The Unemployment-Risk Channel in Business-Cycle Fluctuations*

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Abstract

We quantify the unemployment-risk channel in business-cycle fluctuations, whereby an initial contractionary shock is amplified through workers reducing their demand in fear of unemployment. We document two stylized facts on how unemployment and unemployment risk respond to identified demand and supply shocks in US data. First, separation and job-finding rates play similar important roles in accounting for the overall unemployment response. Second, separations are more important early on, while job-finding rates respond with a lag. We show how a tractable heterogeneous-agent new-Keynesian model with a frictional labor market matches both facts once we include endogenous separations and sluggish vacancy creation. Relative to a model with exogenous separations and free entry, our framework attributes almost twice as large a share of output fluctuations to the inefficient unemployment-risk channel, and thus gives a larger role to stabilization policy.

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1 Introduction

The *unemployment-risk channel* is the equilibrium feedback loop whereby an initial contractionary shock is endogenously amplified through workers reducing their demand in fear of unemployment. As captured in the minutes of an FOMC meeting in the wake of the Great Recession, "fear of unemployment could well lead to further increases in the saving rate that would dampen consumption growth in the near term".[1] Similar concerns were also expressed during the recent Covid-19 crisis.[2] Because workers do not take into account the contractionary effect of their saving decisions on the wider economy, the unemployment-risk channel leads to inefficient amplification of business cycles, and thus warrants stabilizing policy intervention. The size and design of such a policy response, however, rest on an assessment of how powerful this feedback loop is. In this paper, we provide such an assessment.

Our assessment begins with an empirical investigation of the dynamics of unemployment and unemployment risk. In traditional macroeconomic theory, with a representative household or complete markets that allow individuals to insure against idiosyncratic shocks, only aggregate household income matters for consumption decisions. Together with the average wage, the aggregate unemployment rate is thus a sufficient statistic for households' saving decisions, and one does not need to consider the underlying paths of job-finding and separation rates separately. With the realistic feature of incomplete markets and potentially binding credit constraints, this is no longer true. Separation risk and unemployment duration risk have differential impacts on the expected near-term income for employed and unemployed households, and the path of separation risk vis-à-vis unemployment-duration risk matters for the quantification of the overall demand response to fluctuations in unemployment.

Motivated by this, we document two stylized facts regarding the response of unemployment, and unemployment risk, to identified demand and supply shocks in US data: First, movements in the separation rate and the job-finding rate are of similar importance for the response of unemployment. Second, the separation rate peaks more than six months ahead of the trough of the job-finding rate. Both facts also

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[1] See https://www.federalreserve.gov/monetarypolicy/fomcminutes20090318.htm.

[2] See e.g. Furman (2020) and Powell (2020).

hold true in unconditional times-series data.

Our main result is that the importance of the unemployment-risk channel is strongly increased when we generalize a workhorse model for policy analysis to match these stylized facts.

Our model extends the Heterogenous-Agent New-Keynesian model with Search-And-Matching frictions ("HANK-SAM") in Ravn and Sterk (2021); see also Den Haan et al. (2018), McKay and Reis (2020), Challe (2020) and Gornemann et al. (2021). The HANK block of the model features heterogeneous households facing an incomplete asset market and a credit constraint, and firms facing price-adjustment costs. This block is purposefully kept simple, which allows us to derive a number of theoretical results regarding the propagation mechanism. Relative to the aforementioned papers, the two novel features of our model lie in the SAM block. Here, firms' costs of continuing a match and of creating a vacancy are idiosyncratic and stochastic, producing heterogeneity in job and vacancy values, as in Mortensen and Pissarides (1994) and Coles and Kelishomi (2018). We specify the distribution of these shocks such that both the separation rate and the vacancy entry rate have a constant and finite elasticity with respect to expected job and vacancy values, respectively. This contrasts with standard SAM setups with exogenous, i.e., fully inelastic, separations and free entry, i.e., infinitely elastic vacancy creation.

These two defining model components are necessary for matching the data. In particular, we show that the separation and entry elasticities are jointly identified from the two stylized facts we have documented. More precisely, the separation elasticity is identified by the share of the total unemployment response which separations account for in a statistical decomposition performed both in the model and in the data. The entry elasticity is identified by the delay of the response of the job-finding rate relative to the separation rate. The other parameters of the model can be calibrated using standard procedures.

We then show how endogenous separations and sluggish vacancy posting are key determinants of the strength of the unemployment-risk channel. Our estimated model with these features implies that it accounts for 35 percent of total unemployment volatility. With exogenous separations and free entry, keeping other parameters unchanged, the unemployment-risk channel accounts for less than a tenth of unemployment volatility. When re-estimating the model under exogenous separations and free entry to match the same unemployment volatility, the unemployment-risk channel accounts for about half the share in the benchmark model.

To see why endogenous separations and sluggish vacancy creation amplify the unemployment-risk channel, consider the response to a negative TFP shock. In the SAM block of the model firms initially fire more and hire less. In the HANK block the increase in unemployment risk leads to a fall in demand, which feeds back to the SAM block through lower real match profits. Lower profits, in turn, yield more firing and less hiring and the cycle is repeated, forming a multiplier process. This multiplier process implies that the total cumulative effect the demand response in the HANK block is amplified by the separation and vacancy creation responses in the SAM block. For a fixed unemployment-risk-to-demand elasticity in the HANK block, a larger demand-to-unemployment-risk elasticity in the SAM block therefore amplifies the unemployment-risk channel.

Unemployment and unemployment-risk fluctuations are amplified when separations are more sensitive to economic conditions. By contrast, more sluggish vacancy creation can either amplify or dampen unemployment fluctuations. With exogenous separations, the entry response to variations in the match product is the sole source of unemployment fluctuations. More sluggish entry thus dampens the response of unemployment. However, if separations are sufficiently responsive, which the data supports, the effect of sluggish entry is reversed. In this case, when separations sharply rise after an adverse shock, more sluggish entry implies that the resulting increase in unemployment depresses tightness, as vacancies are filled but new vacancies are not posted immediately. This vacancy-depletion effect keeps job-finding rates depressed, and thus amplifies the response of unemployment.

As mentioned, it is possible to re-estimate the model and generate the same amount of total unemployment volatility with the standard SAM setup of exogenous separations and free entry. This, however, counter-factually attributes all of the unemployment volatility to an immediate response of the job-finding rate. Moreover, this depresses the role of the unemployment-risk channel as a propagation mechanism. In our incomplete-markets model, the demand response in the HANK block is determined through the saving decisions of currently employed households. These households save to insure themselves against the risk of hitting a binding liquidity constraint in the near future. Moreover, for these households, higher separation risk has a relatively larger effect on the near-term income stream compared to unemployment duration risk. Their saving thus responds stronger to a higher separation rate than a lower job-finding rate when they affect the overall unemployment rate equally.

Apart from making the theory consistent with the stylized facts, the estimated model has a number of other attractive properties. First, both contractionary demand and supply shocks lead to a hump shaped fall in employment, in contrast to standard new-Keynesian models (Galí, 1999), but in line with the data (Ramey, 2016).[3] This is also true for completely transitory shocks, as the vacancy-depletion mechanism leads to persistently lower job-finding rates following an initial rise in separations.

Second, the model generates total unemployment volatility in accordance with the data without excessively low values of the *fundamental surplus*, or steady-state match profits, in contrast to to a broad class of search-and-matching models with free entry (Shimer, 2005; Hall, 2005; Hagedorn and Manovskii, 2008; Ljungqvist and Sargent, 2017).

Third, the model dynamics are relatively insensitive to different assumptions regarding wage flexibility. In particular, since a sizable fraction of unemployment is generated by separations of existing matches and since vacancy creation is less responsive to changes in vacancy values, we show that the estimated unemployment-risk channel is much less sensitive to fluctuations in the wages of new hires compared to standard exogenous-separations/free-entry models.

Fourth and finally, although a substantial share of recession unemployment is accounted for by a surge in separations, vacancy creation does not surge, as in typical calibrations of free-entry models with endogenous separations. The model thus produces a standard Beveridge-curve relationship.

In sum, our model attributes a large fraction of unemployment fluctuations to the inefficient unemployment-risk channel. While we do not analyze policy in this paper, this result potentially motivates a large role for stabilizing policy interventions, both in response to demand and supply shocks. Because the unemployment-risk channel is due to the interaction between separation decisions made in the labor market, and consumption decisions made by the households, these interventions encompass both traditional monetary and fiscal transfer policy as well as labor-market policies.

[3] Complementary to our focus on cyclical fluctuations in income risk, Guerrieri et al. (2021) show that a HANK model with multiple sectors and acyclical income risk can also generate demand-driven recessions from contractionary supply shocks.

Also using HANK-SAM models, McKay and Reis (2020) and Dengler and Gehrke (2021) show, respectively, that unemployment insurance and match-saving firm subsidies can be used to stabilize demand-driven fluctuations. Optimal policy, however, is not trivial, as our model also has externalities stemming from the vacancy posting and separation decisions, even with fully flexible prices. We regard policy analysis in this class of models as a key area for future research.

After a brief literature review, the rest of the paper is structured as follows. In Section 2, we present our two stylized facts. In Section 3, we outline the model. In Section 4, we characterize and discuss the model propagation mechanism. In Section 5, we show how the stylized facts identify the separation and vacancy creation elasticities in the model, and discuss other calibration choices. In Section 6, we present our results on the importance of endogenous separations and sluggish vacancy creation for quantifying the unemployment-risk channel. Section 7 shows that the model results are largely insensitive to more flexible wages for new hires. Section 8 concludes.

Related literature. On top of the already cited HANK-SAM papers, our paper is related to a number of different strands of the literature. First, the importance of fluctuations in the separation rate for unemployment fluctuations in unconditional time-series data is discussed extensively in Fujita and Ramey (2009) and Shimer (2012). Elsby et al. (2009), Barnichon (2012) and Elsby et al. (2015) argue that separations are more important when unemployment starts to increase from a low point or begin to fall from a peak. Mueller (2017) shows that the separation rate of high-wage earners is particularly highly counter-cyclical. We add to this literature by providing new evidence on the response of separations to identified demand and supply shocks.

Second, the study of sluggish vacancy creation goes back to at least to Fujita and Ramey (2005). Several recent papers have explored related aspects of labor-market dynamics under the lens of finitely elastic vacancy creation, and also provided other micro-foundations. See, e.g., Leduc and Liu (2020), Haefke and Reiter (2020), Mercan et al. (2021), Engbom (2021) and Den Haan et al. (2021). We add to this literature both in terms of providing new evidence from identified demand and supply shocks, where we show that the delay between the peak of the separation rate and the trough of the job-finding rate identifies the entry elasticity in our model, as well as by analyzing the implications of sluggish vacancy creation for business-cycle dynamics in a model with both incomplete markets and pricing frictions, thus having an unemployment-risk channel.

Third, our paper, together with the aforementioned HANK-SAM papers, builds a bridge between two existing new-Keynesian literatures which respectively either have heterogenous agents but no search-and-matching frictions (see, e.g., Oh and Reis, 2012; McKay and Reis, 2016; Guerrieri and Lorenzoni, 2017; Bayer et al., 2019; Hagedorn et al., 2019; Auclert et al., 2020b; Luetticke, 2021),[4] or search-and-matching frictions but a representative agent (see, e.g., Walsh, 2005; Krause and Lubik, 2007; Gertler et al., 2008; Trigari, 2009; Gertler and Trigari, 2009; Galí, 2010; Ravenna and Walsh, 2012; Christiano et al., 2016, 2021). In a real business cycle model, Den Haan et al. (2000) also stressed the importance of endogenous separations for business-cycle fluctuations, but through an interaction with capital adjustment costs rather than household saving decisions as in our paper.

2 Two stylized facts about unemployment risk

Unemployment, and unemployment risk, rise when either more employed workers lose their jobs or when fewer unemployed workers find new ones. In this section, we document the relative importance of these two drivers of unemployment fluctuations in the US economy. We document two stylized facts: First, fluctuations in the separation and job-finding rates on average account for similar shares of unemployment fluctuations. Second, their relative importance changes over the cycle: fluctuations in separations are more important earlier, while the job-finding rate accounts for a higher share later. In other words, fluctuations in the separation rate lead the job-finding rate. We show how these stylized facts hold both in response to identified monetary policy ("demand") shocks and TFP ("supply") shocks, as well as in unconditional time-series data.

[4] A closely connected literature has explored counter-cyclical income and unemployment risk as a driver of aggregate demand, see, e.g., Challe and Ragot (2016), McKay (2017) and Harmenberg and Öberg (2020).

2.1 Data

Labor-market flows. Our labor-market flow data is constructed using the Current Population Survey (CPS) micro data following the methodology in Shimer (2012). It spans 1967-06 to 2019-12.[5] The monthly transition probabilities are derived from observed flows and seasonally adjusted. To account for time aggregation, we retrieve the transition probabilities from estimating a three-state continuous-time model, where workers are either employed (E), unemployed (U) or inactive (I), i.e., out of the labor force. The monthly job-finding probability (the "EU probability") is calculated as the probability of at least one transition from unemployment to employment conditional on not transitioning out of the labor force. The separation probability (the "UE probability") is calculated in a similar manner. Although both are discrete-time probabilities and not continuous-time rates, from here one we refer to them as the job-separation rate and the job-finding rate respectively. Details are in Appendix A.

In Figure 1, we display the evolution of the unemployment rate alongside the estimated time series for the job-finding and the separation rate. The time series are filtered using a Christiano and Fitzgerald (2003) band-pass filter where features below a periodicity of 12 months are filtered out.[6]

Shock series. We use the Romer and Romer (2004)'s monthly series of monetary policy shocks, identified using a narrative method, extended by Miranda-Agrippino and Ricco (2021). As a measure of shocks to total factor productivity (TFP), we use the first difference of the quarterly TFP series in Fernald (2014), which is adjusted for variation in capacity utilization.

Other time series. The other time series we use are standard and retrieved from the Federal Reserve Economic Data.

[5] The data from 1967-06 to 1975-12 were tabulated by Joe Ritter and made available by Hoyt Bleakley.

[6] In the literature documenting fluctuations in the job-separation rate and the job-finding rate, there has been some discussion concerning the appropriate choice of filtering method, see Fujita and Ramey (2009) and Shimer (2012). As we show in Appendix A, a Hodrick-Prescott filter tends to attribute a large share of the Great Recession to the trend rather than the cycle component, and also does not filter out erratic short-term movements in the unemployment rate. Using a Hodrick-Prescott filter, however, only strengthens the facts we emphasize in this section.

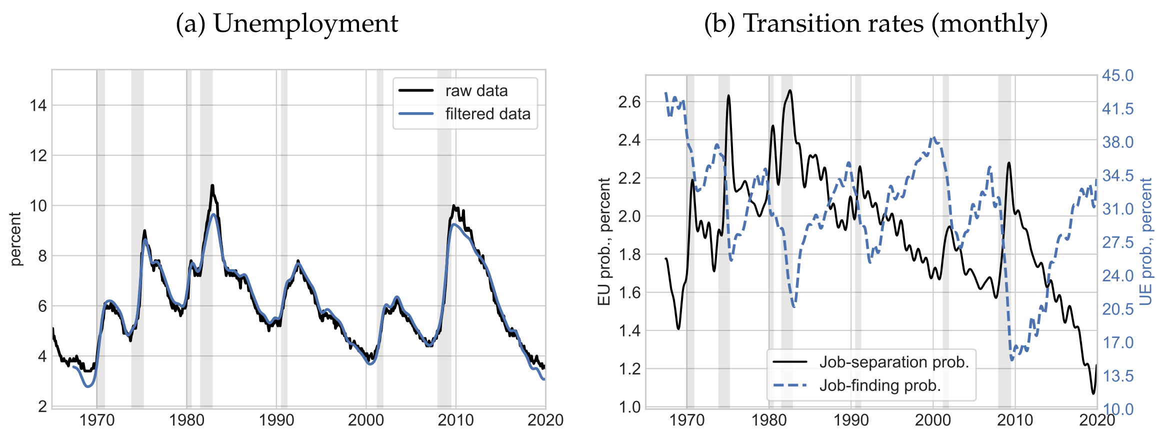


Figure 1: Unemployment and labor-market transition probabilities.

2.2 Impulse responses to identified shocks

We compute impulse responses for the labor-market transitions using a smoothened version of the local projection method from Jordà (2005) introduced by Barnichon and Brownlees (2019).[7] For a generic outcome Y_t, we estimate

$$Y_{t+h} = \alpha_h^Y \nu_t + \beta_h^Y X_t + \epsilon_t^Y, \tag{1}$$

separately for horizons $h \in \{0, 1, ..., T\}$, where ν_t is the shock series, X_t is a set of controls, and ϵ_t^Y is an error term. We set the smoothing parameter to $\lambda = 10^4$.

Our specifications of Equation (1) follows Ramey (2016). For the analysis of monetary policy shocks, the controls include the contemporaneous value and two lags of log industrial production, the unemployment rate and the log of consumer and commodity prices. We also include two lags of the nominal interest rate and the monetary shock series.[8] In the case of TFP shocks, we include as controls two lags of the shock (to account for serial correlation in the shock series), log real GDP per capita, log real stock prices per capita, log labor productivity (equal to real GDP divided by total hours worked), and the dependent variable. The estimation period

[7] Plagborg-Møller and Wolf (2021) show that local projection and VARs estimate the same impulses responses when the lag structure is unrestricted. Li et al. (2021) show in a large Monte Carlo study that smoothing is beneficial in terms of lower variance for a moderate increase in bias.

[8] For commodity prices we use the CRB Commodity Price Index as in Coibion (2012).

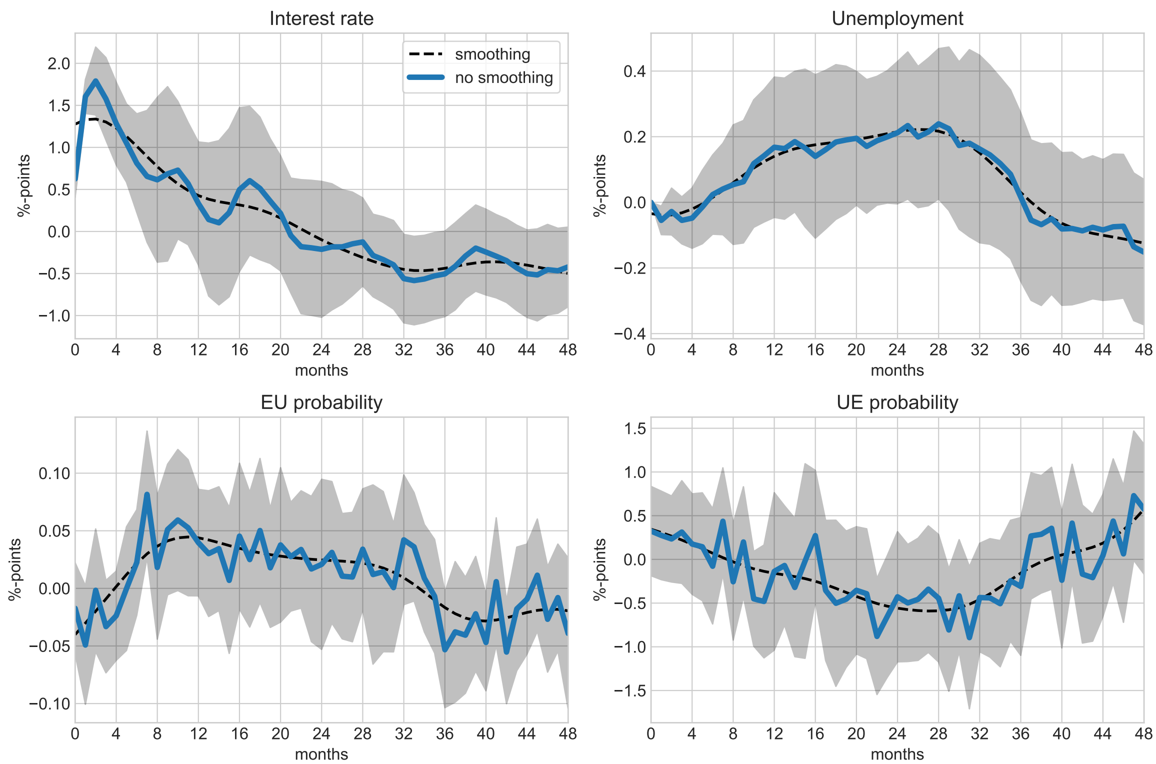


Figure 2: Responses to a monetary policy shock.

is 1969-01 to 2007-12 for the responses to monetary policy shocks and 1967Q4 to 2015Q4 for the TFP shocks. We compute standard errors using a Newey and West (1987) correction for autocorrelation, and report 90 percent confidence intervals. The presented impulse responses are normalized so that a monetary policy shock (TFP shock) generates an increase (decrease) in the nominal interest rate (TFP) of one percent on average over the first year.

In Figure 2, we display the estimated responses of unemployment, the job-separation (EU) rate, and the job-finding (UE) rate, as well as the nominal interest rate, in response to a contractionary monetary policy shock. The monetary shock generates an increase in unemployment, an increase in job-separation rate and a decrease in the job-finding rate.

In Figure 3, we display the estimated responses of unemployment, the job-separation rate, the job-finding rate, as well as of TFP, to a negative TFP shock. The negative productivity shock generates an increase in unemployment, an increase in job-separation rate and a decrease in the job-finding rate.

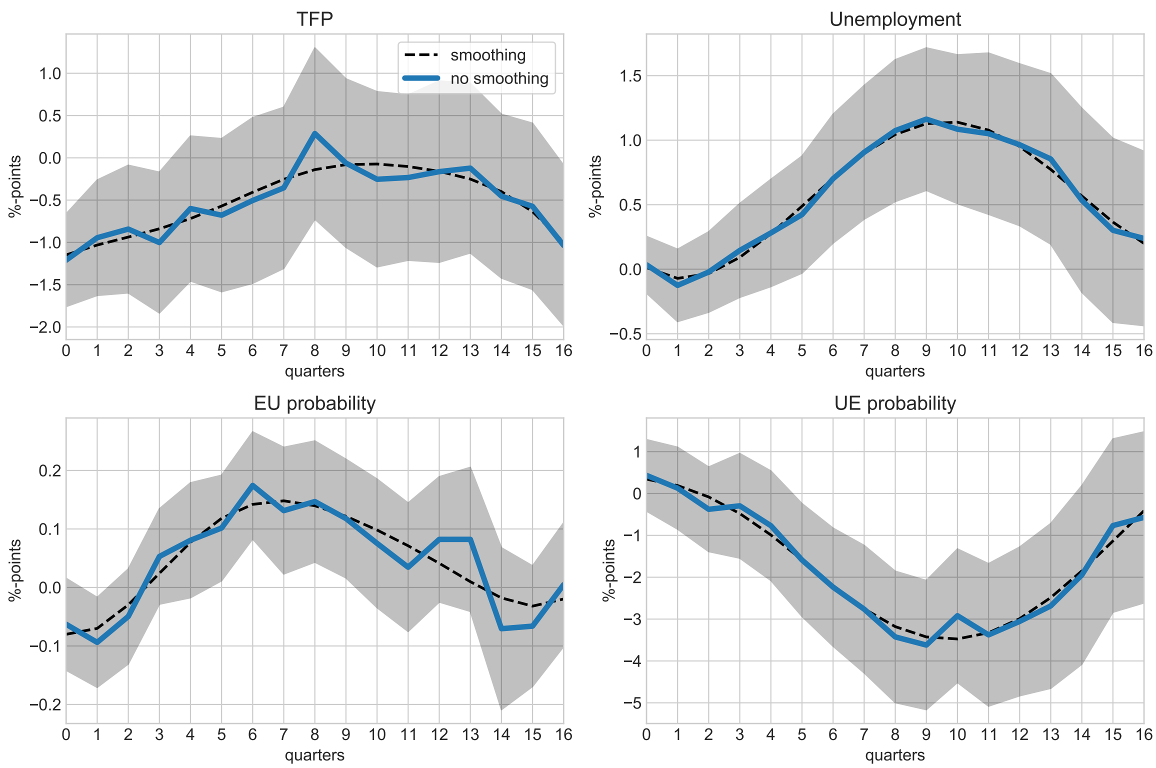


Figure 3: Responses to a TFP shock.

2.3 Stylized facts

Fact 1: Separations account for a significant share of unemployment fluctuations. In order to quantify the importance of changes in the separation rate and job-finding rate to fluctuations in unemployment, we use the static decomposition proposed by Shimer (2012). We calculate the steady-state unemployment rate implied by current probabilities of separation (EU_t) and job finding (UE_t) rate using the formula $u_t^{ss} = \frac{EU_t}{EU_t+UE_t}$, which, given the high value of the US job-finding rate, approximates actual unemployment very well. We approximate the share of fluctuations in the unemployment rate stemming from movements in the job-separation rate as $\frac{EU_t}{EU_t+UE^{ss}}$, thus holding the job-finding rate constant at its average value. Correspondingly, the variation in the unemployment rate stemming from movements in the job-finding rate equals $\frac{EU^{ss}}{EU^{ss}+UE_t}$.

Figure 4 shows the evolution of the steady-state unemployment rate and the respective contributions of the labor-market flows. Panel (a) uses the unconditional time series data. Here, the variation in the job-separation rate contributes 32 percent and the variation in the job-finding rate contributes 66 percent, respectively (because of the non-linearity in the definition of the steady-state unemployment rate, the contributions do not exactly sum to 100 percent). In panel (b), we show the evolution of the same variables in response to a monetary policy shock. Here, the job-separation rate contributes 59 percent and the job-finding rate contributes 43 percent. Finally, in panel (c), we show the evolution of the steady-state unemployment rate and the respective contributions in response to a productivity shock. The job-separation rate contributes 45 percent and the job-finding rate contributes 58 percent. We conclude a broad pattern: Movements in the job-separation rate accounts for a substantial share of fluctuations in the unemployment rate.

Fact 2: The separation rate leads the job-finding rate. Figure 5 illustrates the lead-lag relationship between the job-separation rate and the job-finding rate in the data. In panel (a), we show the correlation structure of the unconditional time series of the job-separation rate and the job-finding rate. The correlation peaks when the job-finding rate lags the job-separation rate by 6 months. In panel (b), we show the smoothened impulse responses to a monetary policy shock. Separations peak after 11 months while the trough for the job-finding rate occurs after 27 months, implying that the job-separation rate leads the job-finding rate by 16 months in response to a

(a) Unconditional data (b) Monetary policy shock (c) TFP shock

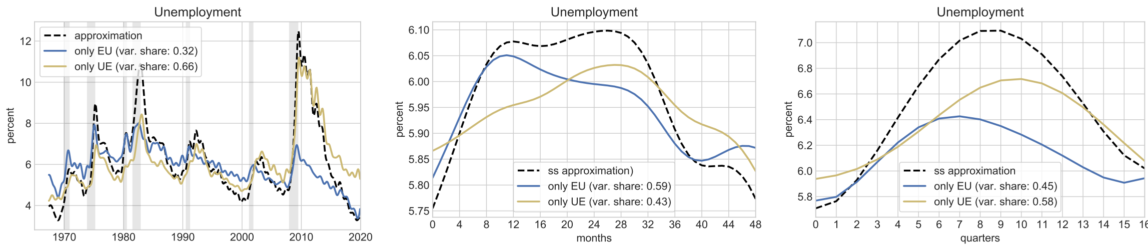


Figure 4: Variance decomposition of unemployment.

(a) Unconditional data (b) Monetary policy shock (c) TFP shock

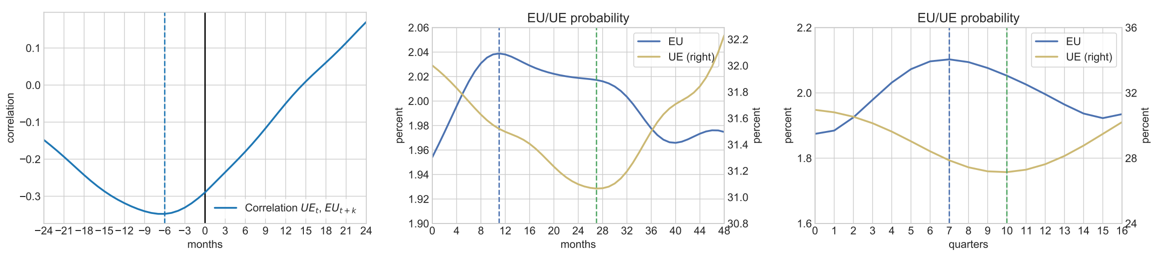


Figure 5: The job-separation (EU) rate leads the job-finding (UE) rate.

monetary policy shock. In panel (c), we show the smoothened impulse responses to a TFP shock. Separations peak after 7 quarters while the trough for the job-finding rate occurs after 10 quarters, implying that the job-separation rate leads the job-finding rate by 9 months in response to a productivity shock. Again, we conclude that there is a broad pattern: Movements in the job-separation rate significantly lead movements in the job-finding rate.

In sum, we have documented two stylized facts: First, fluctuations in the separation rate accounts for a sizable share of unemployment fluctuations, ranging between 32 and 59 percent across the different settings. Second, the relative importance of separations changes over the cycle: fluctuations in separations are more important earlier, while those in the job-finding rate account for a higher share later, with the separation rate leading the job-finding rate by between 6 and 16 months. These two facts hold true both in unconditional time series data and in response to identified monetary policy and TFP shocks. These two facts will discipline our business-cycle model, presented next.[9]

3 Model

In this section, we present an equilibrium model that captures the stylized facts about unemployment dynamics we documented in Section 3, and can be used to quantify the importance of the unemployment-risk channel for business cycle fluctuations.

We build on Ravn and Sterk (2021)'s framework that combines labor-market frictions and nominal frictions.[10] The demand side is purposefully kept simple and analytically tractable. Markets are incomplete: households can save but not borrow in a risk-free bond which is in zero net supply.[11] In consequence, higher unemployment risk increases savings and reduces the demand for goods. On the supply side, firms employ workers in a Diamond-Mortensen-Pissarides frictional labor market, and sell their output in a standard new-Keynesian environment with monopolistic competition and price-setting frictions. In this framework, a fall in the demand for goods reduces the value of a filled job thus making both existing and new matches less valuable. Firms are therefore more likely to fire existing workers, and less likely to post vacancies, which implies less hiring. The framework thus contains a reinforcing feedback loop from unemployment risk to, first, the demand for goods, and then the demand for labor, and therefore back to unemployment risk. We label this feedback loop the *unemployment-risk channel*.

Relative to previous studies of Heterogenous Agent New Keyenesian models with a Search-And-Match labor market (HANK-SAM models) , the distinguishing feature of our model is the combination of endogenous rather than exogenous separations and sluggish vacancy creation rather than free entry. In Section 5 we show how these

[9] Complementary to this paper, Oh and Picco (2020) show that the same pattern holds also for identified macro uncertainty shocks.

[10] See also Den Haan et al. (2018), McKay and Reis (2020), Challe (2020) and Gornemann et al. (2021).

[11] The combination of no borrowing and zero supply of liquidity allows an analytical aggregation that makes the equilibrium dynamics particularly transparent and easy to compute. These convenience assumptions were used in the context of asset pricing by Krusell et al. (2011) and has been used extensively in the HANK literature since, see, e.g., Werning (2015); McKay and Reis (2020); Broer et al. (2020); Bilbiie (2019, 2021); Ravn and Sterk (2021). Acharya and Dogra (2020) use CARA utility to retain analytical tractability with positive liquidity.

two elements are necessary to match the stylized facts of unemployment dynamics documented in Section 2, and in Section 6 we show that they are crucial when quantifying the importance of the unemployment-risk channel.

3.1 Overview

The economy consists of infinitely-lived workers indexed by $i \in [0,1]$, and infinitely-lived capitalists indexed by $i \in (1, 1 + \text{pop}_c]$,with $\text{pop}_c \ll 1$. The workers have CRRA preferences with discount factor β and risk aversion σ. The capitalists are risk neutral with discount factor β and own all firms. Production has three layers:

1. Intermediate-good producers hire labor in a frictional labor market with search and matching frictions. Matches produce a homogeneous good sold in a perfectly competitive market.

2. Wholesale firms buy intermediate goods and produce differentiated goods that they sell in a market with monopolistic competition. The wholesale firms set their prices subject to a Rotemberg adjustment cost.

3. Final-good firms buy goods from wholesale firms and bundle them in a final good, which is sold in a perfectly competitive market.

We first describe the within-period timing in the model, then the determination of vacancy posting and job separations in the frictional labor market, then the price-setting mechanism in the wholesale and final goods market, and finally the households' consumption-saving decisions.

3.2 Timing and labor-market dynamics

Step 0: Stocks and productivity. At the beginning of each period t, all aggregate shocks are revealed. The endogenous state variables are the (beginning-of-period) stocks of unemployed workers u_{t-1} and of vacancies v_{t-1}.

Step 1: Separations and entry. Firms are exposed to an idiosyncratic continuation cost shock. After observing the shock they decide whether to continue or exit, which implies an endogenous, time-varying separation rate δ_t in a manner that we describe below. Vacancies are destroyed with rate δ_{ss}, which for simplicity we assume to be constant and exogenous, and have the same value as the steady state separation rate. Firm-specific costs of entering the labor market are realized. Firms that pay the cost post a new vacancy. The endogenous, time-varying vacancy entry rate is denoted ι_t. The resulting stocks of unemployment and vacancies are given by

$$\tilde{u}_t = (1 - \delta_t)u_{t-1}, \tag{2}$$

$$\tilde{v}_t = (1 - \delta_{ss})v_{t-1} + \iota_t. \tag{3}$$

Step 2: Search and match. Unemployed workers and vacancies randomly match. The matching technology is Cobb-Douglas with matching elasticity α. Denoting market tightness by

$$\theta_t = \frac{\tilde{v}_t}{\tilde{u}_t}, \tag{4}$$

the job-filling rate λ_t^v and job-finding rate λ_t^u are

$$\lambda_t^v = A\theta_t^{-\alpha}, \tag{5}$$

$$\lambda_t^u = A\theta_t^{1-\alpha}. \tag{6}$$

The labor-market stocks after matches are formed are

$$u_t = (1 - \lambda_t^u)\tilde{u}_t, \tag{7}$$

$$v_t = (1 - \lambda_t^v)\tilde{v}_t. \tag{8}$$

Step 3: Production. Production takes place. Dividends and wages are paid.

Step 4: Consumption and saving. All capitalists and workers, both employed and unemployed, make their consumption-and-saving decisions.

3.3 Intermediate-good firms, vacancy creation and job separations

There is a continuum of intermediate-good firms producing a homogeneous good X_t sold in a competitive market, owned by the capitalists. The real price of the intermediate good is P_t^x and one unit of labor produces Z_t units of the intermediate good.

The total production of intermediate goods is thus given by

$$X_t = Z_t(1 - u_t), \tag{9}$$

where the log of total factor productivity Z_t is subject to AR(1)-innovations ν_t^Z,

$$Z_t = Z_{ss}\nu_t^Z, \tag{10}$$
$$\log \nu_t^Z = \rho_A \log \nu_{t-1}^Z + \epsilon_t^Z, \tag{11}$$

where σ_Z is the standard deviation of ϵ_t^Z.

To hire labor the firms must post vacancies which are filled with probability λ_t^v, taken as given by each one-worker firm. We denote by V_t^v the value of a vacancy and by V_t^j the value of a match for the firm.

Separations. At the beginning of the period, a firm must pay a continuation cost $\chi_t \sim G$ or else the job match is destroyed.[12] There is no additional heterogeneity and consequently there exists a common cost cutoff $\chi_{c,t} = V_t^j$, such that for all $\chi_t > \chi_{c,t}$, the firm chooses to separate. Accordingly, the Bellman equation for the value of a job after the separation decision is

$$\begin{aligned} V_t^j &= P_t^X Z_t - W_t + \beta \mathbb{E}_t \left[\int^{\chi_{c,t+1}} (V_{t+1}^j - \chi_{t+1}) dG(\chi_{t+1}) \right] \\ &= M_t + \beta \mathbb{E}_t \left[(1 - \delta_{t+1}) V_{t+1}^j - \mu_{t+1} \right], \end{aligned} \tag{12}$$

where W_t is the real wage, δ_{t+1} is the endogenous separation probability given by $\delta_{t+1} = \int_{V_t^j}^{\infty} G(\chi_t) d(\chi_t)$, μ_{t+1} is the average cost paid, and $M_t = P_t^X Z_t - W_t$ is the gross fundamental surplus, following the terminology in Ljungqvist and Sargent (2017). In steady state we call $\tilde{M}_{ss} = M_{ss} - \beta\mu_{ss}$ the (net) fundamental surplus. Similarly, $m_t = (P_t^X Z_t - W_t)/(P_{ss}^X Z_{ss})$ and $\tilde{m}_{ss} = \tilde{M}_{ss}/(P_{ss}^X Z_{ss})$ are the gross and (net) fundamental surplus *ratios*.

The continuation-cost distribution G is a mixture of a point mass and a Pareto distri-

[12] Following Mortensen and Pissarides (1994), separation decisions are typically modeled as a result of idiosyncratic productivity shocks, such that low-productivity firms optimally decide to exit. Our simplified assumptions have similar material consequences, but avoid ex-post heterogeneity in firm outcomes.

bution with shape parameter ψ, location parameter Υ and mixture parameter p. We choose p and Υ so that in steady state, job separations are δ_{ss} and the continuation costs are approximately zero, $\mu_{ss} \approx 0$. See Appendix B for details. Out of steady state, the endogenous separation probability δ_t are then given by

$$\delta_t \quad = \quad \delta_{ss} \left(\frac{V_t^j}{V_{ss}^j} \right)^{-\psi}, \tag{13}$$

and the average continuation cost, μ_t, is a non-negative increasing function of the job value

$$\mu_t = \mu(V_t^j), \;\; \mu(\bullet) \geq 0, \mu'(\bullet) \geq 0. \tag{14}$$

The idiosyncratic continuation cost implies that the elasticity of job separations to the value of a job is ψ. In the special case where $\psi = 0$ separations occur exogenously at rate δ_{ss}.

Vacancy creation. The Bellman equation for the value of a vacancy is given by

$$V_t^v = -\kappa + \lambda_t^v V_t^j + (1 - \lambda_t^v)(1 - \delta_{ss})\beta \mathbb{E}_t[V_{t+1}^v], \tag{15}$$

where κ is the flow cost of the vacancy, to be paid every period. Vacancies are not subject to the stochastic continuation cost, and are instead destroyed with exogenous probability δ_{ss}. In contrast to the standard assumption of free entry to vacancy creation, we assume that there is a constant mass F of prospective firms drawing a stochastic idiosyncratic entry cost c following a distribution H. The prospective firm posts a vacancy if and only if the value of a vacancy is larger than the entry cost. The total number of vacancies created is therefore $\iota_t = F \cdot H(V_t^v)$. Following Coles and Kelishomi (2018), the entry-cost distribution has a cumulative distribution function $H(c) = F \cdot (c/h)^{\xi}$ on $c \in [0, h]$. With the parameter h sufficiently large so that $h > V_t^v$, the resulting number of vacancies created is $\iota_t = F \cdot (V_t^v)^{\xi}$. Expressing vacancy creation in relation to steady state gives us

$$\iota_t = \iota_{ss} \left(\frac{V_t^v}{V_{ss}^v} \right)^{\xi}. \tag{16}$$

The stochastic-cost entry assumption implies that the elasticity of vacancy creation to the value of a vacancy is ξ. In the limit where $\xi \to \infty$, we must have $V_t^v = V_{ss}^v$

so that all entrants pay the same deterministic entry cost. We set $V^v_{ss} = \kappa_0$ and treat κ_0 as a free parameter. The free entry model is the double limit $\xi \to \infty$ and $\kappa_0 \to 0$, which implies $V^v_t = 0$. To facilitate comparisons with the free entry model we fix κ at a small positive value across all calibrations, $\kappa_0 = 0.1$. In Appendix E we show that changing κ_0 and ξ with the same factor leaves our results unaffected.

Wage setting. With search frictions, an additional condition is required to determine how the resulting match surplus is divided. In the baseline model, we follow Hall (2005) and assume that real wages are fixed

$$W_t = W_{ss}. \tag{17}$$

A recent body of research has documented that downward nominal wage rigidity is pervasive in the US labor market (Dupraz et al., 2021; Grigsby et al., 2021; Hazell and Taska, 2020). A fixed real wage is therefore likely a weak assumption in the context of studying contractionary shocks, as it implies more wage flexibility than a fully rigid nominal wage with pro-cyclical inflation. As we show in Section 4, inflation is pro-cyclical both in response to demand and supply shocks in our model.

There is a body of research suggesting that wages for new hires might be more flexible than that for incumbent employees. In Section 7, we show that the combined assumptions of endogenous separations and sluggish vacancy creation implies that business-cycle dynamics in our model are only weakly affected by incorporating fluctuations in the wages of new hires.

3.4 The final-good sector and the wholesale sector

The representative final-good firm has the production function $Y_t = \left(\int_k Y_{kt}^{\frac{\epsilon_p - 1}{\epsilon_p}} dk \right)^{\frac{\epsilon_p}{\epsilon_p - 1}}$ where Y_{kt} is the quantity of the input of wholesale firm k's output used in production. The implied demand curve is $Y_{kt} = \left(\frac{P_{kt}}{P_t} \right)^{-\epsilon_p} Y_t$ where $P_t = \left(\int_k P_{kt}^{1-\epsilon_p} dk \right)^{\frac{1}{1-\epsilon_p}}$ is the aggregate price level. There is a continuum of wholesale firms indexed by $k \in [0, 1]$ producing differentiated goods using the production function $Y_{kt} = X_{kt}$ where X_{kt} is the amount of the intermediate good purchased by firm k at the intermediate-good price P^X_t. The wholesale firms face Rotemberg price adjustment costs, with scale factor ϕ. Since production is linear, the marginal cost of production is the input price P_t^X. In a symmetric equilibrium, optimal price setting implies a standard Rotemberg Phillips curve

$$1 - \epsilon_p + \epsilon_p \cdot P_t^X = \phi(\Pi_t - 1)\Pi_t - \beta\phi\mathbb{E}_t\left[(\Pi_{t+1} - \Pi_{ss})\Pi_{t+1}\frac{Y_{t+1}}{Y_t}\right], \tag{18}$$

where $\Pi_t = \frac{P_t}{P_{t-1}}$ is the gross inflation rate. Total output given by

$$Y_t = X_t D_t = (1 - u_t) Z_t D_t, \tag{19}$$

where $D_t = \int_k \left(\frac{P_{kt}}{P_t}\right)^{\epsilon_p} di$ is a measure of price dispersion.

3.5 Households

Households are of two types: workers and capitalists. Capitalists can buy and sell shares in an equity fund that owns all firms, but do not participate in the labor market.[13] Workers receive wage income W_t if employed and home production income ϑ if unemployed, but cannot buy and sell equity. All households can save in a zero-coupon one-period nominal bond, in zero net supply, which can be purchased at the price $1/(1+i_t)$, where i_t is the nominal interest rate, and face a no-borrowing constraint.

Because of zero net supply of liquidity and no borrowing, the equilibrium interest rate clears the bond market only if all households decide not to save, and the borrowing constraint must bind for all but one type of household.[14] The model therefore admits analytical aggregation. Specifically, as in Ravn and Sterk (2021), under the assumption that aggregate shocks are small, the presence of idiosyncratic unemployment risk always gives the employed workers the strongest motive to save, and

[13] The assumption that workers but not capitalists participate in the labor market can be rationalized by means of a fixed labor-market participation cost, see Broer et al. (2020).

[14] Formally, any real interest rate low enough such that all three Euler equations are satisfied with weak inequality is consistent with the zero-borrowing limit. The natural interpretation is however to let liquidity approach zero, as in Krusell et al. (2011), then the real interest rate is such that one of the Euler equations holds with equality.

in equilibrium, the interest rate must be consistent with their Euler equation,

$$C_{n,t}^{-\sigma} = \beta_t \mathbb{E}_t \left[\frac{1+i_t}{\Pi_{t+1}} \left\{ (1-\text{URISK}_t) C_{n,t+1}^{-\sigma} + \text{URISK}_t C_{u,t+1}^{-\sigma} \right\} \right],$$

where $C_{n,t}$ is the consumption of the employed, $C_{u,t}$ is the consumption of the unemployed, and $\text{URISK}_t = \delta_{t+1}(1-\lambda_{t+1}^u)$ is the probability that an employed household is unemployed in the next period. β_t is the workers' discount factor, which we assume is subject to mean-one AR(1)-innovations ν_t^β,

$$\beta_t = \beta \nu_t^\beta, \tag{20}$$

$$\log \nu_t^\beta = \rho_\beta \log \nu_{t-1}^\beta + \epsilon_t^\beta, \tag{21}$$

where σ_β is the standard deviation of ϵ_t^β. Up to a first-order approximation, a positive shock to the discount factor is isomorphic to a positive shock to the monetary policy rule.

The no-borrowing constraint implies that all households consume their income in equilibrium. Together with the Euler equation for the employed households, this gives us the following asset-market clearing condition,

$$W_t^{-\sigma} = \beta_t \mathbb{E}_t \left[\frac{1+i_t}{\Pi_{t+1}} \left\{ (1-\text{URISK}_t) W_{t+1}^{-\sigma} + \text{URISK}_t \vartheta^{-\sigma} \right\} \right]. \tag{22}$$

In Appendix B, we formally specify the consumption problems of the capitalists and workers, and derive Equation (22). Higher unemployment risk results both in lower expected income (the first moment of the stochastic income process) and higher income uncertainty (the higher moments) for the household. The unemployment-risk channel includes both these effects.

3.6 Government

A government sets monetary policy according to the following Taylor rule,

$$1 + i_t = (1 + i_{ss}) \Pi_t^{\phi_\pi - 1} \mathbb{E}_t[\Pi_{t+1}]. \tag{23}$$

All our numerical results are robust to using a standard Taylor rule which only responds to current inflation, but the chosen rule allow us to prove a number of analytical results on the propagation mechanism in Section (4). Appendix Figure C.1 shows that the impulse-responses are close to identical when the Taylor rule instead is $1 + i_t = (1 + i_{ss})\Pi_t^{\phi_\pi}$.

3.7 Solution algorithm

Equations (2)-(23) describe a closed system of 22 equations in 22 unknows. In the background, there are equations describing the evolution of profits and consumption of the capitalist, which are determined as residuals from the goods-market clearing condition.

We solve for the non-linear transition path following unexpected MIT shocks to the household discount factor, β_t, (a "demand" shock) and TFP, Z_t, (a "supply shock"). In practice, the system is close to linear for small aggregate shocks, meaning the transition paths we compute form very good approximate solutions to the full rational-expectations equilibrium (Boppart et al., 2018; Auclert et al., 2020a).

4 The propagation mechanism

We now investigate the mechanism through which exogenous shocks propagate through the model, and in particular the feedback loop generated by the unemployment-risk channel. In Section 6, we quantitatively investigate this channel.

Figure 6 shows the impulse responses to a contractionary shock to either supply (TFP, Z_t) or to demand (the discount factor of the workers, β_t), using the estimated parameters discussed in Section 5. We begin analyzing the TFP shock.

To guide the analysis of the propagation mechanism, consider the diagram in Figure 7, which shows the interaction between the key equilibrium variables. The model is composed of a *HANK block* (left-hand side) and a *SAM block* (right-hand side). The two blocks communicate through two variables: unemployment risk, URISK_t and the labor revenue product $P_t^x Z_t$, which in turn consists of *exogenous* TFP and the *endogenous* intermediate goods price. We now follow the unidirectional arrows through the diagram to describe the propagation mechanism.[15]

[15] Formally, each "arrow" just represents an equation linking the path of one variable to the other, and the choice of direction is therefore arbitrary, and here only made in terms of interpretation.

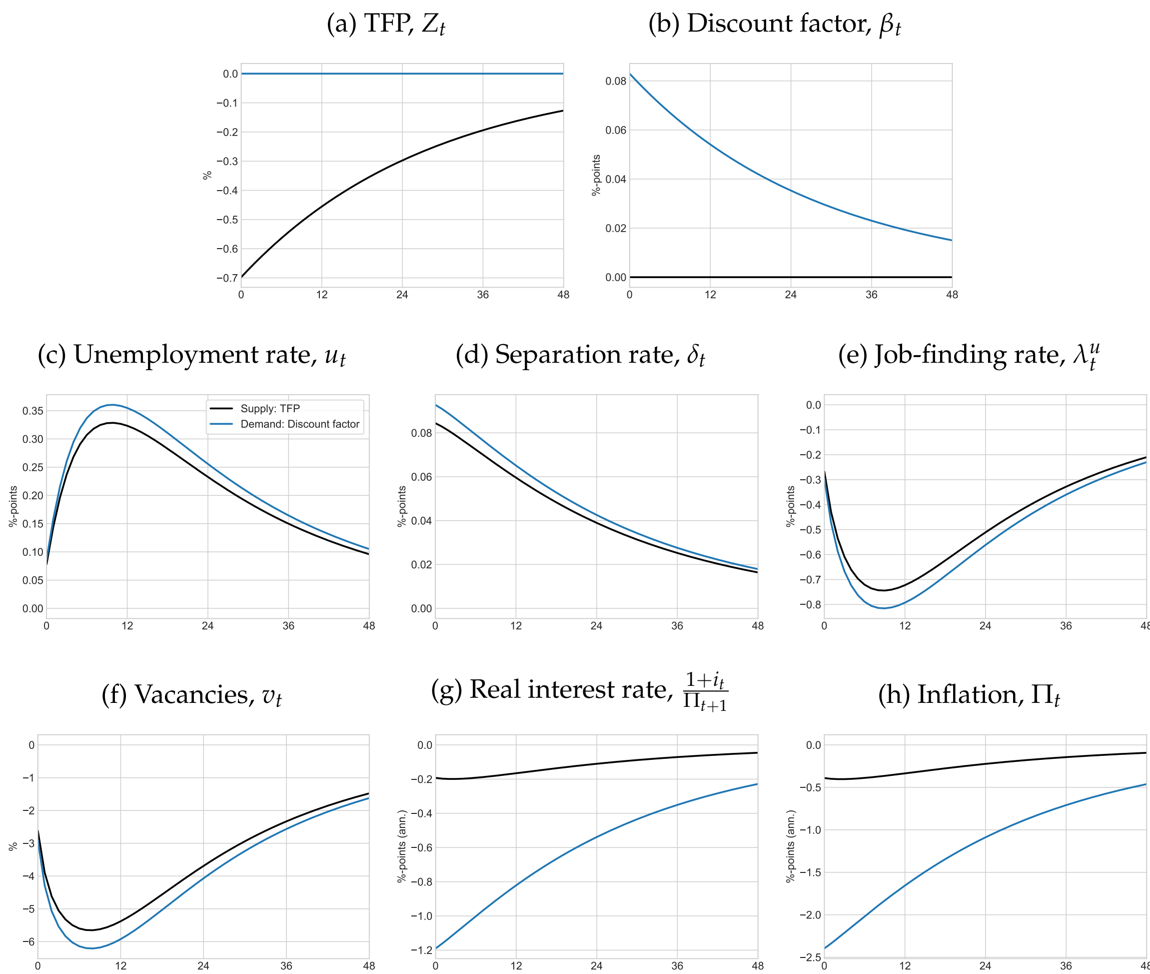


Figure 6: Impulse-responses to 1-std. supply and demand shocks.

Notes: This figure shows the impulse responses to both a 1-std. TFP-shock and a 1-std. discount factor shock (with $\rho_\beta = 0.965$ and $\sigma_\beta = 1.01^{\frac{1}{12}} - 1.0$). All other parameters are set as in Table 1.

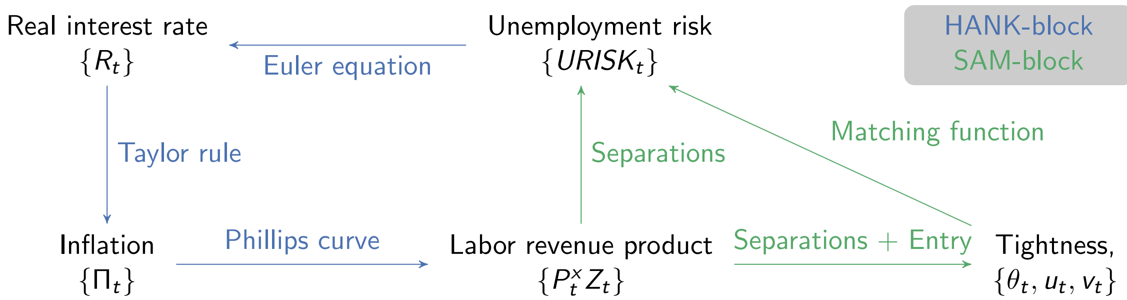


Figure 7: Graphical representation of the model equations.

Starting in the SAM block, a reduction in TFP implies a lower net present value of match surpluses and therefore a spike in separations and a decline in entry. The increase in separations raises unemployment risk directly. The increase in separations, alongside the fall in entry, also leads to a decline in tightness, which leads to a decline in the job-finding rate through the matching function, further raising unemployment risk. In a model with infinitely elastic vacancy creation (as in the standard free-entry model), the effect of separations on tightness would be undone by a corresponding increase in entry. With finitely elastic vacancy creation, the offsetting entry effect is only partial, such that the newly separated households instead deplete the current vacancy stock, causing a persistent hump-shaped decline in tightness and the job-finding rate, as seen in Figure 6.[16] The muted response of vacancy creation also implies that the vacancy stock is pro-cyclical, consistent with the notion of a Beveridge curve.

In the HANK block, an increase in unemployment risk causes desired savings to increase and goods demand to fall. To clear the asset market, the real interest rate must fall, as seen from Equation (22). To be consistent with the monetary policy rule (23), a path of lower real interest rates must be accompanied with a path of lower inflation rates. The Phillips curve (18) stipulates that a path of lower inflation rates must be accompanied by a path of lower real marginal cost, which in our setup equals the intermediate goods price.[17] A path of lower intermediate goods prices

[16] To get a hump shape in separations, a model with more "bells and whistles" such as habit formation or sticky expectations is needed, see, e.g., Auclert et al. (2020b).

[17] In the Phillips curve (18), the growth path of output also enters and affects the determination of the intermediate goods price, but this effect is zero up to a first order approximation and quantitatively unimportant for our results.

lowers the net present value of match surpluses, which sets in motion an additional cycle of separations and decline in entry.

Because the two blocks only interact through unemployment risk and labor revenue product, at a high level a log-linear approximation of the model can be summarized by two infinite-dimensional matrices. First, the SAM block yields a linear mapping M_{SAM} from the path of (log-linearized) labor revenue product $\boldsymbol{p^x} + \mathbf{z} = [p^x_{0,} p^x_1, p^x_2, \ldots]' + [z_0, z_1, z_2, \ldots]'$ to the path of (log-linearized) unemployment risk $\boldsymbol{urisk} = [urisk_0, urisk_{1,}, urisk_2, \ldots]'$,

$$\boldsymbol{urisk} = M_{\mathrm{SAM}}(\boldsymbol{p^x} + \mathbf{z}). \tag{24}$$

Second, the HANK block yields a linear mapping M_{HANK} from the path of unemployment risk $\boldsymbol{urisk}$ to the path of the intermediate-goods price $\boldsymbol{p^x}$,

$$\boldsymbol{p^x} = M_{\mathrm{HANK}}\boldsymbol{urisk}. \tag{25}$$

This leads to Proposition 1.

Proposition 1. *Give an exogenous path of productivity the path of the labor revenue product solves*

$$\boldsymbol{p^x} + \mathbf{z} = (I - M_{HANK} M_{SAM})^{-1}\mathbf{z}. \tag{26}$$

Proof. See Appendix C. □

The geometric sum $(I - M_{\mathrm{HANK}} M_{\mathrm{SAM}})^{-1}$ in Equation (26) represents an intertemporal multiplier which amplifies the business cycle in response to the exogenous shock. The size of the multiplier depends both on the HANK block, as summarized by M_{HANK}, and on the SAM block, as summarized by M_{SAM}. The size of this multiplier in our model relative to a complete-markets version of the same model (where the real interest rate only responds to fluctuations in aggregate unemployment rate) is what we label the *unemployment-risk channel.*

Under flexible prices, $M_{\mathrm{HANK}} = 0$ and the multiplier is zero. With sticky prices, the multiplier $(I - M_{\mathrm{HANK}} M_{\mathrm{SAM}})^{-1}$ captures the repeated propagation through both blocks. In Figure 8, we unpack this multiplier process by solving the model iteratively in response to a TFP shock, again using our preferred calibration, explained

(a) Intermediary goods price, P_x^t (b) Unemployment risk, $URISK_t$ (c) Unemployment, u_t

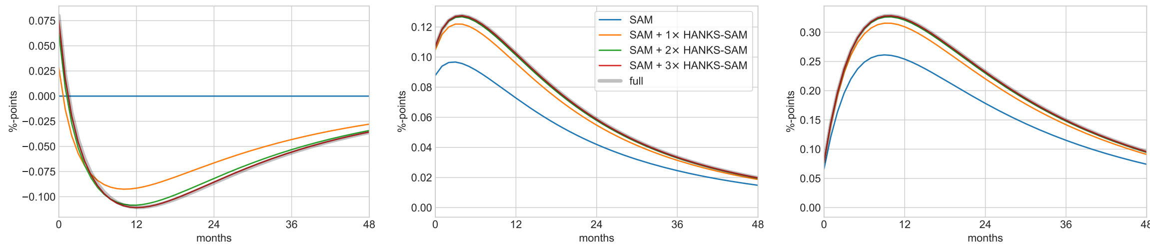


Figure 8: Multiplier process from 1-std. TFP.

Notes: This figure shows the multiplier process leading to the full impulse-response to a 1 std. TFP-shock. All parameters are set as in Table 1.

in Section 5. Initially we keep the intermediary goods price fixed, P_t^X, and solve the model equations of the SAM block. This implies a path for unemployment risk, $URISK_t$. Next, we solve the equations of the HANK block given this path, which implies a new path for the intermediary goods price, P_t^X. We then repeat this process until the input and output intermediary goods price paths coincide.

In Proposition 2, we furthermore explicitly summarize the whole HANK block M_{HANK} and show that the parameters of the HANK block are all captured by one single sufficient statistic.

Proposition 2. *Equation (25) is explicitly described by*

$$p_t^x \quad = \quad -\Omega(urisk_t - \beta \mathbb{E}_t urisk_{t+1}), \tag{27}$$

where

$$\Omega = \frac{\underbrace{\frac{\text{URISK}_{ss} \times \left(\left(\frac{W_{ss}}{\vartheta}\right)^{\sigma} - 1\right)}{1 + \text{URISK}_{ss} \times \left(\left(\frac{W_{ss}}{\vartheta}\right)^{\sigma} - 1\right)}}_{\text{fear of unemployment}}}{\underbrace{(\epsilon^p - 1)\phi^{-1}}_{\text{pricing frictions}} \underbrace{(\phi_\pi - 1)}_{\text{monetary policy}}}. \tag{28}$$

Proof. See Appendix C. □

The sufficient statistic Ω encapsulates the fear of unemployment for households (combining the risk-aversion parameter, the drop in consumption upon unemployment, and the unemployment risk), the conduct of monetary policy, and the pricing frictions. Changing anyone of these parameters has the same effect on the labor-market dynamics.

Finally, we arrive at the following result:th

Proposition 3. *The impulse responses for labor-market variables to a shock to TFP (supply) and to the discount factor of workers (demand) are equivalent up to a scaling factor.*

Proof. See Appendix C. □

This result is confirmed numerically in Figure 6. The fact that the dynamics of unemployment risk behave similarly in response to both supply and demand shocks in our model is reassuring. In the data, the dynamics of unemployment risk looked similar both in response to identified supply and demand shocks. This contrasts with textbook representative-agent versions of the new-Keynesian model. In such settings, negative TFP shocks typically lead to an increase in hours worked, see, e.g., Galí (1999).

5 Identification of the separation and entry elasticities from unemployment dynamics

The distinguishing feature of our framework relative to previous studies is the combination of endogenous separations and sluggish vacancy creation. In this section, we show how the strength of these two mechanisms are identified by the stylized facts on unemployment dynamics we documented in Section 2. Specifically, the separation elasticity, ψ, can be inferred from the share of the unemployment variance explained by separations in the static decomposition used in Section 2. The entry elasticity, ξ, can be inferred from the time difference between the peak of the separation rate and the trough of the job-finding rate in response to a shock. The rest of the calibration is standard and explained in following subsection.

5.1 Calibration

In a first step, we set a number of parameters to typical values found in the literature. These parameters are shown in panel A of Table 1. From Section 4 we know that all of the parameters of the HANK block (σ, ϑ, ϵ_p, ϕ and ϕ_π) in the linear solution only matter through composite parameter Ω in Equation (28). One is, however, worth highlighting: the level of home production ϑ. This parameter directly controls the consumption cost of becoming unemployed, since there is no saving in equilibrium, and therefore also the desire to save in response to increased unemployment risk. We calibrate this parameter to match the estimated consumption drop upon unemployment found in micro data. Gruber (1997) find a 6.8 percent consumption drop upon unemployment using the PSID, Browning and Crossley (2001) find a 14 percent consumption in Canadian survey data and Kolsrud et al. (2018) find a consumption drop between 4.4-9.1 percent in Swedish register data. We target a 10 percent consumption drop in the middle of these estimates and set ϑ to be 90 percent of the wage level. We show that our results are robust to changing the choice of each of these parameter in Appendix E.

In addition, the model contains a number of scale parameters in the matching function and idiosyncratic cost functions. We choose these to satisfy three steady state targets for the separation rate, the job-finding rate, and tightness. The targeted values are shown in Panel B of Table 1. Details are given in Appendix D.

5.2 Estimation of separation and entry elasticities

In the standard model with exogenous job destruction, separations have no role in explaining the dynamics of unemployment, in contrast to our first stylized fact. In models with endogenous separations but free entry to vacancy creation, which implies an infinite entry elasticity, the peak in the separation rate and the trough in the job-finding rate coincide, in contrast to our second fact. To see this, combine Equation (5), (6), (13) and (15) with the free entry condition, $V_t^v = 0$, which implies that the separation rate, δ_t, is simply a monotonic function of the contemporaneous job-finding rate,

$$\delta_t = \delta_{ss} \left(\frac{A(\lambda_t^u / A)^{\frac{-\alpha}{1-\alpha}} / \kappa}{V_{ss}^j} \right)^{-\psi}.$$

To proceed in practice, we must take a stand on the underlying shock process ultimately driving unemployment. For simplicity, we assume a standard monthly TFP process with persistence $\rho_A = 0.965$ and standard deviation, $\sigma_A = 0.007$, see, e.g.,

Parameter	Value	Source
	Panel A: Externally calibrated	
Discount factor, β	$0.96^{1/12}$	Standard
CRRA coefficient, σ	2	Standard
Home production, ϑ	$0.90 \cdot W_{ss}$	See text
Substitution elasticity, ϵ_p	6	Standard
Rotemberg cost, ϕ	600.0	Standard
Taylor rule parameter, ϕ_π	1.5	Standard
Matching function elasticity, α	0.6	Petrongolo and Pissarides (2001)
	Panel B: Steady state targets	
Separation rate, δ_{ss}	0.027	Data
Job-finding rate, λ^u_{ss}	0.31	Data
Tightness, θ_{ss}	0.6	Hagedorn and Manovskii (2008)
	Panel C: TFP process	
Persistence, ρ_Z	0.965	Coles and Kelishomi (2018)
Standard deviation, σ_Z	0.007	
	Panel D: Internally calibrated parameters	
Separation elasticity, ψ	1.000	See Figure 10
Entry elasticity, ξ	0.050	See Figure 10
Fundamental surplus ratio, $\tilde{m}_{ss}$	0.128	See Figure 10

Table 1: Calibration.

Coles and Kelishomi (2018). In the data, the dynamics of unemployment risk looked similar both in response to identified supply and demand shocks. In our model, the responses of the labor market variables to a demand shock are identical to those to a TFP shock, as we saw in Section 4.

We seek to match three central moments for unemployment dynamics. Because our ultimate aim is to quantify the importance of unemployment risk, we target, first, the standard deviation of the unconditional unemployment time series used in Section 2, which equals 2.65 percent. Second, we target that movements in the separation rate account for 40 percent of the unemployment variance. Finally, we target a relative delay of the peak response of the job-finding rate of 9 months. The two latter targets approximately correspond to the average estimates found in response to the shocks reported in Section 2.

To match these moments, we adjust the separation elasticity, ψ, the entry elasticity, ξ, and the fundamental surplus ratio in steady state, $\tilde{m}_{ss}$. Panel I in Figure 9 shows that the separation elasticity, ψ, mainly scales the magnitude of the impulse responses with a particularly large effect on the separation rate. Panel II shows that the entry elasticity hardly affects the separation rates, but a lowered entry elasticity implies larger and more persistent fluctuations in unemployment, through a more pronounced and delayed hump in the job-finding rate. In panel III, we see that the fundamental surplus ratio, $\tilde{m}$, affects all impulse responses proportionally. As discussed in Ljungqvist and Sargent (2017), for a broad class of SAM models, the steady-state level of the fundamental surplus ratio is a key determinant of unemployment volatility since a lower fundamental surplus ratio increases the elasticity of match profits with respect to labor productivity, and therefore also increases the response of separations and vacancy creation to changes in labor productivity. A given surplus ratio pins down the steady state wage, W_{ss}. It also determines the value of the flow vacancy cost, κ, because the fundamental surplus ratio determines the value of a job, which implies the flow vacancy cost must be adjusted to meet the target value of vacancy values in steady state, κ_0. Details are in Appendix D.

In Figure 10, we illustrate how the parameter values are identified. Each dot in the different graphs represents a model for which the fundamental surplus ratio has been set to match overall unemployment volatility. The horizontal lines show the targeted moment values, and the vertical lines the chosen parameter values in our preferred calibration. The canonical free entry model with exogenous separations is

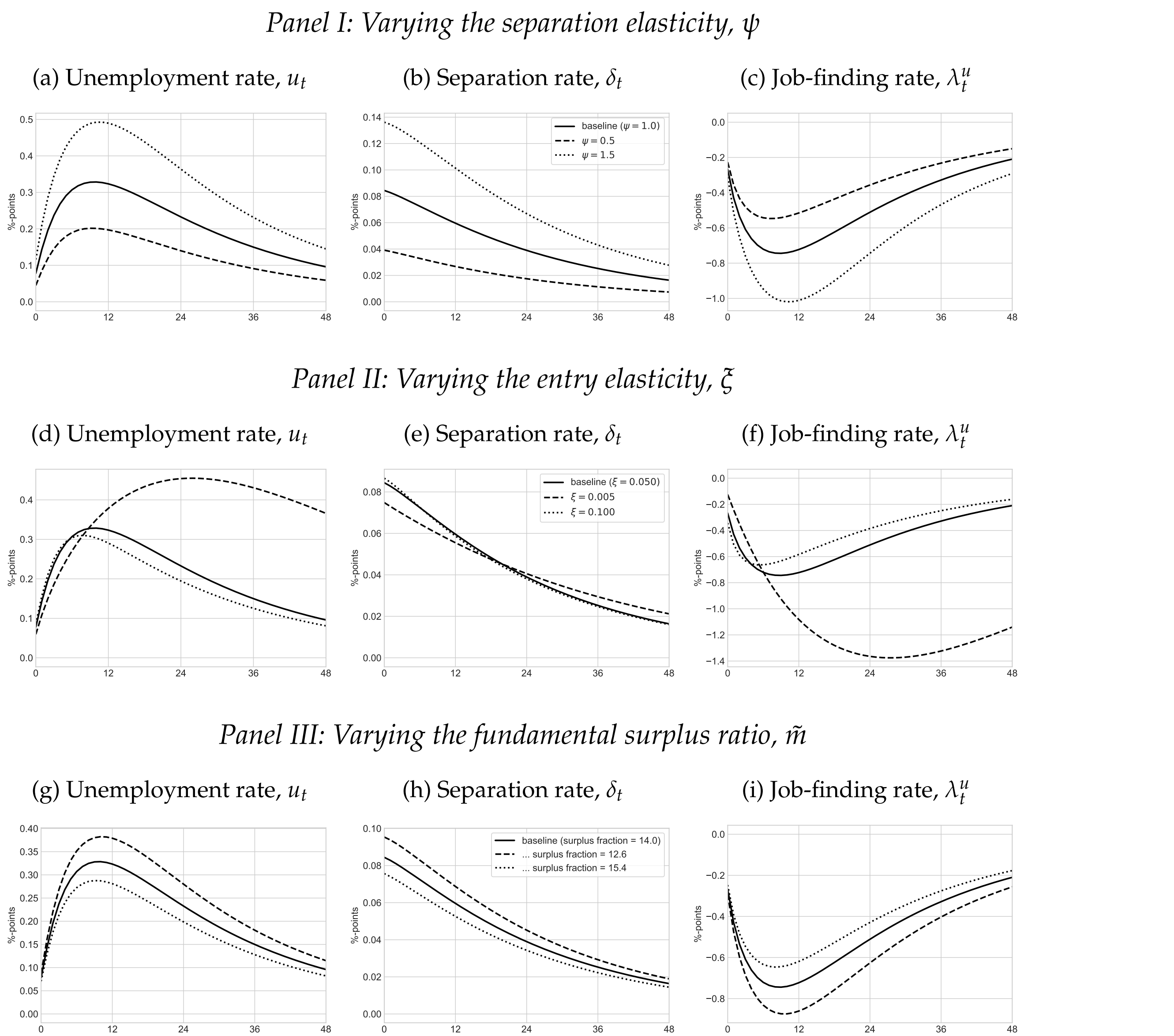
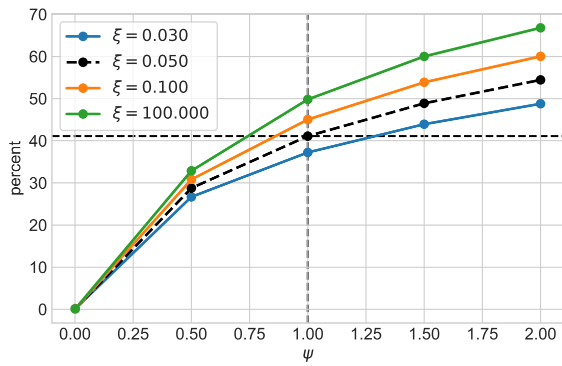


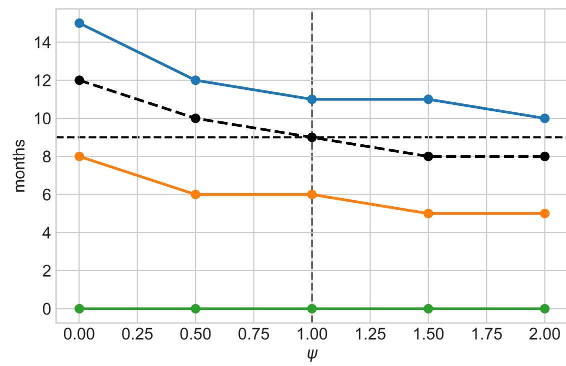
Figure 9: Impulse response to a 1-std. TFP shock - varying parameters.

Notes: This figure shows the impulse response to a TFP shock varying the separation elasticity, ψ, the entry elasticity, ξ, and thefundamental surplus ratio, $\tilde{m}$. All other parameters are set as in Table 1.

(a) Share of var(u_t) explained by separations



(b) Delay of job-finding through to separation peak



(c) Gross fundamental surplus ratio, $\frac{P^x_{ss} Z_{ss} - W_{ss}}{P^x_{ss} Z_{ss}}$

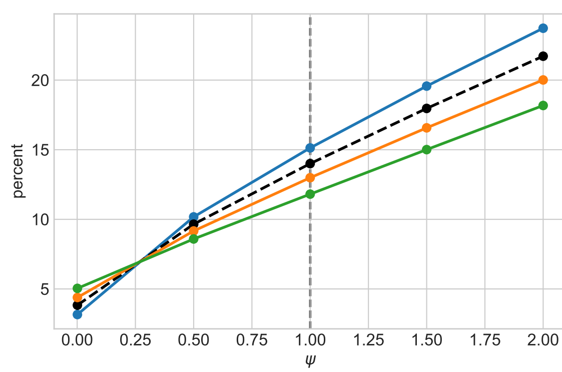


Figure 10: Identification of separation elasticity (ψ) and entry elasticity (ξ).

Notes: This figure shows model outcomes to identify the separation elasticity, ψ, and the entry elasticity, ξ, while re-calibrating the fundamental surplus ratio, $\tilde{m}$, to fit a variance of unemployment of 2.65 (as found in Section 2). All other parameters are set as in Table 1. Panel (a) shows the share of the variance of unemployment accounted for by separations using the static decomposition from Section 2. Panel (b) shows the delay from the separation rate peak to the job-finding rate trough to in months. The horizontal lines show the targeted moment values, and the vertical lines the chosen parameter values in our preferred calibration. Panel (c) shows the implied gross fundamental surplus ratio $M_{ss} = \frac{P^x_{ss} Z_{ss} - W_{ss}}{P^x_{ss} Z_{ss}}$.

in practice indistinguishable from the parameter combination $\psi = 0.0$ and $\xi = 100.0$. The solid black lines in Figure 9 show the impulse response to a 1 std. TFP shock for our preferred calibration.

Figure 10a shows how the share of unemployment volatility attributed to the separation rate, using the same static decomposition as in Section 2, depends on the parameter values. Naturally, a higher separation elasticity leads to a larger share of unemployment fluctuations being accounted for by movements in the separation rate. Our preferred calibration of the other parameters is the black dashed line. This implies a separation elasticity of 1.00 to get a separation share of unemployment variance of 40 percent.

Figure 10b shows the delay between the peak response of the separation rate and the trough response of the job-finding rate. A lower entry elasticity leads to a longer delay in the response of the job-finding rate. In our preferred calibration, we set $\xi = 0.05$ and get a delay of 9 months.

In Figure 10c, we show how the gross fundamental surplus ratio changes across different values of the separation and entry elasticity. A higher separation elasticity, ψ, increases unemployment volatility. To keep unemployment volatility unchanged, the fundamental surplus ratio must thus increase. Changing the vacancy creation elasticity, ξ, can both dampen and amplify unemployment fluctuations, and might thus require either a decrease or an increase in the fundamental surplus ratio. When separations are exogenous (equivalent to a zero separation elasticity, to the left of Figure 10c), the entry response to variations in the match product is the sole source of unemployment fluctuations. More sluggish entry thus dampens the response of unemployment. When separations rise endogenously after an adverse shock, the resulting increase in unemployment raises tightness under sluggish entry, as vacancies get filled but new vacancies are not posted immediately. This vacancy-depletion effect keeps job-finding rates depressed, and thus amplifies the response of unemployment. With separations sufficiently responsive, as in our preferred calibration, more sluggish entry requires a higher fundamental surplus ratio.

Our preferred calibration implies a gross fundamental surplus ratio of approximately 14 percent. In contrast to standard search-and-matching models (Ljungqvist and Sargent, 2017), our model does not require an extremely low surplus to generate sizable unemployment fluctuations.

6 Quantifying the unemployment-risk channel

This section quantifies the drivers of unemployment fluctuations in our benchmark model, and compares them to alternative frameworks with exogenous separations and/or free entry. In particular, we are interested in the unemployment-risk channel (URC). Quantifying this channel is particularly important for policymakers because it clearly identifies an inefficient part of unemployment fluctuations and thus gives a role to both aggregate-demand management as well as labor-market policies.

Decomposing the unemployment response. Figure 11 compares the dynamic response of unemployment to a productivity shock in our preferred calibration to that in alternative models by sequentially and cumulatively adding the assumptions of complete markets, flexible prices, free entry and exogenous separations, in that order. The red solid line corresponds to a plain-vanilla Diamond-Morten-Pissarides (DMP) model. Here, the unemployment variance is reduced to $\text{var}(u_t) = 0.26$, only 10 percent of its value in the benchmark model. This underlying weak volatility of unemployment is a consequence of our substantial fundamental surplus, which implies a low elasticity of match profits with respect to labor productivity.

Adding endogenous separations (with $\psi = 1.00$, depicted as the green line) to the simple DMP model quadruples the unemployment variance when all other parameters are kept unchanged, to $\text{var}(u_t) = 1.06$. Adding sluggish entry increases the variance further to $\text{var}(u_t) = 1.63$, and also increases the persistence of the response. Sluggish entry thus amplifies unemployment volatility in our preferred calibration with rather elastic separations.

Adding sticky prices only increases unemployment volatility modestly, to $\text{var}(u_t) = 1.73$. In other words, adding a demand externality through sticky prices does not matter much under complete markets. Finally, adding incomplete markets gives the benchmark calibration, with a further substantial increase in the unemployment variance to $\text{var}(u_t) = 2.65$.

We denote the difference between the full response and the response under complete markets as the unemployment-risk channel (URC), and indicate it by the shaded area. The URC consequently captures all fluctuations in unemployment caused by

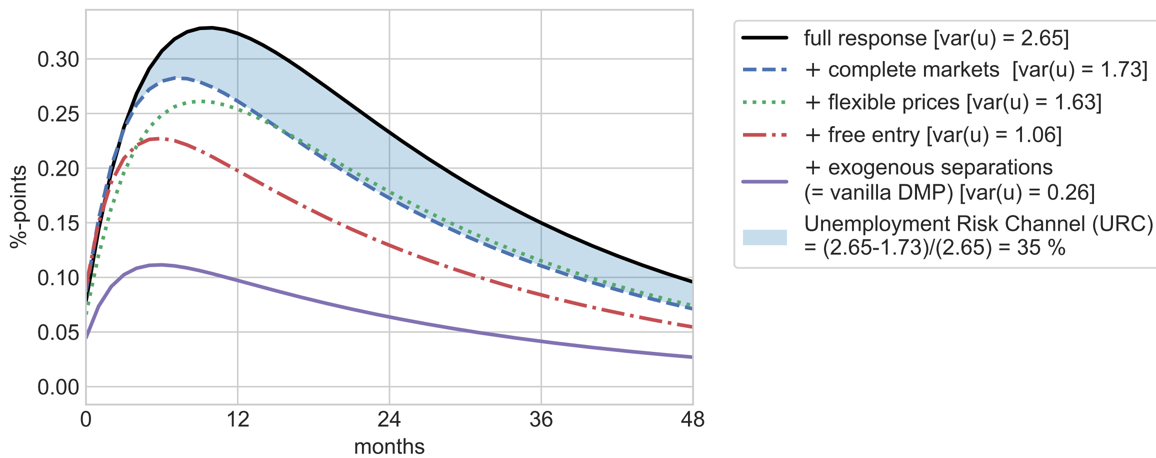


Figure 11: Decomposition of the unemployment response to a 1-std. TFP-shock.

Notes: This figure shows a decomposition of the unemployment response to a 1-std. TFP shock. All parameters are as in Table 1. The Unemployment Risk Channel (URC) is the difference between the full response and the response with complete markets in percent of the full response.

the interaction of idiosyncratic unemployment risk and sticky prices.[18] The URC accounts for 35 percent of the unemployment variance in our preferred calibration. The share generated by the URC in our model does not depend specifically on the TFP shock since supply and demand shocks have equivalent effects on the labor market. In Appendix Figure E.1, we verify that the URC also accounts for 35 percent of the unemployment variance in response to a demand shock to the discount factor, β_t.

Sluggish entry amplifies with endogenous separations, dampens with exogenous separations. In Figure 11, we saw that sluggish entry amplified the response of unemployment. This results is, however, conditional, on starting from a model with *endogenous* separations. Panel (a) of Figure 12 shows that the opposite result is obtained when starting from a model with exogenous separations. Here unemployment is more volatile under free entry because all fluctuations in tightness and unemployment stems from fluctuations in vacancy posting.

Panel (b) shows that the same effect is true for the URC. Moreover, the relative

[18] In complete markets markets some of the fluctuations in unemployment is due to fluctuations in the aggregate unemployment, but there is no idiosyncratic unemployment risk.

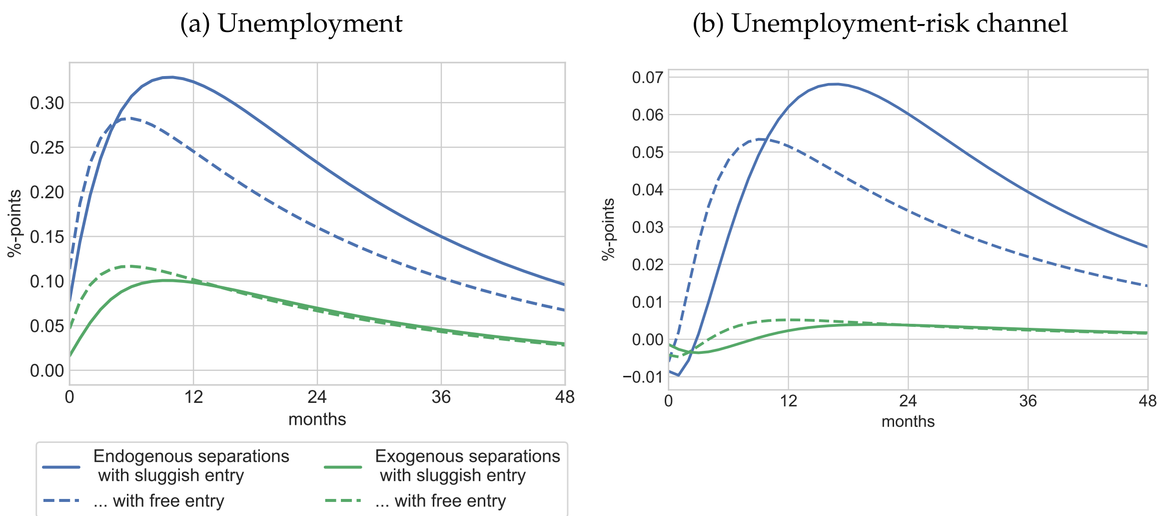


Figure 12: Sluggish entry only gives amplification with endogenous separations.

Notes: This figure shows impulse responses to a 1-std. TFP shock under different combinations of exogenous/endogenous separations and free/sluggish entry. All parameters are as in Table 1.

amplification that endogenous separations and sluggish vacancy creation add to the URC is even larger compared to what it adds to total unemployment volatility. With exogenous separations and free entry, the URC generates less than 10 percent of the overall unemployment volatility. The reason is the multiplier process described in Section 4. The path of match productivity is amplified through the term $(I - M_{\text{HANK}} M_{\text{SAM}})^{-1}$ in Equation 26. When propagation in the SAM block becomes stronger, a larger fraction of the response of match productivity, and therefore total unemployment volatility, is generated by the URC.

The importance of the URC for different combinations of elasticities. Figure 13 shows how the quantitative importance of the URC for unemployment fluctuations varies with the choice of the separation elasticity (ζ) and the entry elasticity (ξ). In panel (a) we keep all other parameters fixed. In panel (b) we re-calibrate the fundamental surplus ratio to keep the overall unemployment variance fixed. We observe that both elasticities, and in particular the separation elasticity, matter for the strength of the URC. In a model with exogenous separations, the URC only accounts for 10-25 percent of unemployment fluctuations, compared to 35 percent in our preferred calibration with elastic separations and inelastic entry.

In Appendix E, we show for a broad range of calibration choices that the URC is substantially larger with endogenous separations and sluggish vacancy creation than with the standard choice of exogenous separations and free entry.The importance of the URC is increasing in the separation elasticity and decreasing in the entry elasticity. Since we hold unemployment variance constant for this experiment, it is only the composition and dynamic shape of the unemployment response which is affected by varying the parameters.

In our model, calibrated at a monthly frequency, the credit constraint is expected to bind for all employed household within one month. Typical calibrations of incomplete-markets model with positive liquidity will instead generate substantial heterogeneity in households' liquidity position, see, e.g., Kaplan and Violante (2018). In general, with a high probability of a binding credit constraint in the near term, the consumption loss upon unemployment is to a large extent determined by the immediate loss of income and less by the net present value of the total expected income loss. Higher separation risk has a relatively larger effect on the immediate income loss while unemployment duration risk has a relatively larger effect on the net present value. With more of the total unemployment volatility accounted for by separations, our incomplete markets model with a tight borrowing limit therefore generates a larger response of the real interest rate to fluctuations in the unemployment rate, amplifying the importance of the URC. With less elastic vacancy creation, the response of the job-finding rate becomes more back-loaded and the same logic implies that the URC is relatively weaker. Understanding how the distribution of households' liquidity position and its correlation with perceived unemployment risk matter for the strength of the URC is an important topic for future work.

7 Wage setting

Until now we have maintained the assumption that real wages are perfectly rigid. In the context of contractionary shocks this is arguably a conservative assumption given the ample evidence that most wages are downward nominally rigid. However, it is well-known that the dynamics of standard search-and-matching models are sensitive to different wage-setting assumptions. In particular, the cyclicality of wages of new hires has occupied the center of the discussion since these are the wages that matter for vacancy dynamics. It has furthermore been documented across many

(a) Comparative statics ($\tilde{m}_{ss} = 0.128$) (b) Re-estimated $\tilde{m}_{ss}$ to fit $\text{var}(u_t)$

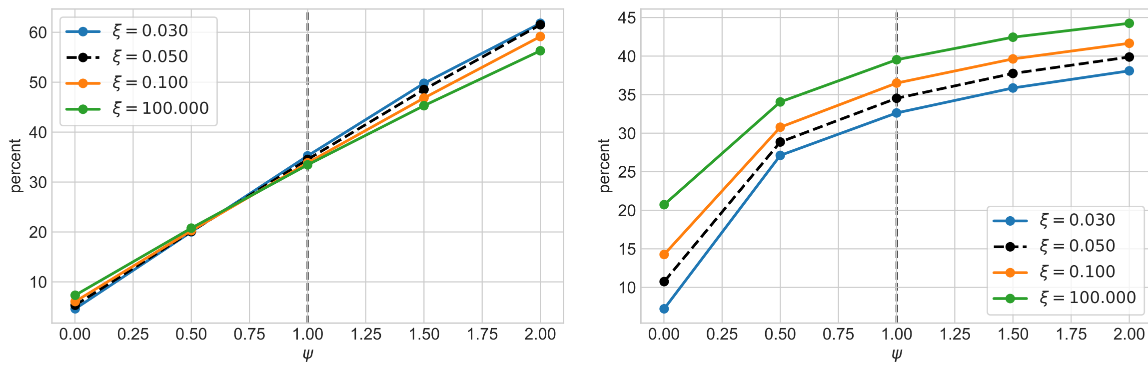


Figure 13: Unemployment Risk Channel

Notes: This figure shows the strength of the the Unemployment Risk Channel (URC) across different values of the separation elasticity (ψ) and entry elasticity (ξ). In panel (a) all other parameters are kept fixed as in Table 1. In panel (b) the fundamental surplus ratio, $\tilde{m}_{ss}$, is re-estimated to fit the observed variance of unemployment, $\text{var}(u_t)$. The URC is the difference between the full response and the response with complete markets in percent of the full response.

different settings that new-hire wages are more cyclical than wages for incumbent workers Pissarides (2009).[19]

In this section, we therefore investigate the sensitivity of the unemployment-risk channel to making the wages of new hires more pro-cyclical. Specifically, we assume that upon matching in period t, the firm pays a wage W_t^{new} to the worker in the first period of the match. In the following periods, the worker receives the same steady-state wage as everybody else $W_{t+k}^{\text{new}} = W_{ss}$. The difference $W_t^{\text{new}} - W_{ss}$ thus corresponds to a “sign-on bonus”. Equation 15 now becomes

$$
\begin{aligned}
V_t^v &= -\kappa + \lambda_t^v V_t^{j,\text{new}} + (1-\lambda_t^v)(1-\tilde{\delta})\beta \mathbb{E}_t[V_{t+1}^v], \\
V_t^{j,\text{new}} &= V_t^j - (W_t^{\text{new}} - W_{ss}),
\end{aligned} \tag{29}
$$

where $V_t^{j,\text{new}}$ is the value of firm j in the first period of filled job.

All other model equations are unchanged. In particular, in response to a contrac-

[19] The evidence that new-hire wages are more cyclical than incumbent employees’ wages has recently been challenged by Grigsby et al. (2021), Hazell and Taska (2020) and Gertler et al. (2020).

tionary shock with $W_t^{\text{new}} < W_{ss}$ the Euler-equation of the marginal saver is unchanged.[20] The wage of the new hires does therefore not in itself affect the equilibrium interest rate.

This particular specification of new-hire wage cyclicality has advantages in terms of tractability as there is no additional match heterogeneity after the initial matching period. From an economic point of view, the allocative price for hiring decisions is only the net present value of the future wage stream.

Pissarides (2009) reports that a unitary real wage elasticity with respect to aggregate productivity is in line with the evidence from several data sources. Assuming that new-hire workers keep the same wage for the duration of their employment contract in the data, a one percent permanent wage increase discounted at rate $\beta(1-\delta_{ss})$ corresponds, in present-value terms, approximately to a 35 percent one-time increase in the current wage W^{new}. We therefore assume a wage rule

$$W_t^{new} = W_{ss} \left(\frac{Z_t}{Z_{ss}} \right)^{\epsilon_w}, \tag{30}$$

with $\epsilon_w = 35$.

Figure 14, panel (a) compares the response of the URC (to the same TFP shock as in the previous sections) in the model with the elastic wage for new hires to the baseline model with completely rigid real wages . To see the effect of endogenous separations and sluggish entry, we add two panels for comparison. For panel (b), we have estimated a model with endogenous separations and infinitely elastic entry, maintaining completely rigid real wages, to match total unemployment volatility and the share of unemployment fluctuations generated by separations. Similar to panel (a), we then compare this model to its counterpart with wage flexibility for new hires. For panel (c), we have estimated a model with exogenous separations and infinitely elastic entry (i.e., the SAM block is simply a vanilla DMP model) to match total unemployment volatility. Since the wage path only responds to exogenous TFP, it is identical across the different models with elastic wages.

As we see from panel (a), making wages for new hires elastic decreases the URC.

[20] It is now the employed workers in "old" jobs, which are the marginal savers. If the steady state wage of new hires is below the steady state wages of everybody else, $W_{ss}^{\text{new}} < W_{ss}$, then the Euler-equation of the marginal saver is also unchanged in response to expansionary shocks with W_t^{new} for sufficiently small aggregate shocks.

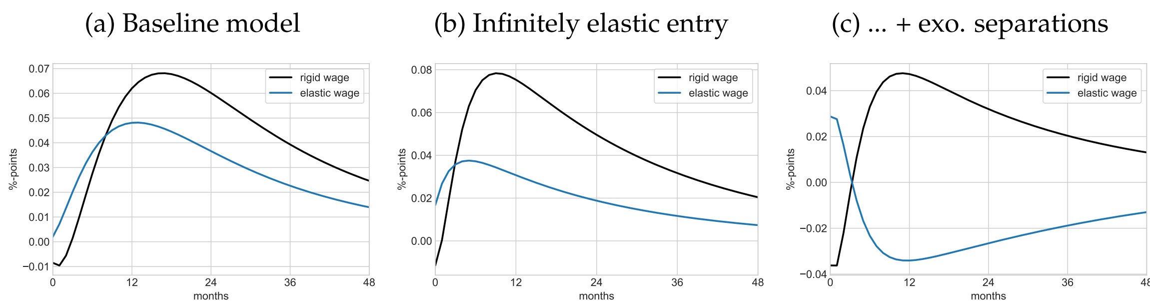


Figure 14: The unemployment-risk channel with wage flexibility of new hires.

Notes: This figure shows the impulse response of the unemployment-risk channel to a TFP shock in our baseline model rigid wages and in an alternative model with flexible wages of new hires as in Equation 29, where the wages of new hires is co-moving with the TFP shock as in Equation 30.

This is not surprising, with wages decreasing in response to the contractionary TFP shock, the value of vacancies falls less than under rigid wages, muting the drop in vacancy creation and, consequently, unemployment risk. We see, however, that the muting effect of wage flexibility is fairly small. In response to a contractionary TFP shock of one percent, the wage payments to new hires are reduced with more than one third of annual earnings, yet two thirds of the URC remains. The relatively small effect of wage flexibility in our model is due to its two main features: endogenous separations and inelastic vacancy creation. By construction, the separation decision only responds to the wage of incumbent workers, which is not affected by making initial wages for new hires more flexible. Also by construction, less elastic vacancy creation means that vacancies do not respond as much to the wages of new hires. In panel (b), we see that with fully elastic vacancy creation, the effect of wage flexibility on the unemployment-risk channel is substantially larger. In panel (c), with both exogenous separations and fully elastic vacancy creation, the effect is so large that it overturns the recession into an expansion.

8 Conclusion

The unemployment-risk channel is quantitatively important for business-cycle fluctuations in unemployment, accounting for over a third of unemployment volatility. This quantitative assessment rests on an evaluation of two key labor-market elasticities: the sensitivity of job separations and vacancies to economic conditions. We identify these elasticities by jointly matching two stylized facts that we document: in response to both supply and demand shocks, (i) the job-separation rate and the job-finding rate account for substantial shares of unemployment fluctuations, and (ii) the job-finding rate responds with a lag relative to the job-separation rate. The implied job-separation and vacancy-creation elasticities needed to match these facts are strictly positive and finite. Further, the details of the labor-market dynamics matter for the assessment of the importance of the unemployment-risk channel. A correspondingly calibrated standard Diamond-Mortensen-Pissarides model, which implicitly sets the job-separation elasticity to zero and the vacancy-creation elasticity to infinity, only attributes 20 percent of unemployment volatility to the unemployment-risk channel.

The message for policymakers from our results is three-fold: first, inefficient demand amplification might be more important than previously thought, providing an extra rationale for stabilization policies. Second, the precise source of a given increase in unemployment matters for its knock-on effect on consumption demand. Third, there are likely to be important interactions and feedback effects between macroeconomic stabilization policies and microeconomic labor-market or insurance policies (such as job subsidies of furlough policies). We leave a detailed positive and normative analysis of these issues for future research.

Our analysis builds on a tractable framework, where we have purposefully kept some parts of the model simple and stylized. This enabled a transparent analysis of the role of endogenous separations and sluggish vacancy creation for the unemployment-risk channel. Some of the maintained assumptions are, however, restrictive and we believe it would be useful to investigate the effect of relaxing them in future work, especially when doing policy analysis. First, the no-borrowing/zero-liquidity assumptions imply that workers have no ability to smooth income fluctuations in our framework. While the compressed asset distribution is in line with small liquid-asset holdings by most workers, and the consumption drop upon unemployment in the model matches that in the data, the relative role of separation risk vis-à-vis unemployment duration risk for fluctuations in consumption demand might be affected by this assumption. Second, our modeling of the response of separations to macroeconomic conditions was intentionally simple, and thus does not capture the persistent heterogeneity in match productivity that are likely drivers of separation decisions in the data. This means that our framework does not fully capture the costs and benefits of demand stabilization though its effect on the allocation of workers to firms. Similarly, the assumption of heterogenous costs of creating a vacancy follows previous work (Coles and Kelishomi, 2018; Haefke and Reiter, 2020), but does not allow us to quantitatively capture the heterogeneity of firm or job productivity, and their correlation with entry and exit decisions. An interesting avenue for future research includes enriching the labor market block with, e.g., recall unemployment, job-to-job transitions, endogenous search and recruitment intensities, and a distinction between separations and job destruction.

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A Appendix to Section 2

A.1 Accounting for time aggregation

To account for time aggregation, we analyze the data through the lens of a three state continuous time model, where workers are either employed (E), unemployed (U) or inactive (I), i.e. out of the labor force.

Let P_t denote the *discrete time transition probability matrix* from month t to month $t+1$. This can be calculated directly from the data. We use seasonally adjusted probabilities.

Let P_t^{AB} denote the transition probability from state $A \in \{E, U, I\}$ to state $B \in \{E, U, I\}$. The implied *transition rate matrix*, also known as the *infinitesimal generator matrix*, is given by[21]

$$
\begin{aligned}
Q_t &= \begin{bmatrix} -(\lambda_t^{EU} + \lambda_t^{EI}) & \lambda_t^{EU} & \lambda_t^{EI} \\ \lambda_t^{UE} & -(\lambda_t^{UE} + \lambda_t^{UI}) & \lambda_t^{UI} \\ \lambda_t^{IE} & \lambda_t^{IU} & -(\lambda_t^{IE} + \lambda_t^{IU}) \end{bmatrix} \\
&= p_t \begin{bmatrix} \ln(\mu_{t1}) & 0 & 0 \\ 0 & \ln(\mu_{t2}) & 0 \\ 0 & 0 & \ln(\mu_{t3}) \end{bmatrix} p_t^t,
\end{aligned}
$$

where μ_{t1}, μ_{t2} and μ_{t3} are the eigenvalues of P_t, and p_t is the associated eigenvector matrix. We can thus derive P_t^{AB}, and the underlying continuous time transition rates, from P_t alone.

We calculate the probability of at least one transition in a month from state A to state B, conditional on no transitions to the third state C, as $\Lambda_t^{AB} = 1 - e^{-\lambda_t^{AB}}$. For simplicity, we refer to this both as the *monthly transition probability*, and as the *monthly transition rate*.

[21] We assume the eigenvalues of P_t are unique, real and positive. This is true in the data.

A.2 Filtering methods

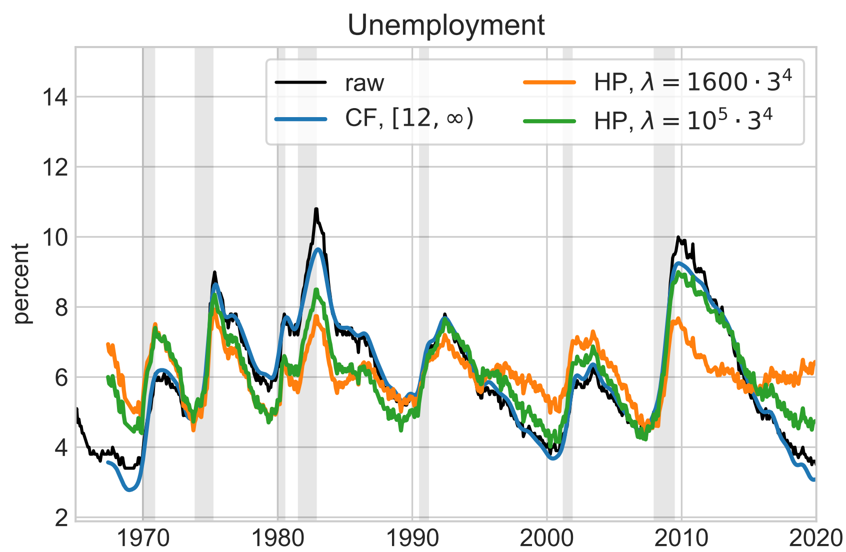


Figure A.1: Unemployment with Christiano-Fitzgerald (CF) or Hodrick-Presscott (HP) filtering

Figure A.1 shows the time series of unemployment using three different filtering methods. As seen from the Figure, a Hodrick-Prescott filter tend to attribute a larger share of the Great Recession to the trend rather than the cycle component, and also does not filter out erratic short-term movements in the unemployment rate.

B Appendix to Section 3

B.1 Separation decision

In Equation 12, we assume that G is a mixture of a point mass at 0 and a Pareto distribution with location parameter $\Upsilon > 0$ and shape parameter ψ,

$$G(\chi_t) = \begin{cases} 0 & \chi_t < 0, \\ 1-p & 0 \leq \chi_t < \Upsilon, \\ (1-p) + p(1-(\chi_t/\Upsilon)^{-\psi}) & \chi_t \geq \Upsilon, \end{cases} \tag{31}$$

This implies

$$\begin{aligned} \delta_t &= \int_{V_t^j}^{\infty} G(\chi_t) d(\chi_t) \\ &= \begin{cases} p & \text{if } V_t^j \leq \Upsilon \\ p\left(\frac{V_t^j}{\Upsilon}\right)^{-\psi} & \text{else} \end{cases} \end{aligned} \tag{32}$$

and

$$\begin{aligned} \mu_t &= \int_0^{V_t^j} \chi_t dG(\chi_t) \\ &= \frac{\mathbb{E}[\chi_t] - \text{Prob.}[\chi_t > V_t^j]\mathbb{E}[\chi_t | \chi_t > V_t^j]}{1 - \text{Prob.}[\chi_t > V_t^j]} \\ &= \begin{cases} 0 & \text{if } V_t^k \leq \Upsilon \\ \frac{p\frac{\psi\Upsilon}{\psi-1} - p\left(\frac{V_t^j}{\Upsilon}\right)^{-\psi}\frac{\psi V_t^j}{\psi-1}}{(1-p)+p(1-(\chi_t/\Upsilon)^{-\psi})} & \text{else} \end{cases} \\ &= \begin{cases} 0 & \text{if } V_t^k \leq \Upsilon \\ \frac{p\frac{\psi}{\psi-1}\Upsilon\left[1-\left(\frac{V_t^j}{\Upsilon}\right)^{1-\psi}\right]}{1-p\left(\frac{V_t^j}{\Upsilon}\right)^{-\psi}} & \text{else} \end{cases} \\ &= \mu(V_t^j) \end{aligned} \tag{33}$$

We always choose $\Upsilon = \left(\frac{\delta_{ss}}{p}\right)^{\frac{1}{\psi}} V^j_{ss}$ which implies Equation (13) in the main text. Furthermore, with $p = \delta_{ss}$ we have $\Upsilon = V^j_{ss}$ which implies $\delta_t = \delta_{ss}$ when $V^j_t \leq V^j_{ss}$. Instead we set $p = (1 + \Delta_\delta)\delta_{ss}$ where $\Delta_\delta > 0$ is a small positive number. This implies that δ_t can rise above δ_{ss} when V^j_t falls below V^j_{ss}. It also implies that μ_{ss} is a small positive number.

B.2 Asset market equilibrium

Workers' optimization problem The post-decision value function for the employed worker is

$$\mathcal{W}^n_t = \mathbb{E}_t \left[(1 - \text{URISK}_t)V^n_{t+1} + \text{URISK}_t V^u_{t+1}\right]$$

where $\text{URISK}_t = \delta_t(1 - \lambda^u_{t+1})$ is the probability of an employed worker becoming unemployed. The Bellman equation for an employed worker is

$$\begin{aligned} V^n_t = \max_{C_{n,t},B_{n,t+1}} & \frac{C^{1-\sigma}_{n,t}}{1-\sigma} + \beta\mathcal{W}^n_t \\ \text{s.t.} & \\ C_{n,t} + & \frac{B_{n,t+1}}{1+i_t} \leq W_t + \frac{B_{n,t}}{\Pi_t}, \\ B_{n,t+1} & \geq 0. \end{aligned} \tag{34}$$

where $B_{n,t}$ are bond holdings. In the zero-liquidity equilibrium, the sum of all agents' asset holdings is zero. Together with assumption that no agent is allowed to borrow, it follows that all individual agents' asseting holdings must be zero. Hence, $B_{n,t} = B_{n,t+1} = 0$, and all employed workers are symmetrical such that $C_{n,t} = W_t$.

The post-decision value function for the unemployed worker is

$$\mathcal{W}^u_t = \mathbb{E}_t \left[\lambda^u_{t+1}V^n_{t+1} + (1 - \lambda^u_{t+1})V^u_{t+1}\right].$$

The Bellman equation for an unemployed worker is

$$V_t^u = \max_{C_{n,t}, B_{n,t+1}} \frac{C_{u,t}^{1-\sigma}}{1-\sigma} + \beta \mathcal{W}_t^u \tag{35}$$

$$\text{s.t.}$$

$$C_{u,t} + \frac{B_{u,t+1}}{1+i_t} \leq \vartheta + \frac{B_{u,t}}{\Pi_t},$$

$$B_{u,t+1} \geq 0.$$

In the zero-liquidity equilibrium, $B_{u,t} = B_{u,t+1} = 0$, and all unemployed workers are symmetrical such that $C_{u,t} = \vartheta$.

Capitalists' optimization problem The Bellman equation for the capitalists, who do not participate in the labor market, is

$$V_t^c = \max_{C_{n,t}, B_{n,t+1}} C_{c,t} + \beta \mathbb{E}_t[V_{t+1}^c] \tag{36}$$

$$\text{s.t.}$$

$$C_{c,t} + \frac{B_{c,t+1}}{1+i_t} + P_t^S S_t \leq \vartheta + \frac{B_{c,t}}{\Pi_t} + (P_t^s + D_t) S_{t-1},$$

$$C_{c,t} \geq 0, \tag{37}$$

$$B_{c,t+1} \geq 0, \tag{38}$$

$$S_t \geq 0,$$

where $B_{c,t}$ are bonds, S_t are equity fund shares. The equity fund owns all firms in the economy, and pays out the firm profits as D_t.

In the zero liquidity equilibrium, $B_{c,t} = B_{c,t+1} = 0$, and with all capitalists symmetrical, $S_t = S_{t+1} = \frac{1}{\text{pop}_c}$. Consumption of the capitalists is given by

$$C_{c,t} = \frac{D_t}{\text{pop}_c} + \vartheta.$$

Since capitalists have linear utility, the discount factor that enter the firm problems is simply β.

Asset market equilibrium Optimality requires that the three Euler equations of the three types of agents are satisfied with weak inequality,

$$W_t^{-\sigma} \geq \beta \mathbb{E}_t \left[\frac{1+i_t}{\Pi_{t+1}} \left((1-\text{URISK}_t) W_{t+1}^{-\sigma} + \text{URISK}_{u,t} \vartheta^{-\sigma} \right) \right], \quad (39)$$

$$\vartheta^{-\sigma} \geq \beta \mathbb{E}_t \left[\frac{1+i_t}{\Pi_{t+1}} \left(\lambda_{t+1}^u W_{t+1}^{-\sigma} + (1-\lambda_{t+1}^u) \vartheta^{-\sigma} \right) \right], \quad (40)$$

$$1 \geq \beta \mathbb{E}_t \left[\frac{1+i_t}{\Pi_{t+1}} \right]. \quad (41)$$

Formally, any real interest rate $(1+i_t)/\Pi_{t+1}$ low enough such that all three Euler equations are satisfied with weak inequality is consistent with the zero-liquidity equilibrium. The natural interpretation is however to let liquidity approach zero, as in Krusell et al. (2011), then the real interest rate is such that one of the Euler equations holds with equality.

At a zero-inflation steady state, the three Euler equations amount to

$$1 \geq \beta(1+i_{ss}), \quad (42)$$

$$1 \geq \beta(1+i_{ss}) \left(1 + \text{URISK}_{ss}((W_{ss}/\vartheta)^{\sigma} - 1)\right), \quad (43)$$

$$1 \geq \beta(1+i_{ss}) \left(1 - \lambda_{ss}^u (1 - (W_{ss}/\vartheta)^{-\sigma})\right). \quad (44)$$

With the transition rates strictly positive, and the wage of the employed larger than the home production of the unemployed, $W_{ss} > \vartheta$, we get the inequalities $1 + \text{URISK}_t((W_{ss}/\vartheta)^{\sigma} - 1) > 1 > 1 - \lambda_{ss}^u(1 - (W_{ss}/\vartheta)^{-\sigma})$ and the marginal saver is the employed worker. For small enough aggregate shocks, around the zero-inflation steady state, the employed worker remains the marginal saver and Equation (22) is the asset-marking clearing condition.

B.3 Solution algorithm

First, we solve for the **steady state** in 3 steps:

1. **Normalizations:** We use $Z_{ss} = 1.0$ and $\Pi_{ss} = 1.0$
2. **Targets:** We choose δ_{ss}, λ_{ss}^u, θ_{ss},$\tilde{M}_{ss}$ and V_{ss}^v, as calibration targets
3. **Solution**: The steady state for the remaining variable can then be found in closed form. See details in D.1.

Second, we solve for the **impulse-response to MIT shocks** around the steady using the following 5 step approach:

1. **Exogenous:** We choose paths for $\{Z_t\}_0^T$ and $\{\beta_t\}_0^T$ where for $t \in [\underline{T}, T]$ with $\underline{T} \ll T$ we have $Z_t = Z_{ss}$ and $\beta_t = \beta_{ss}$.
2. **Inputs:** Guess on 4 inputs paths.

   Intermediary goods price, $\{P_t^X\}_0^T$

   Job value, $\{V_t^j\}_0^T$

   Vacancy value, $\{V_t^v\}_0^T$

   Inflation, $\{\Pi_t\}_0^T$
3. **Evaluation:** Evaluate paths for all remaining variables.
4. **Errors:** Check errors of the 4 target equations.

   Intermediary goods price, $\{P_t^X\}$

   Job value, $\{V_t^j\}$

   Vacancy value, $\{V_t^v\}$

   Inflation, $\{\Pi_t\}$
5. **Convergence:** Loop through step 2-4 until errors are below chosen tolerance.

To speed up the solution, we compute the Jacobian of the equation system using numerical differentiation and solve the problem with a Broyden solver. The code is mostly written in Python, but the evaluation of the equation system is written in C++, and the computation of the Jacobian is parallelized. The code is available online at github.com/JeppeDruedahl/HANKSAM_URC.

C Appendix to Section 4

C.1 Proof of Proposition 1

Combining Equation (24) and (25) implies

$$\mathbf{p}^{\mathbf{x}} = M_{\text{HANK}} M_{\text{SAM}} (\mathbf{p}^{\mathbf{x}} + \mathbf{z}).$$

Solving for $\mathbf{p}^{\mathbf{x}}$ this implies

$$\mathbf{p}^{\mathbf{x}} = (I - M_{\text{HANK}} M_{\text{SAM}})^{-1} M_{\text{HANK}} M_{\text{SAM}} \mathbf{z},$$

so

$$\begin{aligned}
\mathbf{p}^{\mathbf{x}} + \mathbf{z} &= (I - M_{\text{HANK}} M_{\text{SAM}})^{-1} M_{\text{HANK}} M_{\text{SAM}} \mathbf{z} + \mathbf{z} \\
&= (I - M_{\text{HANK}} M_{\text{SAM}})^{-1} M_{\text{HANK}} M_{\text{SAM}} \mathbf{z} \\
&\quad + (I - M_{\text{HANK}} M_{\text{SAM}})^{-1} (I - M_{\text{HANK}} M_{\text{SAM}}) \mathbf{z}. \\
&= (I - M_{\text{HANK}} M_{\text{SAM}})^{-1} (M_{\text{HANK}} M_{\text{SAM}} + (I - M_{\text{HANK}} M_{\text{SAM}})) \mathbf{z} \\
&= (I - M_{\text{HANK}} M_{\text{SAM}})^{-1} \mathbf{z}.
\end{aligned}$$

C.2 Proof of Proposition 2 and Proposition 3

The log-linearized equations for the HANK block are the asset-marking clearing condition,

$$i_t - \mathbb{E}_t \pi_{t+1} = \frac{\text{URISK}_{ss} \times \left(\left(\frac{W_{ss}}{\vartheta} \right)^{\sigma} - 1 \right)}{1 + \text{URISK}_{ss} \times \left(\left(\frac{W_{ss}}{\vartheta} \right)^{\sigma} - 1 \right)} urisk_t - \log \nu_t^{\beta},$$

the Taylor rule,

$$i_t = (\phi_\pi - 1)\pi_t + \mathbb{E}_t[\pi_{t+1}],$$

and the Phillips curve,

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + (\epsilon^p - 1)\phi^{-1} p_t^x.$$

Solving for $i_t - \mathbb{E}_t[\pi_{t+1}]$ in the Taylor rule and substituting in the expression for $i_t - \mathbb{E}_t[\pi_{t+1}]$ from the asset-marking clearing condition gives

$$\pi_t = \frac{1}{\phi_\pi - 1}\left(\frac{\text{URISK}_{ss} \times \left(\left(\frac{W_{ss}}{\vartheta}\right)^\sigma - 1\right)}{1 + \text{URISK}_{ss} \times \left(\left(\frac{W_{ss}}{\vartheta}\right)^\sigma - 1\right)} urisk_t - \log \nu_t^\beta\right).$$

Substituting into the Phillips curve gives

$$\begin{aligned} p_t^x =& \frac{\frac{\text{URISK}_{ss} \times \left(\left(\frac{W_{ss}}{\vartheta}\right)^\sigma - 1\right)}{1+\text{URISK}_{ss} \times \left(\left(\frac{W_{ss}}{\vartheta}\right)^\sigma - 1\right)}}{(\phi_\pi - 1)(\epsilon^p - 1)\phi^{-1}}(urisk_t - \beta\mathbb{E}_t urisk_{t+1}) \\ &- \frac{1}{(\phi_\pi - 1)(\epsilon^p - 1)\phi^{-1}}(\log \nu_t^\beta - \beta\mathbb{E}_t \log \nu_{t+1}^\beta) \end{aligned}$$

which, by invoking that $\log \nu_{t+1}^\beta$ follows an $AR(1)$ with persistence ρ^β, gives

$$p_t^x + z_t = \frac{\frac{\text{URISK}_{ss} \times \left(\left(\frac{W_{ss}}{\vartheta}\right)^\sigma - 1\right)}{1+\text{URISK}_{ss} \times \left(\left(\frac{W_{ss}}{\vartheta}\right)^\sigma - 1\right)}}{(\phi_\pi - 1)(\epsilon^p - 1)\phi^{-1}}(urisk_t - \beta\mathbb{E}_t urisk_{t+1}) - \frac{1 - \beta\rho^\beta}{(\phi_\pi - 1)(\epsilon^p - 1)\phi^{-1}} \log \nu_t^\beta + z_t,$$

Therefore, labor revenue product, $p_t^x + z_t$, responds identically to a TFP shock and a demand shock, up to the proportionality factor $\frac{1-\beta\rho^\beta}{(\phi_\pi-1)(\epsilon^p-1)\phi^{-1}}$. This proves Proposition (3).

In the absence of demand shocks, we have

$$p_t^x = \frac{\frac{\text{URISK}_{ss} \times \left(\left(\frac{W_{ss}}{\vartheta}\right)^\sigma - 1\right)}{1+\text{URISK}_{ss} \times \left(\left(\frac{W_{ss}}{\vartheta}\right)^\sigma - 1\right)}}{(\phi_\pi - 1)(\epsilon^p - 1)\phi^{-1}}(urisk_t - \beta\mathbb{E}_t urisk_{t+1}),$$

proving Proposition (2).

C.3 Standard Taylor Rule

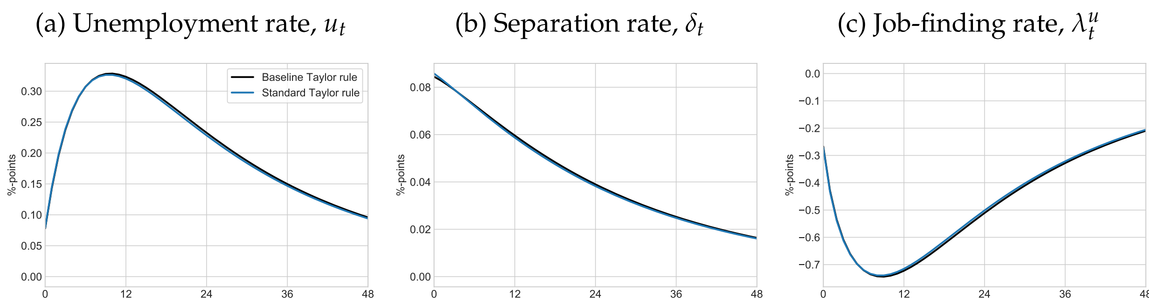


Figure C.1: Impulse-response to a 1-std. TFP shock - varying the Taylor Rule .

Notes: This figure shows the impulse-response to a TFP-shock varying the Taylor rule. The baseline Taylor rule is Equation 23. The standard Taylor is $1 + i_t = (1 + i_{ss})\Pi_t^{\phi_\pi}$. All other parameters are set as in Table 1.

D Appendix to Section 5

D.1 Calibration

From Table 1, we have the externally calibrated parameters (β, ρ, ϑ,ϵ_p, ϕ, δ_π, α), the steady targets (δ_{ss}, λ_{ss}^u, θ_{ss}), and the internally calibrated parameters ($\tilde{m}_{ss}$, ψ, ξ). Together with the two auxiliary parameters ($\kappa_0 = 0.1 \approx 0$, $\Delta_\delta = 0.1 \approx 0$), the remaining model parameters can be deduced. From the matching function, we directly have

$$A = \frac{\lambda_{ss}^u}{\theta_{ss}^\alpha}.$$

This implies that the steady states of labor markets stocks and flows can be found by,

$$\begin{aligned}
\lambda_{ss}^v &= A\theta_{ss}^{-\alpha}, \\
u_{ss} &= \frac{\delta_{ss}(1-\lambda_{ss}^u)}{\lambda_{ss}^u + \delta_{ss}(1-\lambda_{ss}^u)}, \\
\tilde{u}_{ss} &= \frac{u_{ss}}{1-\lambda_{ss}^u}, \\
\tilde{v}_{ss} &= \tilde{u}_{ss}\theta_{ss}, \\
v_{ss} &= (1-\lambda_{ss}^v)\tilde{v}_{ss}, \\
\iota_{ss} &= \tilde{v}_{ss} - (1-\delta_{ss})v_{ss}.
\end{aligned}$$

We can now also calculate both the value of a job and the value of a vacancy,

$$V^j_{ss} = \frac{\tilde{m}_{ss}}{1-\beta(1-\delta_{ss})},$$
$$V^v_{ss} = \kappa_0.$$

Hereby, we can infer p, F, κ, Y and W_{ss} by

$$\begin{aligned}
p &= (1+\Delta_\delta)\delta_{ss} \\
F &= \iota_{ss}(V^v_{ss})^{-\xi} \\
\kappa &= \lambda^v_{ss}V^j_{ss} - (1-\beta(1-\lambda^u_{ss})(1-\delta_{ss}))V^v_{ss} \\
\text{Y} &= \left(\frac{\delta_{ss}}{p}\right)^{\frac{1}{\psi}} V^{ss}_j \\
\mu_{ss} &= \frac{p\frac{\psi}{\psi-1}\text{Y}\left[1-\left(\frac{V^j_{ss}}{\text{Y}}\right)^{1-\psi}\right]}{1-p\left(\frac{V^j_{ss}}{\text{Y}}\right)^{-\psi}} \\
M_{ss} &= \tilde{m}_{ss}P^x_{ss}Z_{ss} + \beta\mu_{ss} \\
W_{ss} &= P^x_{ss}Z_{ss} - M_{ss}
\end{aligned}$$

Hereafter the steady state values of all other variables can be found as well.

E Appendix to Section 6

Figure E.1 shows the impulse response of unemployment to a 1-std. β-shock, alongside the same counterfactual models considered in Figure 11. As seen from the figure, the contribution of the URC is the same as in response to a TFP shock, and explains 35 percent of the total unemployment response.

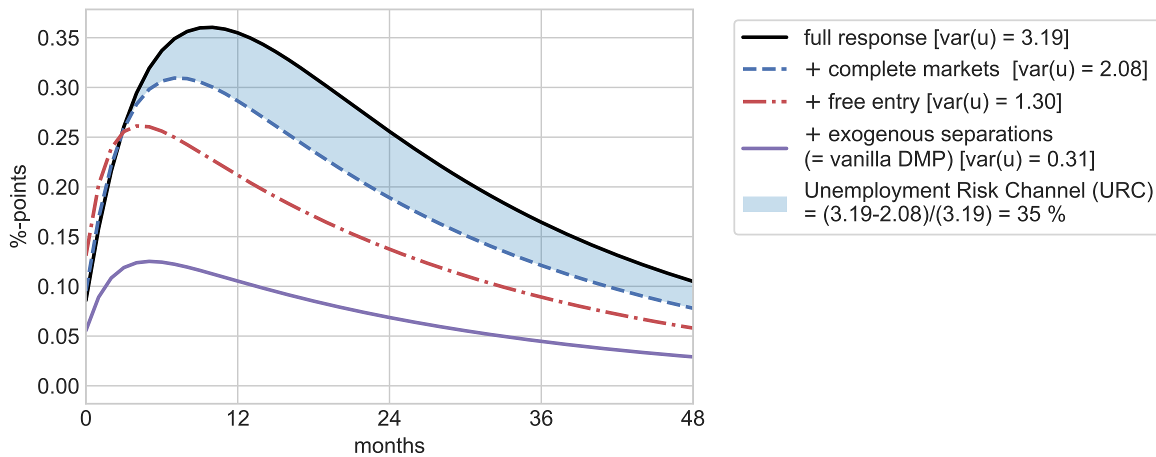
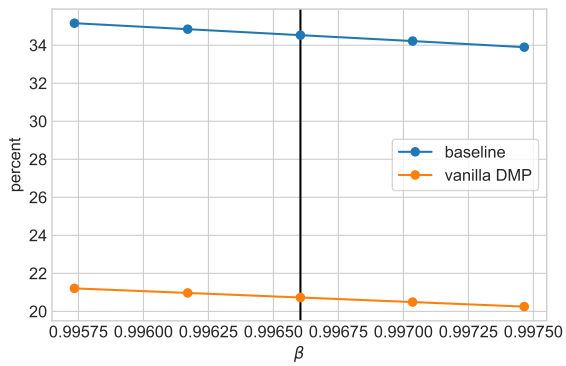


Figure E.1: Decomposition of the unemployment response to a 1-std. β-shock.

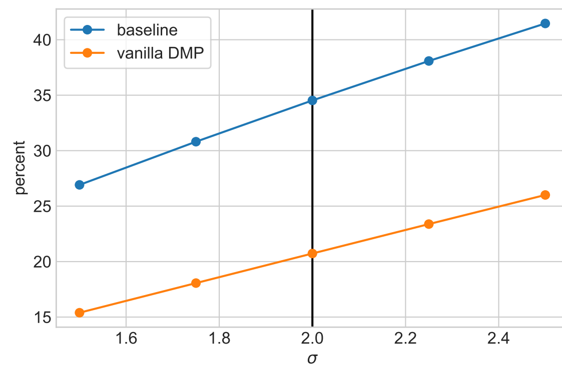
Notes: This figure shows a decomposition of the unemployment response to a 1-std. β-shock. All parameters are as in Table 1. The Unemployment Risk Channel (URC) is the difference between the full response and the response with complete markets in percent of the full response.

Figure E.2-E.4 show how the URC changes with each of the calibrated parameters starting from both the baseline model and a vanilla DMP model with exogenous separations and free entry. The fundamental surplus ratio, $\tilde{m}_{ss}$, is re-estimated to fit the observed variance of unemployment, $\text{var}(u_t)$. The URC in the baseline model is always substantially larger than in the vanilla DMP model.

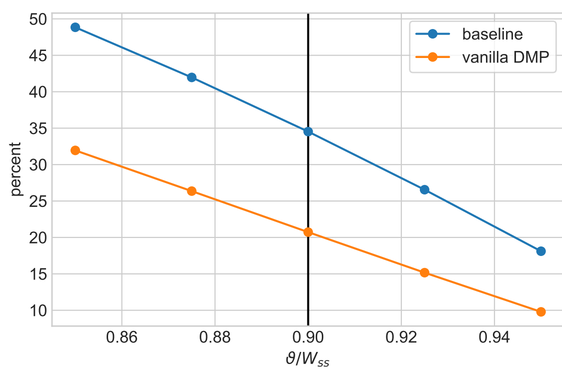
(a) Changing β



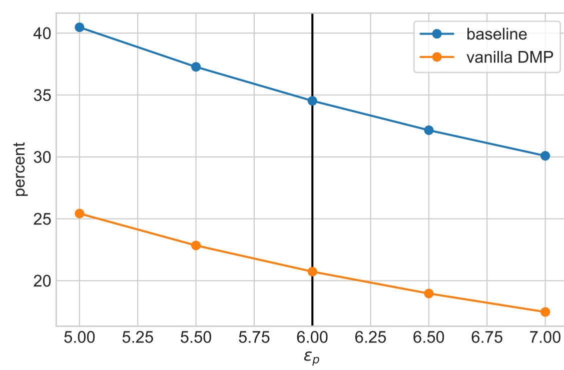
(b) Changing σ



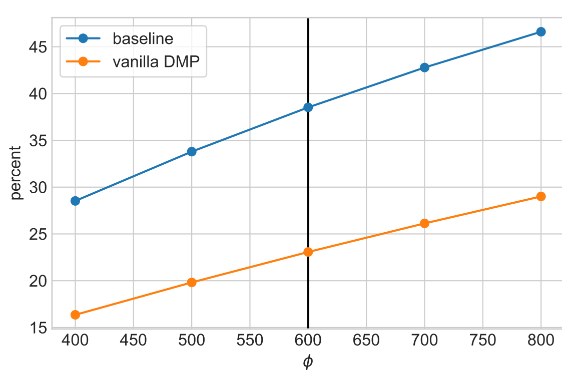
(c) Changing σ



(d) Changing ϵ_p



(e) Changing ϕ



(f) Changing ϕ_π

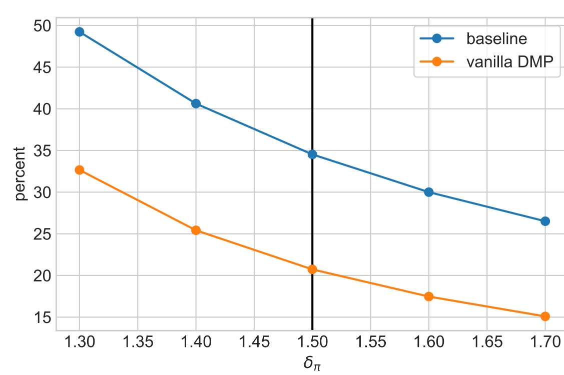


Figure E.2: Robustness I: URC with alternative calibration choices

Notes: This figure shows how the URC changes with alternative calibration choices. The vanilla DMP model has exogenous separations and free entry. The vertical line indicates the baseline calibration value. The fundamental surplus ratio, $\tilde{m}_{ss}$, is re-estimated to fit the observed variance of unemployment, var(u_t). All other parameters are as in Table 1. The Unemployment Risk Channel (URC) is the difference between the full response and the response with complete markets in percent of the full response.

(a) Changing α (b) Changing θ_{ss}

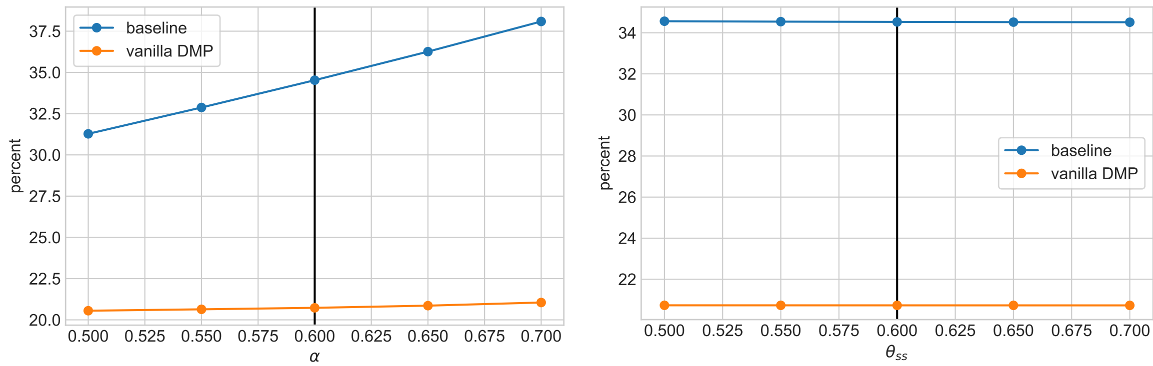


Figure E.3: Robustness II: URC with alternative calibration choices

Notes: See Figure E.2

(a) Changing p (b) Changing κ_0 and ξ

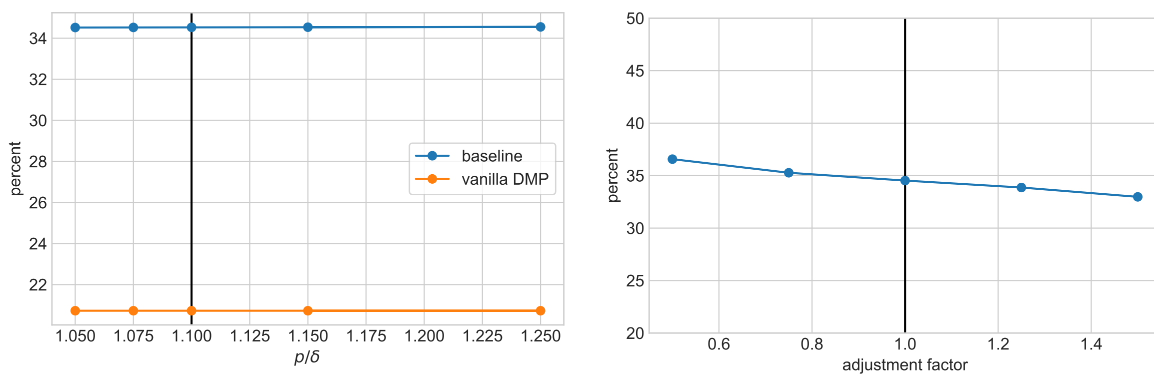


Figure E.4: Robustness III: URC with alternative calibration choices

Notes: See Figure E.2