooting it.

Figures 3 and 4 show that results hold true in multivariate VARs in which I also include the effective federal funds rate and the consumption price index. In this specification, the variables enter in the following order: GDP, the uncertainty indicator, the other measure of economic activity, the CPI index and the federal funds rate. Notice that the inclusion of the federal funds rate captures the source of variations coming from monetary policy. Disentangling the two shocks (monetary and uncertainty shocks) appears particularly relevant in this context, since it has been argued that uncertainty shock behave like aggregate demand shocks (cfr. Leduc and Liu (2012)). Quite interestingly, the VAR estimates show that the negative effect of uncertainty does not disappear once demand shocks coming from a rise in the policy interest rate are taken into account.

2.2 Counterfactual experiments

I showed in the previous Section that uncertainty has a significant detrimental effect on many macroeconomic outcomes. However, the previous analysis leaves open the important question about the transmission channels of uncertainty. Consider, for instance, the drop in vacancies which comes with an uncertainty shock. Many explanations are consistent with this observation. As illustrations: i) uncertainty induces firms to pause from investing and complementarity between capital and labor determines a simultaneous drop in labor demand; ii) uncertainty on financial markets leads lenders to ask for higher premia; financially constrained firms are thus forced to reduce their inputs and production; iii) firms consider hiring a risky activity and thus reduce the amount of vacancies to post; this, in turn, produces or amplifies the recession.

Understanding the transmission mechanism of a given empirical phenomenon is important in order to discriminate among theoretical frameworks which exploit different mechanisms to reproduce the same observations. By using the econometric model previously

estimated, I can perform counterfactual experiments and compare them to the baseline results¹⁵.

Let

$$\underbrace{\begin{bmatrix} GDP \\ uncertainty \\ economic activity \\ \pi \\ i \end{bmatrix}}_{Y_t} = \hat{B}_0 + \hat{B}_1 Y_{t-1} + \dots + \hat{B}_p Y_{t-p} + \hat{A}_0 \varepsilon_t \quad (1)$$

be the VAR estimated above with the inclusion of inflation and the nominal interest rate. Hatted variables stand for the estimated coefficients. For any measure of economic activity appearing in the vector Y we can thus ask the following question: if that variable does not directly react to uncertainty, what is the reaction of GDP to uncertainty shocks? If this reaction is significantly weaker than the one obtained in the unrestricted model, we have a mild evidence of that variable being an important transmission channel of uncertainty shocks.

Formally, the experiment is conducted by modifying the matrices of coefficients as follows:

$$\hat{B}_i = \begin{bmatrix} \hat{b}_{11} & \hat{b}_{12} & \dots & \hat{b}_{15} \\ \hat{b}_{21} & \hat{b}_{22} & \dots & \hat{b}_{25} \\ \hat{b}_{31} & 0 & \dots & \hat{b}_{35} \\ \dots & & & \\ \hat{b}_{51} & & \dots & \hat{b}_{55} \end{bmatrix}, \quad i = 1, \dots, p \quad (2)$$

All the coefficients stay the same but the one denoting the direct reaction of economic activity to uncertainty (third row, second column). The matrix of contemporaneous reaction \hat{A}_0 needs to be modified accordingly. Notice that this exercise is more conservative than, say, considering economic activity as an exogenous variable or holding fixed its value when a shock hits. The restriction I impose, in fact, only excludes a direct effect of uncertainty but does not prevent the variable called into question to be impacted indirectly by

¹⁵The exercise is conducted in the same spirit as in Beetsma and Giuliodori (2012), who investigate the respective roles of stock market returns and stock market volatility on the macroeconomy.

general equilibrium feedback. This means that I allow the drop in GDP to have a negative impact on vacancies, which itself feeds back into the economy. However, if the drop in GDP observed in the unrestricted model is mainly due to an initial stop in hiring, this would show up as a significant weaker response of production¹⁶.

Results are reported in Figure 5. All panels plots the response of GDP to 1 SD shock to the uncertainty indicator. The blue solid line is the response obtained in the unrestricted model; the red dashed line is the response of GDP in the counterfactual experiment where the variable indicated on top with a tilde is not allowed to respond directly to uncertainty. Consider the top left panel: the red dashed line comes from a model like (1) where economic activity is represented by vacancies and matrices are restricted like in (2). The graph shows that if job creation does not directly respond to uncertainty, the economy is affected less severely by uncertainty. The top right and the bottom right panels report the results when the variables included in the VAR are investment and stock market returns, respectively. In this case, the counterfactual response of GDP is not significantly different from the unrestricted one. Finally, consumption appears to play an important role in the transmission of uncertainty (see the bottom left panel). Overall, this figure tends to attribute a small importance to investment and financial decisions in the propagation of uncertainty, while highlighting the significance of consumption and hiring behaviors.

3 Intuition

Before introducing the model and formally discussing the results, I provide the economic intuition of the dynamic reactions triggered by an uncertainty shock. To this aim, I find useful to compare a Diamond-Mortensen-Pissarides (DMP) type of model, like the one I develop in Section 4, with a model featuring a competitive labor market.

To have a simple intuition, consider a standard RBC model: agents' utility is defined over consumption and leisure and firms use capital and labor to produce a homogeneous good which is sold to households. Under the assumption of risk aversion, we can draw quite easy and intuitive predictions about agents' reaction when facing more uncertain economic conditions. By definition, risk-averse households desire to self-insure against risk: higher uncertainty about the future state of the world leads them to save more for precautionary

¹⁶This type of counterfactual exercise is not immune from the Lucas' critique. However, this concern is mitigated by restricting only one coefficient in each matrix, i.e. the direct response of the economic variable to uncertainty.

motives. If utility is separable in consumption and leisure, the higher marginal return to income pushes them to increase labor supply. With perfectly competitive capital and labor markets, the interest rate and the wage fall to clear the respective markets; in equilibrium, inputs are employed in a greater amount and production increases. If no other shock occurs and assuming that the rise in volatility is temporary, the following period agents realize that no change has intervened in altering their consumption possibilities. Then, first order effects prevail on the volatility effect and all variables quickly revert to their steady state values. In this context, the overall effect of uncertainty is mainly determined by the households' consumption-savings decision. The absence of real or nominal frictions makes firms indifferent to future shocks dispersion and ready to employ any amount of capital and labor supplied by households.

The empirical analysis conducted in Section 2 makes it clear that other economic forces are at play to shape the effects of uncertainty on real economic activity. First candidates are either nominal or real frictions, which modify the firms' optimization problem and lead them to contract production.

Nominal rigidities are the focus of Basu and Bundick (2014), who consider Rotemberg price adjustment costs in the final good market. In this New-Keynesian type of model, output is demand-determined and the mark-up counter-cyclically adjusts to clear the market. In this way, the authors are able to generate the observed co-movement of consumption, output and investment. The authors also show that the effects of uncertainty shocks are amplified when monetary policy is constrained by the zero-lower bound because it shuts down another price adjustment channel.

Other works (Arellano, Bai, and Kehoe (2012) and Gilchrist, Sim, and Zakrajsek (2014)) study the distortions implied by imperfect financial markets. For instance, micro-uncertainty shocks can increase the cost of external finance, thus affecting firms' demand for capital.

This paper does instead consider a particular type of real rigidity, close to the real option value studied in the literature which analyzes investment decisions under uncertainty. As highlighted by many contributions (see, for instance, Bloom, Bond, and van Reenen (2007), Bloom (2009) and Bloom et al. (2012)) non-convex adjustment costs and partial or total irreversibility of investment generate an option value to postpone decisions. Firms trade-off the benefits from early investment with the advantage of waiting for more information: the latter increases as firms are more uncertain about future returns, so that they adopt a "wait and see" behavior.

On the ground of the counterfactual analysis presented in Section 2.2, it seems promising to investigate a similar rigidity in the labor market. I thus exploit the widely used Diamond-Mortensen-Pissarides framework to study how the presence of search frictions affects firms' hiring decisions in presence of uncertainty. In my setup hiring a worker resembles an investment decision: the firm pays a fixed cost to post a vacancy against the present discounted value of future profit flows generated by the match. Firms' hiring decisions thus take into account expectations about the future states of the world, whose probability distribution depends on the amount of uncertainty in the economy.

In my model I allow for several extensions with respect to related papers based on search and matching frameworks. First, I consider a more general utility function, with habit in consumption and disutility from labor. Relaxing the hypothesis of rigid labor supply can have important consequences when habit is introduced. In fact, habit formation enters the marginal rate of substitution between consumption and leisure, thus affecting the wage asked by the workers. Second, I introduce investment decisions, because my goal is to explain how uncertainty impacts the macroeconomy through the labor market channel. The presence of capital accumulation can alter the predictions of a simpler model in which labor is the unique input of production. For instance, when households derive a great value from non-market activities (as in the Hagedorn and Manovskii (2008)'s calibration), the responses of the labor market to uncertainty shocks are amplified, because firms anticipate that they could not lower the wage below that value in case of adverse productivity shocks. However, this also induces firms to partially substitute labor with capital, thus generating an increase in investment which does not square well with the empirical observations. On the other side, investment can be negatively affected by uncertainty because of the complementarity with labor in the production function.

Finally, a real model with search frictions and investment is not enough to explain the macroeconomic effect of uncertainty shocks. This is due to the fact that the interest rate - which also represents the remuneration of capital - is tightly linked to the households' discount factor, determining a demand for capital which is strongly negatively correlated with consumption. By introducing prices and attributing to a monetary authority the power of setting the interest rate according to its preferences on output gap and inflation, this link is eased, so that it is possible to obtain a simultaneous drop of consumption and investment. For this reason I consider a monetary environment where the interest rate is set by a central bank which follows a standard Taylor rule. This further allows me to investigate the role of price stickiness and the implications for monetary policy. The model is then

able to replicate the desired co-movement among output, consumption, investment and labor market variables which follows a spike in uncertainty, a robust empirical prediction.

Another issue is worth mentioning here. In my model the separation rate is exogenous. One may thus be concerned that the presence of endogenous separations would alter the results. However, I am interested in the effects of aggregate uncertainty in a representative agent framework. In my setup, uncertainty shocks equally affect all job relationships, whose surplus never becomes negative because shocks are small and because wages are always incentive compatible. Then, the classical result due to McCall (1970) that a mean preserving spread of the job offer distribution increases the expected utility of a match does not apply here. In a representative agent framework there is no distribution of wage offers. Firms' and workers' decisions are not characterized by reservation properties, because they only regard the optimal amount of vacancies to post and working hours to supply, respectively. McCall (1970)'s insights would certainly apply in a model with heterogeneous agents and microeconomic uncertainty widening the distribution of idiosyncratic match productivities (as in Schaal (2015)).

4 The model

The benchmark model combines features of the standard medium scale DSGE models, search frictions *à la* Mortensen-Pissarides in the labor market and stochastic volatility of the technological process.

Time is discrete. The economy is populated by households and firms. Households consume, invest in bonds and physical capital, choose the capital utilization rate and supply labor. I distinguish between wholesale firms and retailers. Wholesale firms employ capital and labor to produce a homogeneous good sold to retailers in a perfectly competitive market. Workers are recruited on a frictional labor market and wages are the outcome of a Nash bargaining process between workers and firms. Retailers own a technology which allows them to differentiate the good without any other input. The differentiated good is then sold to households under monopolistic competition.

Technology follows an exogenous AR(1) process. The volatility of the technology shocks is itself stochastic.

4.1 Households

The economy is populated by a continuum of identical households of mass 1. They consume a composite good (C_t) which incorporates all the varieties produced by the retailers, hold bonds (B_t), accumulate physical capital (K_t^p), choose the capital utilization rate (ν_t) and supply labor. Since in any period workers are either employed or unemployed (i.e. matched or unmatched), a distributional problem may arise. As in Merz (1995), I assume that households pool consumption (they behave like a big family which fully insures each member against unemployment).

The consumption program solves:

$$\begin{aligned} \max_{C_t, N_t, B_t, I_t, K_t^p, \nu_t} \quad & E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_t - hC_{t-1})^{1-\sigma_c}}{1-\sigma_c} - \psi \frac{N_t^{1+\sigma_n}}{1+\sigma_n} \right] \\ \text{s.t.} \quad & C_t + I_t + \frac{B_t}{R_t P_t} = \frac{B_{t-1}}{P_t} + \frac{w_t}{P_t} N_t + R_t^k \nu_t K_{t-1}^p - \mathcal{A}(\nu_t) K_{t-1}^p + F_t \\ & K_t^p = (1 - \delta) K_{t-1}^p + I_t \end{aligned}$$

where σ_c is the relative risk aversion, σ_n is the inverse of Frisch elasticity and h expresses the degree of habit in consumption. At time t , households can allocate their income among consumption, investment, and nominal bonds. Nominal bonds pay the nominal (gross) interest rate R_t . The physical capital is transformed into effective capital at a rate ν_t and rent to firms at price R_t^k . Capital utilization is costly: the costs are expressed by the function $\mathcal{A}(\nu_t)$. As in in Gertler, Sala, and Trigari (2008), ν_t in steady state is 1, $\mathcal{A}(1) = 0$ and $\frac{\mathcal{A}'(1)}{\mathcal{A}''(1)} = \eta_\nu$. Notice that η_ν can be interpreted as the elasticity of the capital utilization rate to R_t^k ¹⁷. In addition, households' supply labor: the labor income is represented by the real wage paid to the household's members who are employed during the period (N_t). Finally, households' own firms, whose profits are denoted as F_t .

Aggregate production Y_t consists of a bundle of differentiated goods and can be ex-

¹⁷See Christiano, Eichenbaum, and Evans (2005).

pressed by the Dixit-Stiglitz aggregator¹⁸:

$$Y_t = \left[\int_0^1 Y_{it}^{\frac{\epsilon-1}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}}$$

where ϵ is the demand elasticity.

The first order conditions are the following:

$$(C_t) \quad (C_t - hC_{t-1})^{-\sigma_c} - \beta h E_t [(C_{t+1} - hC_t)^{-\sigma_c}] = \lambda_t \quad (3)$$

$$(B_t) \quad \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} R_t \right] = 1 \quad (4)$$

$$(I_t) \quad q_t = 1 \quad (5)$$

$$(\nu_t) \quad \mathcal{A}'(\nu_t) = R_t^k \quad (6)$$

$$(K_t^p) \quad q_t = \beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \left[R_{t+1}^k \nu_{t+1} - \mathcal{A}(\nu_{t+1}) + q_{t+1}(1 - \delta) \right] \right\} \quad (7)$$

where λ_t is the marginal value of wealth and q_t is Tobin's q .

Moreover, the demand for variety i is

$$C_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\epsilon} C_t \quad (8)$$

The aggregate retail price index is: $P_t = \left[\int_0^1 P_{it}^{1-\epsilon} di \right]^{\frac{1}{1-\epsilon}}$.

Labor supply decisions must take into account the frictions characterizing the labor market and are derived in Section 4.2.1. Notice that, with perfectly competitive labor markets, the following condition would hold:

$$\frac{w_t}{P_t} = \psi \lambda_t^{-1} N_t^{\sigma_N} = MRS_t \quad (9)$$

Eq. (9) states that, absent any friction, households supply labor by equating the real wage to the intratemporal marginal rate of substitution.

¹⁸I assume that there exists a unique type of good which can be either consumed, invested or used to cover capital utilization and vacancy posting costs.

4.2 The labor market

Labor market clearing is prevented by search and matching frictions *à la* Mortensen-Pissarides (see Mortensen and Pissarides (1994)). Demand and supply conditions (number of vacancies posted and job-seekers, respectively) and labor market characteristics (matching efficiency) jointly determine the employment level.

In order to hire workers, firms must post vacancies on the labor market, incurring the real cost k^f . The realized number of matches is the outcome of a Cobb-Douglas technology, which depends on the number of vacancies (V_t) and searchers (u_t): $M_t(V_t, u_t) = \chi V_t^\eta (u_t)^{1-\eta}$. The probability that a firm matches with a worker is $p_t^f = \frac{M_t(V_t, u_t)}{V_t}$. $q_t^w = \frac{M_t(V_t, u_t)}{u_t}$ expresses the job-seeker's probability of being hired. Labor market tightness is defined as $\theta_t = \frac{V_t}{u_t}$. It is easy to show that p_t^f is a decreasing function of θ , while q_t^w is an increasing function of θ . Furthermore, there exists the following relationship: $q^w(\theta) = \theta p^f(\theta)$.

In each period, timing is the following: i) workers and firms search on the labor market and matches are formed, ii) shocks realize, iii) production occurs, iv) matches exogenously severe and separated workers enter the unemployment pool.

Employment dynamic is thus given by:

$$N_t = (1 - s)N_{t-1} + M_t \tag{10}$$

where s is the exogenous separation rate. The first term in the r.h.s of eq. (10) represents workers matched in the previous period who do not separate (surviving matches); the second term represents new matches realized at the beginning of the period before production occurs. As a consequence, the number of searchers is

$$u_t = 1 - (1 - s)N_{t-1}$$

that is, all the currently unmatched workers. Unemployment is defined after the realization of the matches and is simply $U_t = 1 - N_t$.

4.2.1 Workers

Workers can be either employed or unemployed. I now characterize their value function in both cases. The value function of an employed worker is:

$$W_t = \frac{w_t}{P_t} - MRS_t + \beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \left[(1-s)W_{t+1} + s(q_{t+1}^w W_{t+1} + (1-q_{t+1}^w)U_{t+1}) \right] \right\} \quad (11)$$

where w_t is the nominal wage. The second term in r.h.s. of eq. (11) is the marginal rate of intratemporal substitution, which expresses labor disutility in terms of consumption goods. The term in brackets is the continuation value of the match: the match continues with probability $1-s$, while with probability s the worker enters the unemployment pool. In the latter case, in the following period she rematches with probability q_{t+1}^w , otherwise she remains unemployed.

With a little abuse of notation, let U_t be the value of unemployment at time t :

$$U_t = \beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} [q_{t+1}^w W_{t+1} + (1-q_{t+1}^w)U_{t+1}] \right\} \quad (12)$$

The value function of an unemployed worker is defined when the matches of the current period have already been formed. It is thus represented by a weighted average of the values attached to each employment status in the next period, where the weights are the probabilities of finding a job and staying unemployed, respectively.

The surplus which accrues to an employed worker is thus given by:

$$\begin{aligned} S_t^W &= W_t - U_t = \\ &= \frac{w_t}{P_t} - MRS_t + (1-s)\beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} (1-q_{t+1}^w) S_{t+1}^W \right\} \end{aligned} \quad (13)$$

4.2.2 Wholesale firms

Wholesale firms must take decision on capital and labor. To study the optimal investment decision, I set up the firm's maximization problem:

$$\begin{aligned} \max_{K_t, N_t} \quad & E_0 s \sum_{t=0}^{\infty} \beta^t \frac{\lambda_{t+1}}{\lambda_t} \left[\frac{P_t^w}{P_t} Y_t - k^f V_t - \frac{w_t}{P_t} N_t - R_t^k K_t \right] \\ \text{s.t.} \quad & Y_t = A_t K_t^\alpha N_t^{1-\alpha} - Q_t \end{aligned}$$

where $\frac{P_t^w}{P_t}$ is the relative price of the wholesale good in terms of the final good, k^f is the real costs of posting a vacancy and Q_t are fixed costs of production.

Optimization with respect to K_t yields:

$$R_t^k = \frac{P_t^w}{P_t} \alpha A_t K_t^{\alpha-1} N_t^{1-\alpha} \quad (14)$$

Eq. (14) is the standard optimizing condition: firms equate the marginal productivity of capital to its price.

In order to hire workers, firms must post vacancies on the labor market, by paying the fixed real cost k^f . The value of a vacancy is:

$$J_t^V = -k^f + p_t^f J_t^F + (1 - p_t^f) \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} J_{t+1}^V \right) \quad (15)$$

Eq. (15) states that with probability p_t^f the firm fills the vacancy and gets the value of the match (J_t^F) and with a complementary probability the vacancy remains unfilled. Free entry implies:

$$J_t^F = \frac{k^f}{p_t^f} \quad (16)$$

The value of a productive match is represented by the following equation:

$$J_t^F = \frac{P_t^w}{P_t} (1 - \alpha) A_t K_t^\alpha N_t^{1-\alpha} - \frac{w_t}{P_t} + \beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} [(1 - s) J_{t+1}^F + s J_{t+1}^V] \right\} \quad (17)$$

where the first term is the productivity on an additional worker given the current level of employment and capital stock, w_t is the nominal wage and the term in brackets represents the continuation value of the match, which ends with probability s .

Eq. (17) and free entry lead to the job creating condition:

$$\frac{k^f}{p_t^f} = \frac{P_t^w}{P_t} (1 - \alpha) A_t K_t^\alpha N_t^{-\alpha} - \frac{w_t}{P_t} + \beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \left[(1 - s) \frac{k^f}{p_{t+1}^f} \right] \right\} \quad (18)$$

Eq. (18) says that firms keep posting vacancies until the real cost they bear (which depends on the fixed cost and the search spell) equates the current productivity gains and the savings on future vacancy costs. The job creating condition thus links the firm's decision to the expected stream of profits, providing a channel through which uncertainty can affect hiring.

4.2.3 Nash bargaining

Wages are established through Nash bargaining, thus implying:

$$S_t^W = \frac{\gamma}{1 - \gamma} S_t^F$$

where S_t^W is defined in eq. (13), γ is the worker's bargaining power and $S_t^F = J_t^F$ is the firm's surplus.

After some algebra¹⁹, I obtain this expression for the real wage which prevails in equilibrium:

$$\frac{w_t}{P_t} = MRS_t + \frac{\gamma}{1 - \gamma} \left\{ \frac{k^f}{p_t^f} - (1 - s) \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} (1 - q_{t+1}^w) \frac{k^f}{p_{t+1}^f} \right] \right\} \quad (19)$$

Eq. (19) shows that workers must be compensated for the disutility of working (as in the competitive framework) but, as long as they have a positive bargaining power, they can also extract part of the firm's surplus (the first term inside the brackets). The last term inside the brackets represents the expected future gains from employment, which enter with a negative sign: if, say, the worker expects the future surplus to be high, she is willing to accept a lower wage in the current period.

4.3 Retailers

Wholesale firms sell the homogeneous good to retailers at the competitive price P_t^w . Then retail firms differentiate it at no cost and sell it households. In the benchmark case, prices

¹⁹More details about the derivation can be found in Appendix B.

are flexible. This allows me to show to what extent uncertainty shocks affect the real economy only through the search frictions. In the extension, however, I also introduce nominal rigidities. Price stickiness is modeled as price adjustment costs *à la* Rotemberg.

Retailers maximize their profits subject to the demand schedule for each individual good i :

$$\begin{aligned} \max_{P_{it}} \quad & E_0 \sum_{t=0}^{\infty} \beta^t \frac{\lambda_{t+1}}{\lambda_t} \left[\left(\frac{P_{it} - P_t^w}{P_t} \right) Y_{it} - \frac{\phi}{2} \left(\frac{P_{it}}{P_{it-1}} - 1 \right)^2 Y_t \right] \\ \text{s.t.} \quad & Y_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\epsilon} Y_t \end{aligned}$$

Price flexibility is obtained for $\phi = 0$. In this case, retailers just impose a mark up on the wholesale price:

$$P_t = \mu P_t^w$$

where $\mu = \frac{\epsilon}{\epsilon-1}$.

With non zero adjustment costs, the price schedule reads:

$$\frac{P_t^w}{P_t} = \frac{1}{\epsilon} \left\{ (\epsilon - 1) + \phi(\pi_t - 1)\pi_t - \phi\beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} (\pi_{t+1} - 1)\pi_{t+1} \frac{Y_{t+1}}{Y_t} \right\} \right\} \quad (20)$$

4.4 The monetary authority

The monetary authority follows a standard Taylor rule:

$$R_t = R_{t-1}^{\rho_r} \left[\frac{1}{\beta} \left(\frac{Y_t}{\bar{Y}} \right)^{\delta_y} \left(\frac{P_t}{P_{t-1}} \right)^{\delta_\pi} \right]^{1-\rho_r} \exp(\sigma^r \epsilon_t^r)$$

where $\frac{1}{\beta}$ is the steady state interest rate, ρ_r is the degree of monetary policy inertia and δ_y and δ_π express the monetary policy reaction to the output gap and to inflation, respectively. ϵ_t^r is monetary policy shock with a standard Normal distribution.

4.5 Exogenous processes and market clearing

The aggregate resource constraint implies:

$$Y_t = C_t + I_t + k^f V_t + \mathcal{A}(\nu_t) K_{t-1}^p + \frac{\phi}{2} \left(\frac{P_{it}}{P_{it-1}} - 1 \right)^2 Y_t$$

Besides the standard monetary policy shock²⁰, the model features two exogenous processes for the log(technology) and the log(volatility):

$$\ln A_{t+1} = \rho_a \ln A_t + \sigma_t \epsilon_{t+1}^a, \quad \epsilon_{t+1}^a \sim \mathcal{N}(0, 1) \quad (21)$$

$$\ln \sigma_{t+1} = (1 - \rho_\sigma) \ln \bar{\sigma} + \rho_\sigma \ln \sigma_t + (\sigma^\sigma) \epsilon_{t+1}^\sigma, \quad \epsilon_{t+1}^\sigma \sim \mathcal{N}(0, 1) \quad (22)$$

where $\bar{\sigma}$ is the steady state standard deviation of ϵ^a and ρ_a and ρ_σ represent the persistence of technology and volatility shocks, respectively. ϵ^a is a shock to the (log)level of technology: for this reason I will sometimes refer to it a first moment shock. ϵ^σ is instead a shock to the (log)volatility of technology: I will refer to it equivalently as volatility shock, uncertainty shock or second moment shock. The log-specification of the volatility process ensures that the standard deviation remains positive even when hit by negative shocks. This is the same specification adopted by Justiniano and Primiceri (2008).

The process described by eq. (22) is the true innovation with respect to an otherwise standard search framework. In what follows, I am interested in studying the response of the economy to a pure uncertainty shock, that is the response to ϵ_t^σ . It is worthy to stress that I do not consider here the impact of realized volatility, meaning that the actual level of technology remains constant. This implies that agents' reactions are not motivated by a change in the fundamentals, as it would be in the case for any type of first moment shock²¹.

Notice that I include a stochastic component in the monetary policy rule (ϵ_t^r) even if I am not interested in studying the effects of monetary policy shocks. As it will be more clear when I come to the calibration strategy, this is done to avoid to attribute a too high

²⁰The monetary policy shock is introduced to avoid extreme calibrations of the volatility process to match the volatility of the data.

²¹This approach is rather different from the one taken by Schaal (2015), who combines technology and volatility shocks to replicate the times series behavior during the recent crisis and the following sluggish recovery in unemployment.

variance to the volatility shock; this would have artificially amplified the model-based impulse responses. However, monetary policy shocks do not feature stochastic volatility. I choose to focus on the stochastic volatility of aggregate technology to establish a useful comparison with standard macro models. Leduc and Liu (2012) consider stochastic volatility in the demand shock and in the government spending shock in a similar setup. They show that results stay unchanged irrespective of the type of uncertainty being considered. This suggests that the results can be interpreted as the effects of a more general form of economy-wide uncertainty which is not specific to supply shocks.

5 Solution method and calibration

5.1 Solution method

The model is calibrated and then solved through perturbation. Aruoba, Fernandez-Villaverde, and Rubio-Ramirez (2006) and Caldara et al. (2012) show that higher than first order perturbation performs well in terms of speed and accuracy. Due to certainty equivalence, the volatility of the technological process does not play any role in the first order approximation of the policy functions. I thus employ a third order perturbation around the deterministic steady state²², which allows me to analyze the effects of second moments shocks.

The presence of volatility in higher order approximations move the economy away from its deterministic steady state²³. This implies that impulse responses computed as deviations from the deterministic steady state (as it is usually done with log-linearized models) do not converge. Hence, by looking at these responses it is not possible to distinguish the true effect of a volatility shock from the convergence to the new steady state.

To overcome this problem, I take the deterministic steady state as a starting point and I simulate the model for 2000 periods shutting off any shock. I consider the values reached by the variables after the simulation period as the "stochastic steady state". The stochastic steady state is defined as the state where agents choose to stay when they expect future risk and the realization of the shocks is zero²⁴. In what follows, all impulse responses are computed by imposing a 1 SD volatility shock after the 2000 periods simulation and

²²The latest version of Dynare allows pruning also for third order perturbation algorithms.

²³In a second-order approximation, for instance, the effect of volatility shows up in a constant which adds to the policy and transition functions. See Jin and Judd (2002) and Schmitt-Grohé and Uribe (2004) for a formal proof.

²⁴This is the same definition as in Coeurdacier, Rey, and Winant (2011).

plotted as deviations from the stochastic steady state.

5.2 Calibration

In order to confront the outcomes of the model with the empirical evidence presented in Section 2, I calibrate the model on US quarterly data. Calibration of preferences, monetary policy, the technological process and the labor market parameters is based on standard values widely employed in the previous literature and on the data. This facilitates comparisons and make sure that results are not driven by the extreme parametrization strategies.

The benchmark calibration is reported in Table 2. β is 0.99, so that the annual steady state interest rate is around 4 %. Capital depreciation is 10 % on a annual basis. I adopt a utility function log-linear in consumption and leisure (this implying $\sigma_c = 1$ and $\sigma_n = 0.5$) with a moderate degree of habit ($h = 0.2$). For the elasticity of the capital utilization rate (η_ν) I retain a value of 10²⁵. The fixed costs of production are calibrated to be 10 % of the output in steady state. This yields a value of 0.33, which is close to Christiano, Motto, and Rostagno (2010)'s estimates and lower than that estimated by Christiano, Eichenbaum, and Evans (2005).

I assume a steady state unemployment of 7 %, which is in the range of the values employed in the literature. It is slightly above the average of the unemployment in the period I consider in my empirical analysis (1968q4-2015q3)²⁶. The exogenous separation rate is 10%: this is consistent with the evidence reported by Davis, Faberman, and Haltiwanger (2006). For the job filling rate (p^f) I take a value of 0.7, as in den Haan, Ramey, and Watson (2000). This implies a job finding rate of 0.57. For the benchmark calibration I retain a value of 0.5 for η , the elasticity of the matching function. I also take a conservative stand in imposing the same value on the firms' bargaining power ($1 - \gamma$), so that the Hosios efficiency condition holds. As in Walsh (2005) and Blanchard and Galì (2010), the total vacancy expenditure on GDP ($\frac{k^f V}{Y}$) is 1%. I calibrate α in order to obtain a labor share

²⁵See Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007).

²⁶I abstract from labor market participation: since I only consider two employment status (namely employed and unemployed), population is intended to be active labor force. Other authors like Andolfatto (1996) address this issue by including in the definition of U both people out of the labor force and unemployed. They accordingly calibrate U on much higher values.

of $2/3^{27}$. The mark up is calibrated at 1.2.

I adopt a standard specification of the monetary policy rule, with quite high inertia ($\rho_r = 0.8$), and monetary policy reactions which respect the Taylor principle ($\delta_y = 0.5$ and $\delta_\pi = 1.5$). The variance of the monetary policy shock is calibrated at 0.002, as in Walsh (2005). For the exogenous process of technology I use the standard values in King, Plosser, and Rebelo (1988): 0.9 of persistence and steady state volatility ($\bar{\sigma}^a$) equal to 0.007. The persistence of the volatility process is generally assumed to be quite high: I thus adopt a value of 0.8, as in Basu and Bundick (2014) and Gilchrist, Sim, and Zakrajsek (2014). As regards the standard deviation of the volatility shock, there is no general consensus. I thus calibrate it to match the empirical standard deviation of my uncertainty indicator (forecast dispersion) which is around 16 times higher than GDP volatility²⁸.

²⁷In presence of labor market frictions α is no more equal to the labor share. For the retained calibration, α turns out to be 0.322.

²⁸To get this value I must impose $\sigma_\sigma = 0.2$.

Table 2. Benchmark calibration

	Definition	Calibrated value	Notes
Preferences and technology			
β	discount factor	0.99	S.s. annual interest rate of $\simeq 4\%$
δ	capital depreciation rate	0.025	Annual rate 10 %
η_ν	K util. rate elasticity	2	cfr. Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007)
Q	Fixed cost of production	10 % of \bar{Y}	
σ_c	relative risk aversion	1	Log-utility
σ_n	inverse of Frisch elasticity	0.5	Utility log-linear in leisure
h	habit in consumption	0.2	
μ	mark-up over wholesale price	1.2	
Labor market			
U	Unemployment	0.07	
s	Separation rate	0.1	Davis, Faberman, and Haltiwanger (2006)
p^f	Job filling rate	0.7	den Haan, Ramey, and Watson (2000)
q^w	Job finding rate	0.57	
$\frac{WN}{Y}$	Labor share	2/3	
$\frac{k^f V}{Y}$	Vacancy costs/GDP	0.01	Walsh (2005), Blanchard and Galì (2010)
η	Elasticity of the match. func.	0.5	Blanchard and Galì (2010)
γ	worker's bargaining power	0.5	Hosios condition respected
Monetary Policy			
ρ_r	Monetary policy inertia	0.8	
δ_y	Reaction to output gap	0.5	
δ_π	Reaction to inflation	1.5	
σ^r	Volatility of the shock	0.002	Walsh (2005)
Exogenous processes			
ρ^a	Persistence of the tech. process	0.9	
$\bar{\sigma}^a$	S.s. SD of the techn. process	0.007	King, Plosser, and Rebelo (1988)
ρ^σ	Persistence of the volatility process	0.8	Basu and Bundick (2014); Gilchrist, Sim, and Zakrajsek (2014); Arellano, Bai, and Kehoe (2012)
σ^σ	SD of the volatility process	0.45	$SD(\sigma_a)/SD(\log(y)) \simeq 16$, as in the data

6 The effects of uncertainty shocks

To highlight the role of labor market frictions, I first report and discuss the IRFs to a 1 SD volatility shock in a model as the one I described above but featuring a perfectly competitive labor market, no choice on the capital utilization rate and no habit in consumption²⁹. Calibration is the same discussed in Section 5. I then show the results for the model with search in the labor market.

6.1 The competitive labor market

Let me first discuss the results in the case where the labor market is perfectly competitive. Figure 6 plots the IRFs to a 1 SD volatility shock. The desire for precautionary saving drives a drop of consumption on impact, which directly translates into a rise in investment. Because the marginal utility of income has increased, households supply more labor. Price adjustment ensures labor and capital market clearing; firms use more inputs and expand production. All variables quickly revert to steady state as soon as the higher risk fades away. Notice that these responses are obtained when the utility function is time separable ($h = 0$). The presence of habit formation can actually reverse the responses of consumption and investment. However, the model is never able to reproduce the empirical co-movement among consumption, investment, employment and output.

6.2 Search in the labor market

Figures 7 and 8 report the IRFs to a 1 SD volatility shock obtained from the model with search on the labor market. From Figure 7 we can observe a drop in both consumption, investment and output on impact.

Labor market responses are reported in Figure 8. An unexpected rise in uncertainty induces firms to post less vacancies and causes labor market tightness to fall. Less vacancies translate into less job positions and a rise in unemployment, which is of the same magnitude as the drop in vacancies. The fall in the job finding rate follows as a direct consequence.

The ultimate reaction of the aggregate economy to an uncertainty shock comes from the interaction between the decisions of all economic agents. Households are pushed by precautionary motives to lower consumption and supply more labor. However, the presence

²⁹With a perfectly competitive labor market, the wage is equal to the marginal rate of substitution between consumption and labor and to the marginal productivity of labor.

of search frictions also modifies the firm’s decision problem. Meeting a job seeker requires the payment of a fixed cost and takes time. It follows that employment cannot adjust instantaneously and behaves like a state variable. Firms thus adopt a future-oriented perspective, by weighting the current real vacancy posting cost against the expected stream of profit from the match. When confronted to more uncertain future returns, they prefer being cautious and reducing the number of vacancies posted. Then, complementarity of inputs in the production function determines a fall in investment. The presence of habit does not alter any of the responses when prices are perfectly flexible. However, as we will see in the next Section, it does play a role when price stickiness is introduced.

The model is thus able to replicate the empirical responses, namely the contemporaneous drop in output, consumption and investment and the negative impact on the labor market. As the comparison with the model without frictions should make clear and as argued by Basu and Bundick (2014) this result is not trivial.

6.3 Price stickiness

Incorporating nominal rigidities in the previous framework is interesting for several reasons. First of all, this is recognized to be a realistic feature of many economies; indeed its presence greatly amplifies the response of the economy to uncertainty shocks, making it closer to what observed in the data. Second, it allows to investigate the effects on inflation: by studying this issue, Leduc and Liu (2012) argue that uncertainty shocks act like negative aggregate demand shocks because they are deflationary. Finally, the presence of price stickiness gives a meaningful role to monetary policy.

I introduce price stickiness in the form of price adjustment costs *à la* Rotemberg. The calibration of the price adjustment costs corresponds to a probability of not resetting the price of 0.75 in the Calvo setting. As pointed out by Basu and Bundick (2014), the presence of price stickiness adds an additional channel to the transmission of uncertainty shocks. Nominal rigidities prevent prices to adjust downwards and force firms to cut production to meet depressed demand. The results are shown in Figures 9 and 10. With sticky prices, the reduction in vacancies is 5 times larger and the drop in output is multiplied by 15. Notice that now the response of investment is reversed. In this specification, inflation increases and the central bank reacts by raising the interest rate. Then, households’ savings increase, leading to more capital accumulation. However, these decisions largely depend on the dynamics of the household’s discount factor. It can be shown that a larger degree of habit can restore the negative response of investment, because it dampens the response

of consumption.

In a very similar framework, Leduc and Liu (2012) show that uncertainty shocks have deflationary effects. However, they do not consider capital accumulation and they adopt a production function linear in labor. For the sake of comparison, from now on I present results from a simplified model without capital. I consider two specifications of the production function: the first with constant marginal returns to labor (like in Leduc and Liu (2012)) and another one featuring decreasing marginal returns. Figure 11 depicts the responses of output, inflation and the nominal interest rate in presence of price stickiness, under the two different specifications of the production function. The blue solid line reproduces the findings in Leduc and Liu (2012), with uncertainty weighting negatively on inflation. However, the red dashed line shows that the sign of the response is reversed for a model with decreasing marginal returns to labor. As discussed by Fernández-Villaverde et al. (2015), the reaction of inflation depends on two factors. On the one hand, the decrease in aggregate demand puts a downward pressure on prices. On the other hand, the final good producers ask for higher markups, an effect called "upward pricing bias"³⁰. In fact the retailers' profit function is convex in the relative price. Hence, confronted with a more dispersed future optimal pricing, retailers are better off setting a price which is relatively higher than their competitors rather than a price which is relatively lower. Fernández-Villaverde et al. (2015) further show that the strength of the "upward pricing bias" depends on the covariance between marginal costs and aggregate demand. Decreasing returns to scale in the production function determine larger variations of retailers' marginal costs, strengthening the "upward pricing bias" and causing a rise in inflation.

The effects of uncertainty on inflation is an empirical question, that can be addressed with the same methodology presented in Section 2. Unfortunately, no robust conclusion can be drawn from this exercise: the results depend on the proxy of uncertainty being used. Inflation raises when I use my favorite uncertainty indicator (forecast dispersion from SPF), while drops when uncertainty is proxied by perceived consumers' uncertainty from the Michigan Survey (the same used by Leduc and Liu (2012)) or stock market volatility. One possibility is that these two measures capture different sources of uncertainty which have opposite effects on prices. Addressing this issue in the context of my simple theoretical framework is beyond the scope of this paper. The take-away from both the theoretical and empirical exploration is that it is not possible to make a confident statement on the reaction

³⁰Born and Pfeifer (2014) denote the same mechanism as the "inverse Oi-Hartman-Abel effect".

of inflation in face of heightened uncertainty. One should thus be cautious in comparing uncertainty shocks to aggregate demand shocks.

The presence of nominal rigidities provides the central bank with an important stabilizing role. In macroeconomic modeling it is standard practice to assume that the central bank fixes the nominal interest by reacting to output gap and inflation, as summarized by the so-called Taylor rule. This is also the approach taken by this paper. To the best of my knowledge, there is no paper studying the optimal monetary policy response to uncertainty shocks. A similar study would be interesting to pursue but it is beyond the scope of this work. I choose to present simulations from different parameterizations of the Taylor rule, instead. Results are presented in Figure 12: the IRFs of output, inflation and the interest rate to a 1 SD uncertainty shock are plotted for different weights attributed to the arguments of the Taylor rule. Notice that, despite the coefficients of the monetary policy rule change only slightly, the responses differ significantly. The weaker recession is achieved when the reaction to inflation is stronger and the interest rate does not respond to the output gap³¹. These results can be contrasted to the implications of different monetary policy reactions to standard demand shocks, which are represented in Figure 13. In this case, the three parameterizations lead to very similar results. As highlighted by Born and Pfeifer (2014), a stronger central bank's reaction to inflation dampens the "upward pricing bias", because firms anticipate that the monetary authority will not allow prices to rise for long periods of time. This effect is not present in case of realized negative demand shocks, which do not affect firms' expectations about future optimal price adjustments. Contrary to my findings, in Born and Pfeifer (2014)'s framework the impact of uncertainty is reduced when the interest rate responds more strongly to the output gap. They show that this result is due to the interplay of wage and price stickiness, while I have fully flexible wages. In my setup, as in Fernández-Villaverde et al. (2015), a stronger reaction to the output gap signals a more accomodative stance of the central bank, which strengthens the upward pricing bias. Overall, this simple exercise shows that uncertainty shocks cannot be regarded as negative aggregate demand shocks under many respects, including for monetary policy prescriptions.

³¹The results are presented for a specification of the production function with decreasing marginal return to labor, which implies a positive response of inflation. However, the same conclusion about the effectiveness of monetary policy is achieved with a production function linear in labor.

7 Conclusions

This paper examines the impact of uncertainty shocks on the labor market, both empirically and theoretically. In the empirical part, I proxy uncertainty with forecasts dispersion in the Survey of Professional Forecasters. I perform VAR estimates including TFP, the uncertainty indicator and different measures of economic activity. I show that uncertainty plays an autonomous and significant role, negatively affecting the aggregate economy. I provide new evidence on the negative impact of uncertainty on the labor market, especially on employment, vacancies, the labor market tightness and the job finding rate. Moreover, counterfactual experiments show that hiring and consumption choices are important transmission mechanisms of uncertainty shocks, whereas I do not find any evidence of a significant propagation role for investment and financial markets.

In the theoretical part, I build a DSGE model featuring search and matching frictions *à la* Mortensen-Pissarides in the labor market and stochastic volatility. Uncertainty shocks are defined as unexpected increases in the volatility of the technological process. In contrast to competitive environments, the model is able to generate the observed comovement of consumption, investment, output, employment, vacancies, the labor market tightness and the job finding rate. Price stickiness is shown to greatly magnify the impact of uncertainty shocks, bringing the model-based impulse response functions closer to the empirical ones. However, contrary to what suggested by Leduc and Liu (2012), I find that uncertainty shocks cannot be always compared to aggregate demand shocks for two reasons. First, the effects on inflation depend on the relative strength of competing forces; different specifications of the production function lead to opposite conclusions. Second, even small changes in the conduct of monetary policy can lead to significantly different reactions of the economy when hit by uncertainty, while the differences are negligible for demand shocks. Simulations show that the central bank has more chances to mitigate an uncertainty-driven recession by following a Taylor rule with a high weight on inflation and null weight on the output gap.

These findings can be interpreted in the light of previous research and suggest that uncertainty is likely to play a detrimental role on the overall economy when the firms' profit function is affected by the expectation on future returns. The search and matching framework naturally embeds this mechanism and can be considered an alternative explanation to the negative impact of uncertainty on the macroeconomy observed in the data.

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Appendix A Measuring uncertainty

The empirical estimates discussed in the main text proxy uncertainty with a measure of disagreement drawn by the Survey of Professional Forecasters (SPF), for which I provide further details below. Other survey-based measures of uncertainty have been previously employed in the empirical literature (see Bachmann, Elstner, and Sims (2013) and references therein). Bachmann, Elstner, and Sims (2013) use forecast dispersion from the Business Outlook Survey, administered by the Philadelphia Fed.

Both the unrestricted VAR estimates and the results of the counterfactual experiments are robust to the use of alternative measures of uncertainty. The alternative indicators that I have considered are: i) stock market volatility; ii) the variance of the TFP growth rate obtained from a GARCH(1,1) model (in logs); iii) the Economic Policy Uncertainty (EPU) index computed by Baker, Bloom, and Davis (2015); iv) the index constructed by Jurado, Ludvigson, and Ng (2015). Previous contributions have claimed stock market volatility to be a good proxy for uncertainty. Schwert (1989) argues that financial asset volatility helps to predict future macroeconomic volatility and both of them increase during recessions. Bloom (2009) shows that stock market volatility is highly correlated with other cross-sectional measures of uncertainty at the micro-level and takes it as a basis to build a volatility indicator that has significant effects in VAR estimates. Alexopoulos and Cohen (2009) use stock market volatility and a newspaper-based indicator to assess the effect of uncertainty on a wide range of variables, including industrial production, consumption goods, employment, unemployment and productivity.

The second measure I consider is the variance of the TFP growth rate. More specifically, I use the TFP growth rate computed by Fernald (2012)³² and I estimate a GARCH(1,1) model to retrieve the conditional heteroskedasticity³³. This measure has been introduced by Bloom et al. (2012), who only show the coincidence between spikes in macroeconomic volatility and NBER recession dates, but do not use it in VAR estimates.

³²The series is downloadable from John Fernald's website:

<http://www.frbsf.org/economics/economists/staff.php?jferald>. The series I employ is called dtfp.

³³I estimate the following GARCH model:

$$\begin{aligned} \text{dtfp}_t - \bar{\text{dtfp}} &= c + \sigma_t \epsilon_t \\ \sigma_t^2 &= k + \alpha_1 \epsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \end{aligned}$$

where $\bar{\text{dtfp}}$ is the mean of the dtfp series. As a measure of uncertainty I consider the estimated conditional heteroskedasticity series represented by σ_t .

Third, I consider the EPU index, which has received considerable attention in the latest period ³⁴.

Finally, I test my result using the aggregate uncertainty index constructed by Jurado, Ludvigson, and Ng (2015) as simple average of individual uncertainty measures. Their methodology aims at isolating the unpredictable component of the volatility of forecast errors of macroeconomic activity. The baseline estimates are robust to the use of this indicator, but the counterfactual experiment fails to identify a significant role of the labor market in the transmission of uncertainty.

Other commonly used measures of uncertainty are corporate bond spread (Bachmann, Elstner, and Sims (2013)), newspaper or Google-based indicators (Alexopoulos and Cohen (2009), Bachmann, Elstner, and Sims (2013), Knotek II and Khan (2011)) and cross-sectional measures of dispersion in TFP growth and level, profit and sales at the sector, industry and firm level (Bloom (2009), Bloom et al. (2012), Kehrig (2011)). Gilchrist, Sim, and Zakrajsek (2014) use high-frequency stock market data at the firm level to construct a novel proxy for idiosyncratic uncertainty.

A.1 The Survey of Professional Forecasters

The quarterly Survey of Professional Forecasters (SPF henceforth) was conducted by the American Statistical Association (ASA) and the National Bureau of Economic Research (NBER) from 1968:Q4 to 1990:Q1. It was then taken over by the Philadelphia Fed in 1990:Q2.

Currently, the SPF includes forecasts for 32 economic variables, but not all of them were present since the beginning. Respondents are researchers in the academy and professionals from financial institutions, banks and consulting firms.

For any given quarter, the timing of the Survey is the following³⁵:

- end of first month: release of the advanced report by the Bureau of Economic Analysis. It contains a first estimate of GDP and components of the previous quarter
- same day of the advanced report release: the SPF is send to panelists. It includes the estimates of the most recent advanced reports as well as other recent estimates

³⁴A comprehensive literature review can be found on the website: www.policyuncertainty.com.

³⁵The exact timing is available only from 1990:Q2 onwards. However, the Philadelphia FED believes not major changes have occurred from the previous years.

from other statistical agencies.

- first week of the second month: the BLS releases the Employment Situation Report, with employment data in the previous month.
- second/third week of the second month: deadline for returning the questionnaire.
- fourth week of the second month: release of the results of the survey to the public.

Appendix B Derivation of the wage setting rule

Nash bargaining implies that the surplus is split according to the following rule:

$$S_t^W = \frac{\gamma}{1-\gamma} S_t^F \quad (23)$$

where γ is the worker's bargaining power. Free entry implies that the value of a vacancy is driven to zero. Then, $S_t^F = J_t^F$. Substituting eq. (13) and eq. (16) into (23) leads to:

$$\frac{w_t}{P_t} - MRS_t + (1-s)\beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} (1 - q_{t+1}^w) S_{t+1}^W \right\} = \frac{\gamma}{1-\gamma} \frac{k^f}{p_t^f} \quad (24)$$

Iterating forward eq. (23), we can express the worker's surplus one period ahead as $S_{t+1}^W = \frac{\gamma}{1-\gamma} S_{t+1}^F = \frac{\gamma}{1-\gamma} \frac{k^f}{p_{t+1}^f}$. Then, rearranging eq. (24), we obtain

$$\frac{w_t}{P_t} = MRS_t + \frac{\gamma}{1-\gamma} \left\{ \frac{k^f}{p_t^f} - (1-s)\beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} (1 - q_{t+1}^w) \frac{k^f}{p_{t+1}^f} \right] \right\} \quad (25)$$

which is eq. (19) in the main text.

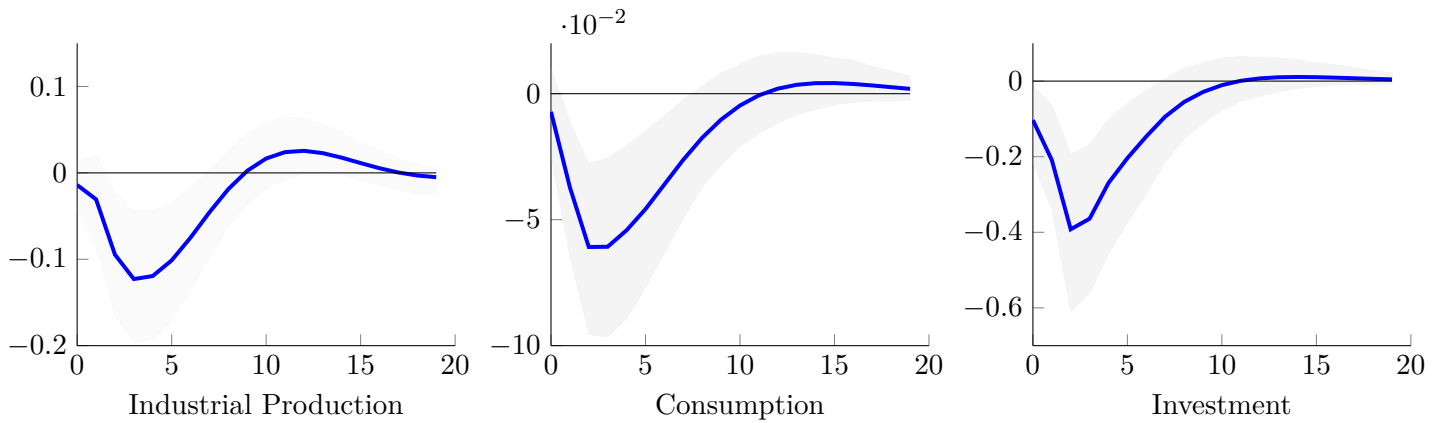


Figure 1. IRFs to 1 SD uncertainty shock. ^a

^aTrivariate VAR on United States data from 1968q4 to 2015q3. Series included are, in order: log(GDP) (FRED'S ID: GDPC96), the uncertainty indicator (i.e. the cross-sectional dispersion of forecasts on nominal GDP in the next quarter from the Philadelphia FED's SPF) and one variable proxying economic activity.

The variables included in each subfigure are, respectively: log(industrial production index) (FRED'S ID: INDPRO), log(real personal consumption expenditures) (FRED'S ID: PCECC96) and log(real gross private domestic investment) (FRED'S ID: GPDIC96). Variables enter with two lags, selected according to the Akaike criterion. All variables are expressed as percentage deviations from the hp-filtered series with smoothing parameter 1600.

The figure plots the response of each macro variable ordered last to 1 SD shock to the uncertainty indicator. The shaded area represents the 95% confidence interval estimated using a bootstrap with 1000 replications.

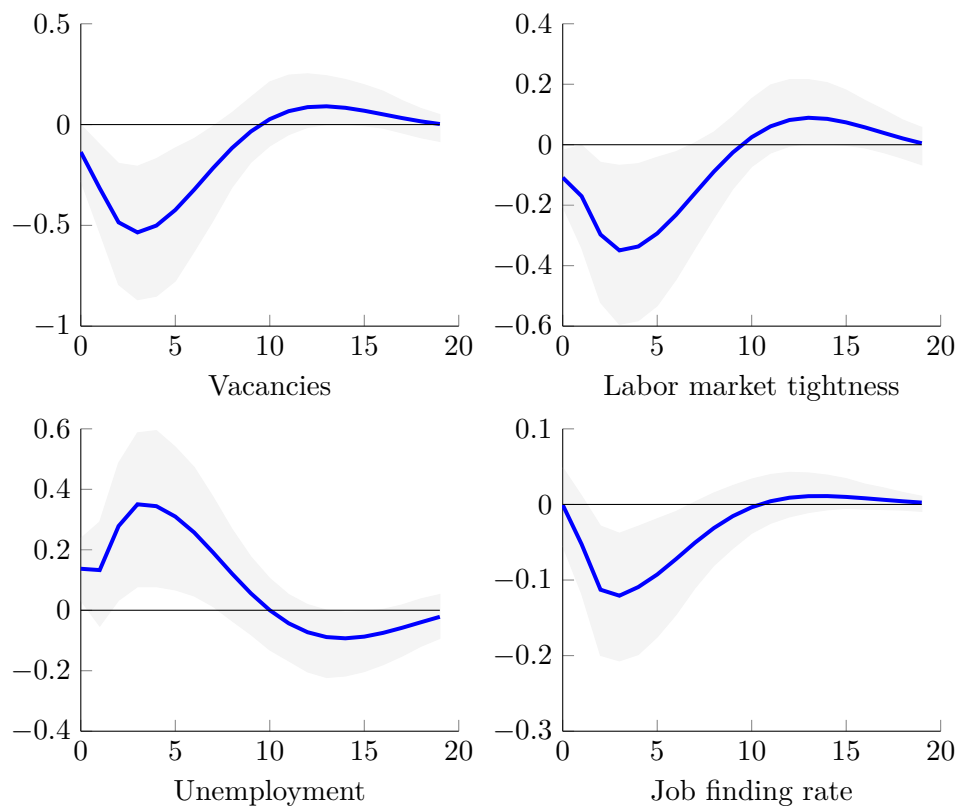


Figure 2. IRFs to 1 SD uncertainty shock. ^a

^aTrivariate VAR on United States. Series included are, in order: log(GDP) (FRED'S ID: GDPC96), the uncertainty indicator (i.e. the cross-sectional dispersion of forecasts on nominal GDP in the next quarter from the Philadelphia FED's SPF) and one labor market variable.

The variables included in each subfigure are, respectively: the log of the composite help-wanted advertising index (from the Conference Board and Regis Barnichon's website <https://sites.google.com/site/regisbarnichon/research>; the series is available up to 2014q3), labor market tightness defined as $\log(\text{hwi}) - \log(\text{unemployment})$, $\log(\text{unemployment})$ (thousands of people, from CPS, from 1968q4 to 2015q3) and the job finding rate (series constructed by Robert Shimer and downloadable from his website <https://sites.google.com/site/robertshimer/research/flows>, updated until 2007). The VAR specification with the labor market tightness and unemployment is estimated with 8 lags, whereas vacancies enter with 2 lags and the job finding rate with 4 lags. Lags are all selected according to the Akaike criterion. All variables are expressed as percentage deviations from the hp-filtered series with smoothing parameter 1600.

The figure plots the response of each macro variable ordered last to 1 SD shock to the uncertainty indicator. The shaded area represents the 95% confidence interval estimated using a bootstrap with 1000 replications.

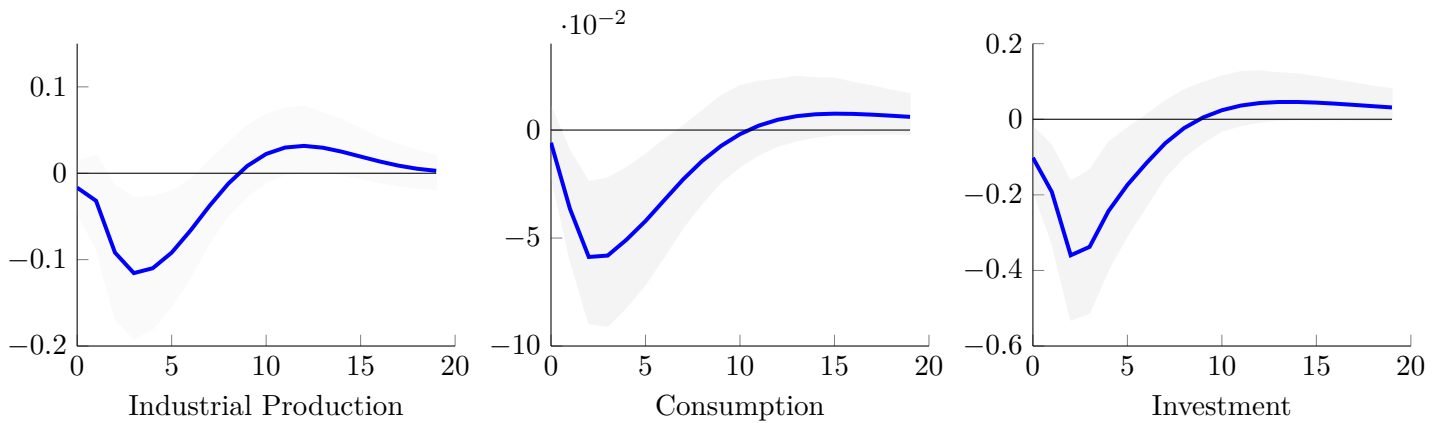


Figure 3. IRFs to 1 SD uncertainty shock in a 5 variables VAR. ^a

^aVAR on United States data from 1968q4 to 2015q3. Series included are, in order: log(GDP) (FRED'S ID: GDPC96), the uncertainty indicator (i.e. the cross-sectional dispersion of forecasts on nominal GDP in the next quarter from the Philadelphia FED's SPF), one variable proxying economic activity, log(CPI) (FRED'S ID: CPIAUCSL) and the federal funds rate (FRED'S ID: FEDFUNDS).

The variables included in each subfigure are, respectively: log(industrial production index) (FRED'S ID: INDPRO), log(real personal consumption expenditures) (FRED'S ID: PCECC96) and log(real gross private domestic investment) (FRED'S ID: GPDIC96). The VAR specifications for industrial production and consumption are estimated with 2 lags, while investment enters with three lags. Lags are selected according to the Akaike criterion. The first three variables are expressed as percentage deviations from the hp-filtered series with smoothing parameter 1600.

The figure plots the response of each macro variable to 1 SD shock to the uncertainty indicator. The shaded area represents the 95% confidence interval estimated using a bootstrap with 1000 replications.

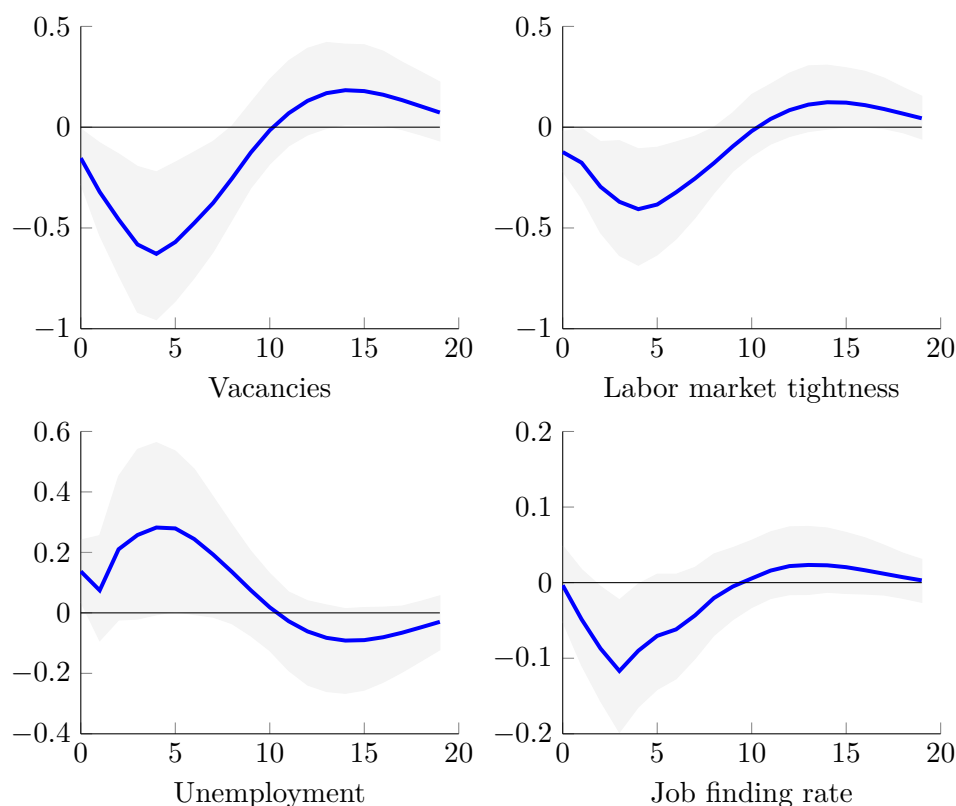


Figure 4. IRFs to 1 SD uncertainty shock in a 5 variables VAR. ^a

^aVAR on United States data. Series included are, in order: log(GDP) (FRED'S ID: GDPC96), the uncertainty indicator (i.e. the cross-sectional dispersion of forecasts on nominal GDP in the next quarter from the Philadelphia FED's SPF), one labor market variable, log(CPI) (FRED'S ID: CPIAUCSL) and the federal funds rate (FRED'S ID: FEDFUNDS).

The variables included in each subfigure are, respectively: the log of the composite help-wanted advertising index (from the Conference Board and Regis Barnichon's website <https://sites.google.com/site/regisbarnichon/research>, available up to 2014q3), labor market tightness defined as $\log(\text{hwi}) - \log(\text{unemployment})$, $\log(\text{unemployment})$ (thousands of people, from CPS, from 1968q4 to 2015q3) and the job finding rate (series constructed by Robert Shimer and downloadable from his website <https://sites.google.com/site/robertshimer/research/flows>, updated until 2007). Variables enter with two lags, selected according to the Akaike criterion. The first three variables are expressed as percentage deviations from the hp-filtered series with smoothing parameter 1600.

The figure plots the response of each macro variable to 1 SD shock to the uncertainty indicator. The shaded area represents the 95% confidence interval estimated using a bootstrap with 1000 replications.

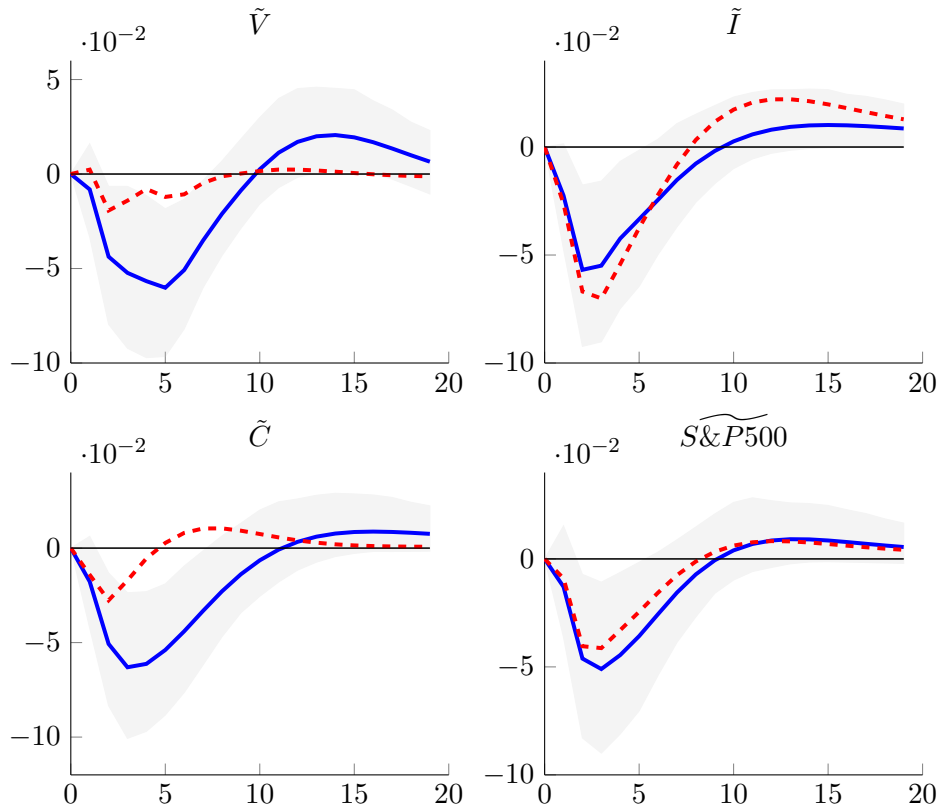


Figure 5. IRFs to 1 SD uncertainty shock, counterfactual experiments ^a

^a Each panel plots the response of GDP to 1 SD shock to the uncertainty indicator. The blue solid line is the response obtained in the full model and the shaded area represents the 95% confidence interval estimated using a bootstrap with 1000 replications. The red dashed line is the response of GDP in the counterfactual experiment where the variable indicated at the top is not allowed to respond directly to uncertainty.

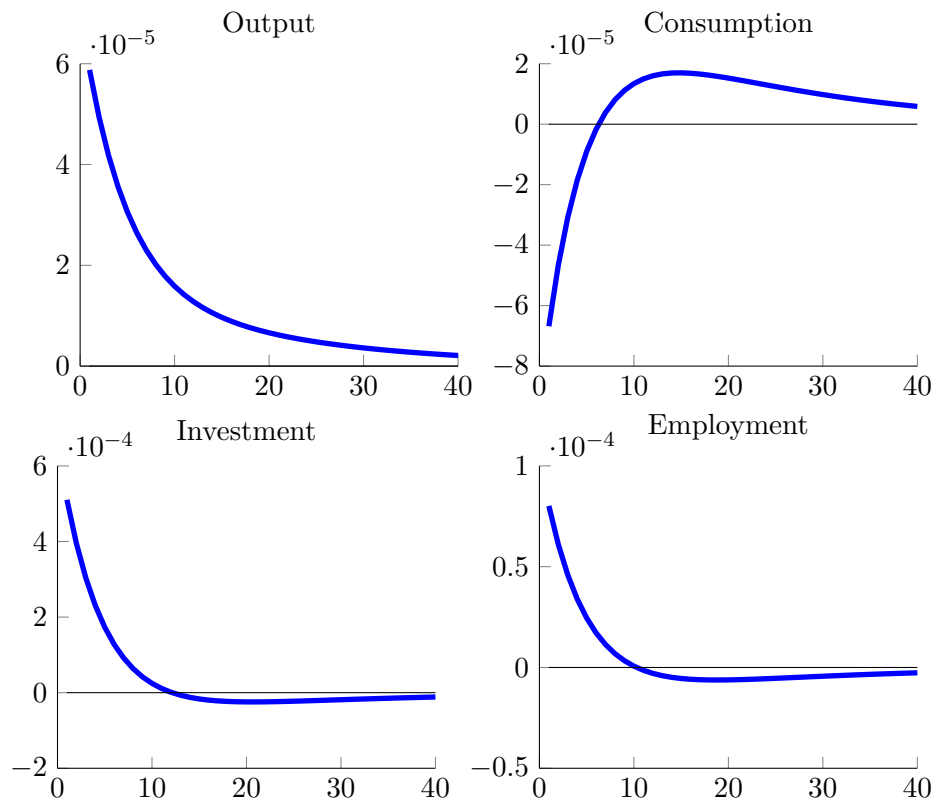


Figure 6. Competitive labor market: IRFs of GDP to a 1 SD volatility shock ^a

^aIRFs to a 1 SD deviation shock to σ^a occurred in period 0. The figure plots percentage deviations of $\log(\text{output})$, $\log(\text{consumption})$, $\log(\text{investment})$, $\log(\text{employment})$ from their stochastic steady state, as defined in the main text.

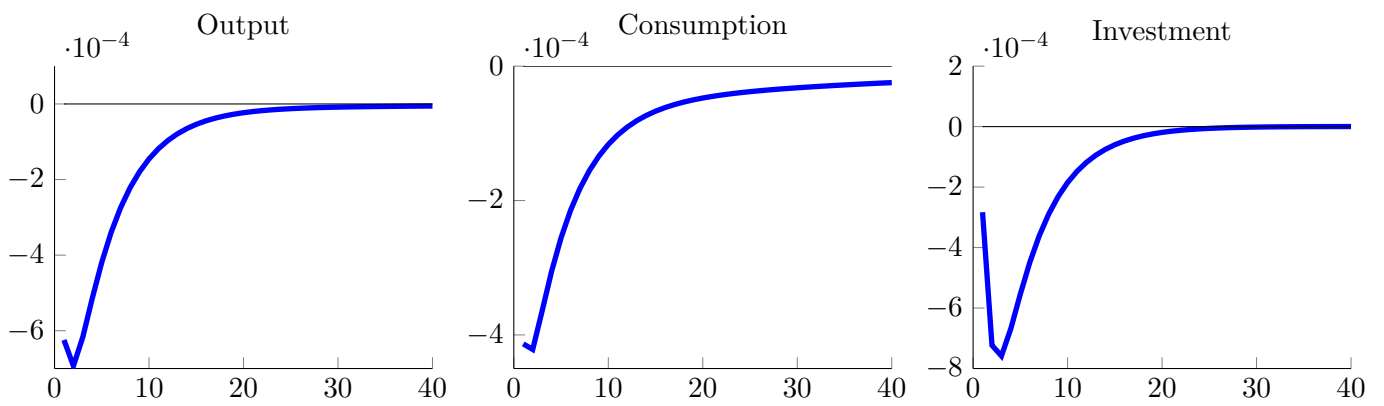


Figure 7. Search in the labor market: IRFs to a 1 SD volatility shock ^a

^aIRFs to a 1 SD deviation shock to σ^a occurred in period 0. The figure plots percentage deviations of $\log(\text{output})$, $\log(\text{consumption})$, and $\log(\text{investment})$, from their stochastic steady state, as defined in the main text.

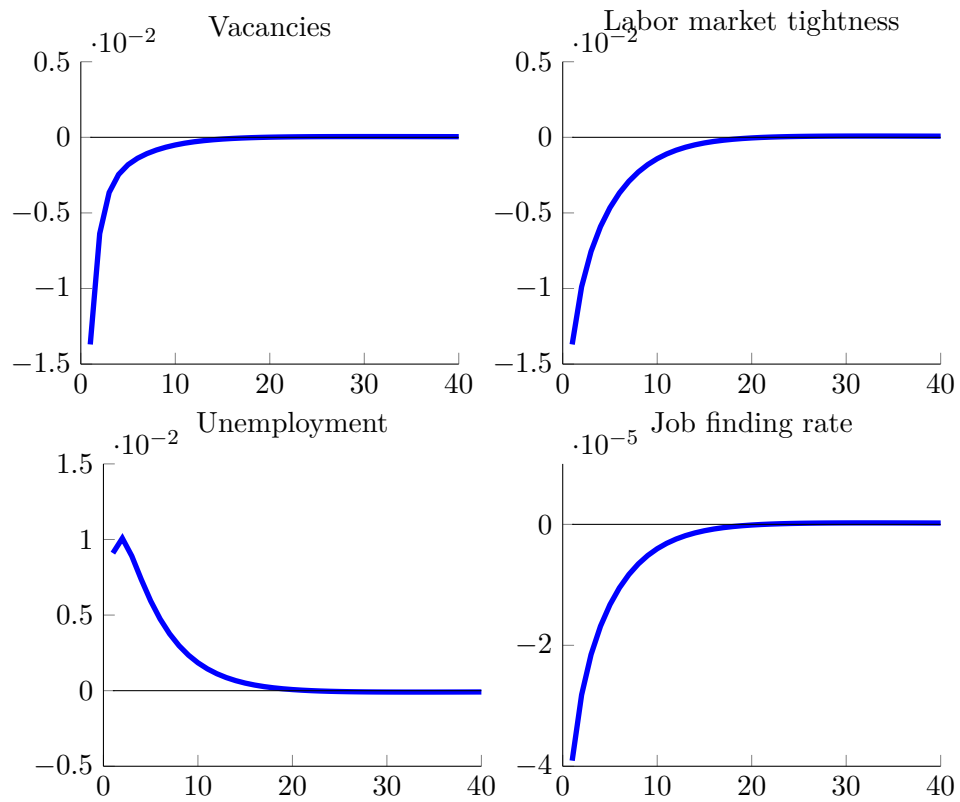


Figure 8. Search in the labor market: IRFs to a 1 SD volatility shock ^a

^aIRFs to a 1 SD deviation shock to σ^a occurred in period 0. The figure plots percentage deviations of $\log(\text{vacancies})$, $\log(\theta)$, $\log(\text{unemployment})$, and the job finding rate (q^w) from their stochastic steady state, as defined in the main text.

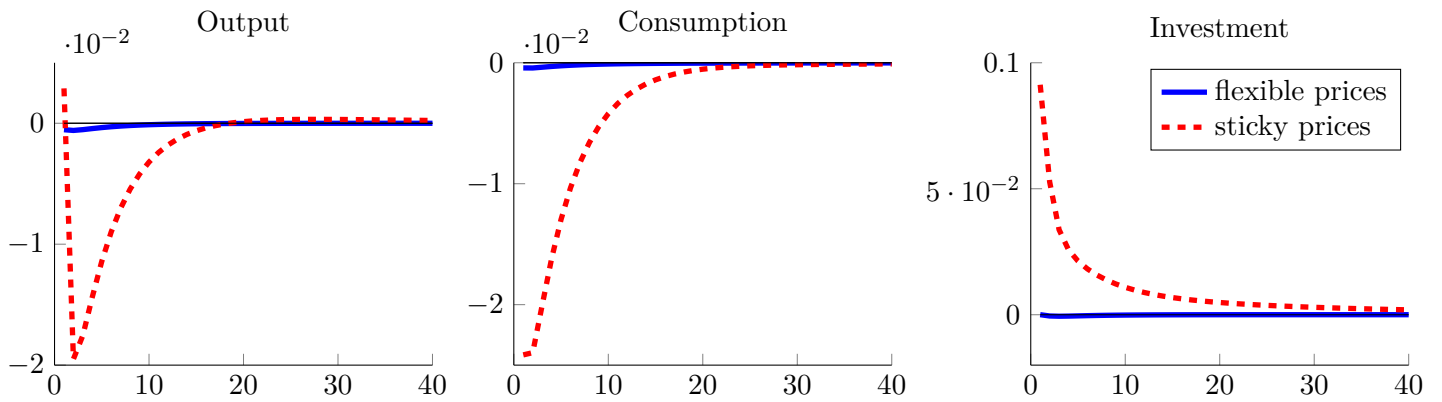


Figure 9. Flexible vs sticky prices: IRFs to a 1 SD vol. shock^a

^aThe figure plots percentage deviations of $\log(\text{output})$, $\log(\text{consumption})$, and $\log(\text{investment})$, from their stochastic steady state (as defined in the main text), for flexible and sticky prices.

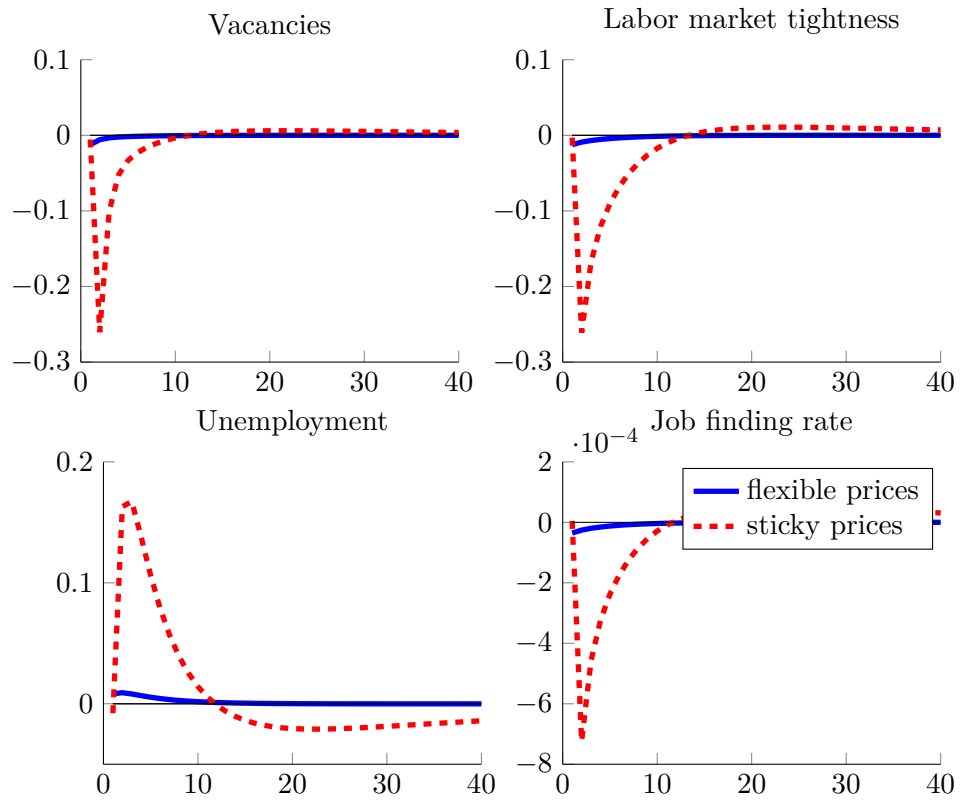


Figure 10. Flexible vs sticky prices: IRFs to a 1 SD vol. shock^a

^aIRFs to a 1 SD deviation shock to σ^a occurred in period 0. The figure plots percentage deviations of $\log(\text{vacancies})$, $\log(\theta)$, $\log(\text{unemployment})$, and the job finding rate (q^w) from their stochastic steady state (as defined in the main text), for flexible and sticky prices.

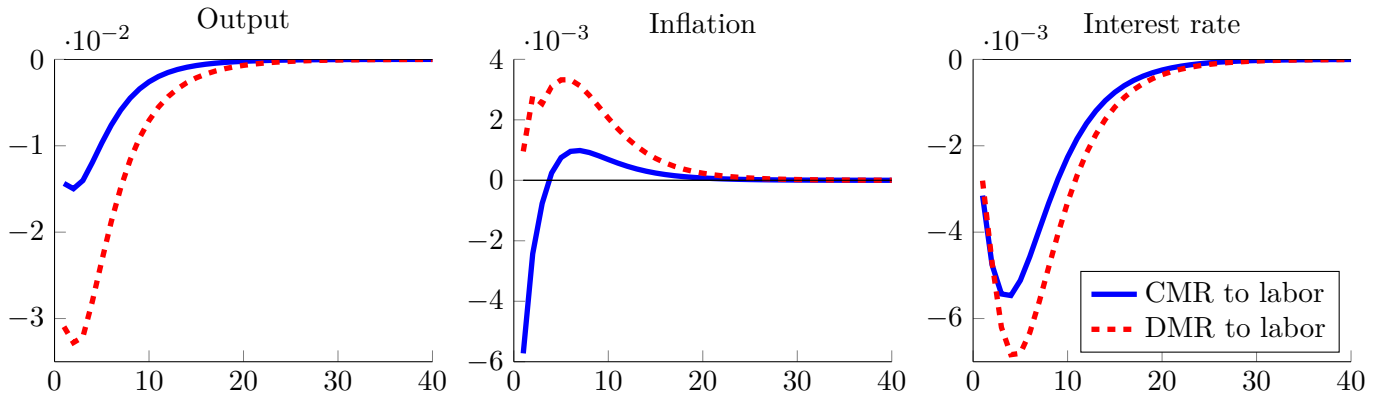


Figure 11. IRFs to a 1 SD vol. shock: model without capital and with sticky prices^a

^aIRFs to a 1 SD deviation shock to σ^a occurred in period 0. The figure plots percentage deviations of $\log(\text{output})$, inflation and the interest rate from their stochastic steady state (as defined in the main text). These IRFs are derived from a model with only labor in the production function and sticky prices.

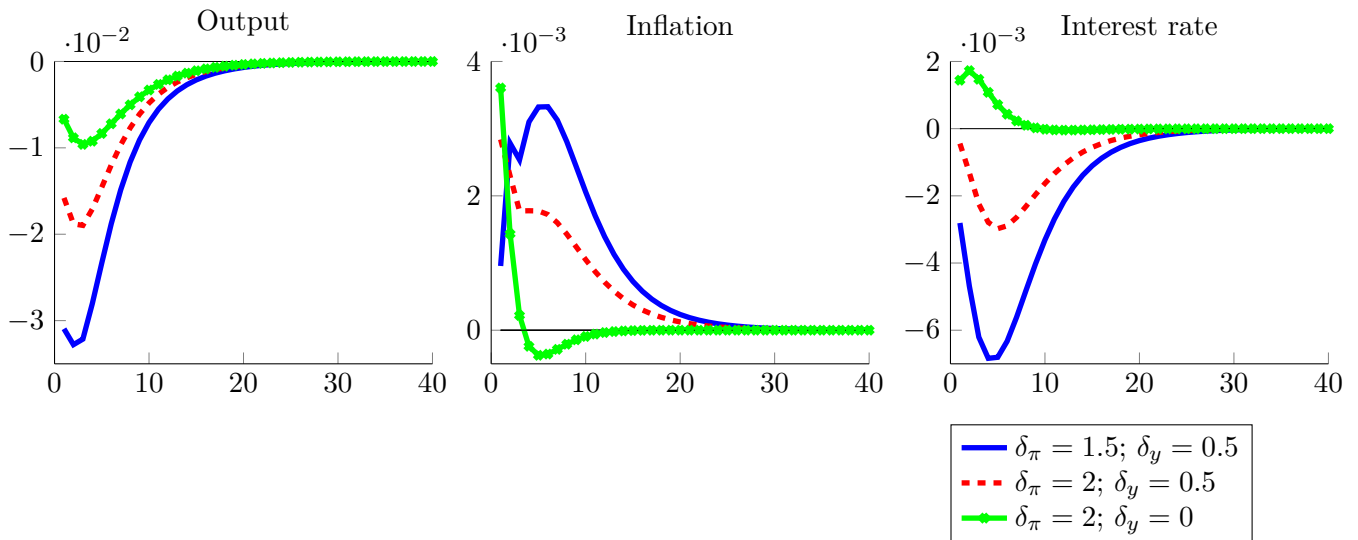


Figure 12. IRFs to a 1 SD vol. shock: model without capital and with sticky prices^a

^aIRFs to a 1 SD deviation shock to σ^a occurred in period 0. The figure plots percentage deviations of $\log(\text{output})$, inflation and the interest rate from their stochastic steady state (as defined in the main text). These IRFs are derived from a model with only labor in the production function and sticky prices.

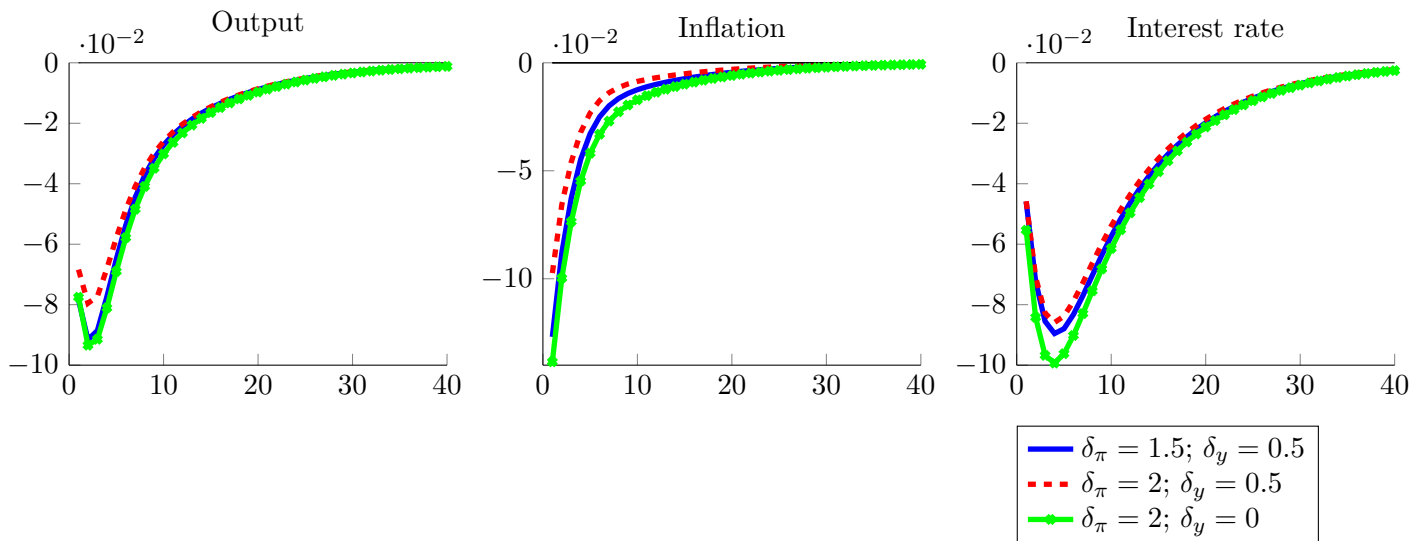


Figure 13. IRFs to a demand shock: model without capital and with sticky prices^a

^aIRFs to a 1 SD deviation shock to the households' discount factor occurred in period 0. The figure plots percentage deviations of $\log(\text{output})$, inflation and the interest rate from their stochastic steady state (as defined in the main text). These IRFs are derived from a model with only labor in the production function and sticky prices.

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