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ENDOGENOUS JOB DESTRUCTION RISK AND AGGREGATE DEMAND SHORTAGES

by Nicolò Gnocato*

Abstract

This paper studies, analytically and quantitatively, the occurrence of demand-deficient recessions due to uninsurable unemployment risk when jobs are endogenously destroyed. The ensuing unemployment fears induce a precautionary saving motive that counteracts the desire to borrow during recessions: negative productivity shocks may cause falling natural interest rates and positive unemployment gaps. Analytically, these demand-deficient recessions are shown to require a lesser degree of real wage rigidity when jobs are destroyed endogenously rather than exogenously. Quantitatively, the demand-deficient nature of supply-driven recessions can only be captured when accounting for endogenous job destruction.

JEL Classification: E12, E21, E24, E32, J64.

Keywords: heterogeneous agents, unemployment risk, endogenous separation, Keynesian supply shocks.

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1 Introduction

Recent recessions in the euro area have been characterised by deficient demand. For instance, there has recurrently been a surge in the percentage of businesses reporting insufficient demand as a relevant factor limiting their production (Figure 1, panel (a)). Falling natural interest rates, indicating that output fell below potential, suggest as well that these recession episodes have been demand-deficient (Figure 1, panel (b)). While it can be the direct result of negative demand shocks, it is difficult to rationalise this demand deficiency as the result of adverse supply-side shocks, at least according to standard macroeconomic theory. Indeed, in the presence of complete markets, a supply-driven recession would imply a desire to borrow out of better future income prospects, thus helping to sustain rather than depressing aggregate demand. Consequently, there has recently been renewed explicit interest in how negative supply shocks can cause demand shortages (Guerrieri et al., 2022). Actually, at least since the work of Keynes (1936), it has been understood that unemployment fears on the part of households can make a recession worse, as the desire to hoard a buffer stock of savings in light of a heightened risk of income losses can cause sizable falls in demand. In this respect, the empirical literature has indeed documented that workers suffer substantial losses in both income and consumption during unemployment.[1] Recent studies (Den Haan et al., 2018; Ravn and Sterk, 2021; Challe, 2020, among others) have then explicitly modelled these unemployment fears within macroeconomic models featuring imperfect unemployment insurance, wherein an increased risk of becoming unemployed triggers a precautionary saving behaviour on the part of households. Yet, these models are mostly silent about how job losses happen in the first place, as they typically assume an exogenous separation rate, implying that all unemployment risk stems only from reduced job creation rates. However, recessions are also characterised by increased job destruction rates. Hence, an endogenous separation rate cannot be neglected when considering the cyclical properties of worker flows (Fujita and Ramey, 2012). Through the lens of macroeconomic models with uninsurable unemployment risk, it then appears crucial to account for endogenously countercyclical job destruction in explaining how unemployment fears and the precautionary saving behaviour they trigger arise in the first place.

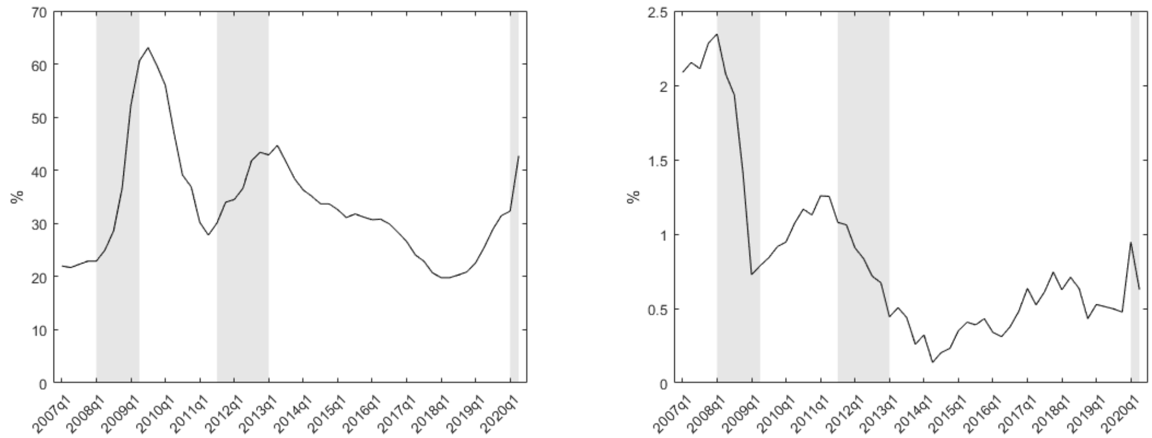
In this paper, I extend the tractable Heterogeneous Agent New Keynesian (HANK) framework with Search and Matching (S&M) frictions of Ravn and Sterk (2021) with endogenous job destruction, showing both analytically and quantitatively how it stands as a key channel in allowing models

[1] Many studies have reported consumption losses ranging from 14% to 26% (Den Haan et al., 2018).

Figure 1: Demand Shortage Indicators for the Euro Area

(a) Insufficient Demand

(b) Natural Interest Rate



Notes: The figure reports, on the left panel, the percentage of businesses in the euro area reporting insufficient demand as a limiting factor to production, according to the business climate survey of the European Commission. The right panel reports estimates of the euro-area natural rate of interest conducted by the NY Fed using the Holston et al. (2017) methodology. Shaded areas correspond to recession episodes in the euro area. *Sources:* European Commission's Business Climate Survey and NY Fed.

with uninsurable unemployment risk to be able to be consistent with demand-deficient recessions. Intuitively, this implies that the probability of becoming unemployed increases both due to an increased job destruction rate and a reduced job-finding probability, while only this latter channel is at work in the exogenous separation case considered e.g. by Ravn and Sterk (2021). Therefore, endogenous job destruction amplifies unemployment risk and strengthens precautionary saving motives out of fears of becoming unemployed, making a demand deficiency more likely when realistically paired with the observed presence of rigid real wages.[2]

From an analytical perspective, whether the endogenous job destruction margin becomes relevant in amplifying unemployment risk and precautionary savings during a productivity-driven recession, compared to a reduced job creation margin alone, is formally shown to depend on the degree of real wage rigidity. When wages can flexibly adjust downward in response to negative productivity shocks, the rise in job destruction and the reduction in job creation are contained, and unemployment risk ends up being contained as well. As a result, the desire to precautionarily save on the part of households is not as strong as the desire to borrow in light of the prospects of future income gains

[2]Macroeconomic models with S&M frictions typically incorporate rigid real wages, as these stand as a necessary feature for explaining the cyclical volatility of unemployment in this class of models (Christiano et al., 2021). However, endogenous job destruction has largely been ignored, to date, in settings with imperfect unemployment insurance.

from improving economic conditions, conditional on remaining employed, and this predominant desire to borrow helps to sustain aggregate demand.

By contrast, the picture can be overturned when real wages respond more sluggishly to the downward pressure exerted by negative productivity shocks. The desire to precautionarily save eventually dominates, causing, under flexible prices, the natural real interest rate to fall, which is a sign that there is a shortage of demand in the economy: in the presence of nominal price rigidity and under simple inflation targeting, as the real interest rate does not adjust in line with the natural rate, this demand deficiency implies a larger surge in unemployment, i.e. a positive unemployment gap. Formally, it is analytically shown that a lower degree of real wage rigidity is required, in the presence of endogenous job destruction risk, to have such an occurrence. Intuitively, with exogenous separation when aggregate productivity falls wage rigidity dampens borrowing desires and reduces job creation incentives, as new matches would be less profitable. When paired with endogenous job destruction, wage rigidity also implies that more existing matches become unprofitable when aggregate productivity falls. As a consequence, the presence of the endogenous job destruction margin amplifies unemployment risk and the precautionary saving motive, making therein demand-deficient recessions a more plausible occurrence.

From a quantitative perspective, accounting for the endogenous job destruction risk channel is shown to be particularly relevant for the so-called "sclerotic" labour markets of continental European countries (Blanchard and Galí, 2010), characterised by low separation and job-finding rates, and high duration of unemployment spells. Through the lens of models with uninsurable unemployment risk, not considering this channel implies ignoring the potential demand-deficient nature of productivity-driven recessions. Indeed, when calibrating the model to target continental European labour markets, the endogenous job destruction risk channel is quantitatively found to be the predominant driver in causing demand shortages: falling natural rates and positive unemployment gaps are primarily the result of increased job destruction rather than reduced job creation. When the endogenous job destruction margin is shut down, even in the presence of a comparable reduction in job creation, the desire to borrow dominates, and the natural interest rate increases, suggesting that aggregate demand is sustained rather than depressed, as indicated as well by a negative unemployment gap.

Related Literature. This paper provides a link between the recent literature on the aggregate impact of uninsured unemployment risk due to incomplete markets (Challe et al., 2017; Ravn and Sterk, 2017, 2021; Den Haan et al., 2018; Challe, 2020) and the earlier literature on search and matching frictions and endogenous job destruction (Mortensen and Pissarides, 1994; Den Haan et al., 2000; Walsh, 2005; Krause and Lubik, 2007; Trigari, 2009).

In Ravn and Sterk (2021) and Challe (2020), due to incomplete markets, households precautionarily save as they cannot fully insure against unemployment risk from reduced job creation. Therefore, greater unemployment risk strengthens precautionary savings, potentially causing a fall in aggregate demand, which would, in turn, feed back to greater unemployment risk due to the presence of nominal rigidities. In my work, greater unemployment risk stems both from reduced job creation and increased job destruction. This strengthens further the precautionary saving motive, causing a more sizeable response in the demand block of the model, i.e. it becomes more plausible that a fall in the natural interest rate and a positive unemployment gap occur during productivity-driven recessions. A closely related paper is Broer et al. (2021), who quantify the unemployment-risk channel in business-cycle fluctuations, allowing not only for endogenous separations but also sluggish vacancy creation. However, their analysis relies only on numerical solutions, while by focusing on a single specific amplification mechanism, posed by endogenous job destruction, I can characterise and investigate its implications not only numerically but also analytically.

My paper also relates to the recently renewed interest in whether negative supply shocks can cause aggregate demand shortages. Guerrieri et al. (2022) present a theory of such so-called Keynesian supply shocks, claiming that while transitory and unanticipated supply shocks are never Keynesian in one-sector economies, they are possible in economies with multiple sectors, and incomplete markets, in particular, make the conditions for Keynesian supply shocks more likely to be met. While Guerrieri et al. (2022) study this issue in a two-sector economy hit by transitory and unanticipated supply shocks, such Keynesian supply shocks can occur as well in a one-sector economy à la Ravn and Sterk (2021) due to the presence of uninsurable unemployment risk when earning risk is sufficiently countercyclical. I build on this by showing that Keynesian supply shocks are indeed most likely when the job destruction margin is endogenised. To my knowledge, this is one of the first attempts to model endogenous job destruction within heterogeneous-household, incomplete-market models.

Roadmap. The remainder of this paper is structured as follows. Section 2 provides empirical motivation by reviewing the empirical evidence on the cyclicality of job destruction. Section 3 describes the model. Section 4 provides an analytical treatment of local fluctuations in response to aggregate productivity shocks. Section 5 deals with quantitative analysis. Section 6 concludes.

Table 1: Relative Contributions to Unemployment Fluctuations

Relative Contribution(%)	Country	Source
25 : 75	US	Shimer (2007, 2012)
43 : 57	Spain	Petrongolo and Pissarides (2008)
29 : 71	UK	Elsby et al. (2011)
15 : 85	Anglo-Saxon	Elsby et al. (2013)
45 : 55	Continental Europe	Elsby et al. (2013)
35 : 65	France	Hairault et al. (2015)

Notes: The table reports the relative contribution (in percentage terms) of the inflow and outflow rates to unemployment fluctuations. Anglo-Saxon countries include Australia, Canada, New Zealand, the United Kingdom, and the United States. Continental European Countries include France, Germany, Italy, Portugal, and Spain.

2 Job Destruction Cyclicality: The Empirical Evidence

The conventional wisdom suggests that increased unemployment during recessions stems primarily from increased job destruction rather than diminished job creation. Pioneering empirical research in this respect was conducted by Davis and Haltiwanger (1992): using the US census of manufacturers over the 1972–1986 period, they documented job creation to be less volatile than job destruction, implying, on net, countercyclical job reallocation.

More recently, Shimer (2007, 2012) has cast doubts on this previously established conventional wisdom that recessions are periods characterised primarily by a high exit rate from employment, claiming instead that most of the fluctuations in the US unemployment rate since 1987 were a consequence of movements in the job-finding rate alone. However, this conclusion for the US economy has been challenged by Fujita and Ramey (2009) and Elsby et al. (2009), who have concluded instead that a complete understanding of cyclical unemployment requires as well an explanation of countercyclical separation rates, especially for layoffs. This conclusion holds even more strongly for Continental European countries. Some evidence in this regard is summarised in Table 1, which reports the relative contributions of inflow (separation) and outflow (job-finding) rates to unemployment fluctuations, according to various studies.

Overall, Pissarides (2009) claims that consensus estimates for the relative contribution of the inflow rate lie between one-third and one-half of the total, concluding that one should model cyclicality in both the flows in and out of unemployment.

In other words, a complete understanding of unemployment fluctuations requires modelling fluctuations in both job-finding and separation rates (Elsby et al., 2013). To this respect, Fujita and Ramey (2012) show that standard S&M models with a constant separation rate fail to produce realistic volatility and productivity responsiveness of the separation rate and worker flows, while models with endogenous and countercyclical separation succeed along these dimensions.

3 The Model

In the model I construct, households face uninsurable unemployment risk, and job destruction is endogenous. In this vein, my model matches, on the household side, Challe (2020) and Ravn and Sterk (2021) in modelling incomplete markets and imperfect insurance. On the producer side, firms/matches are allowed to differ idiosyncratically in their productivity in a similar way as they do in S&M models with endogenous separation.[3]

3.1 Households

On the household side, risk-neutral firm owners simply collect and consume hand-to-mouth the dividends they collect from the firms they manage. Separately from them, there is a unit measure of workers. All these workers cannot borrow. Due to their inability to borrow, workers cannot perfectly insure against the risk of income losses from unemployment.[4]

Formally, at any period, a worker $h \in [0,1]$ can be either employed ($n_{ht} = 1$) or unemployed ($n_{ht} = 0$), and solves

$$\max_{\{c_{ht}, a_{ht}\}_{t=0}^{\infty}} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \ln(c_{ht}) \right]$$

subject to, for all $t \geq 0$,

$$\begin{cases} c_{ht} + b_{ht} = n_{ht}\, w_t + (1 - n_{ht})\, \delta + R_{t-1}\, b_{h,t-1} \\ b_{ht} \geq 0 \end{cases}$$

where c_{ht} is current period consumption, b_{ht} is the amount of assets held at the end of period

[3] Mortensen and Pissarides (1994) extend Pissarides's (1985) model to allow for idiosyncratic productivity shocks: adverse aggregate shocks raise the threshold for maintaining employment relationships, leading to the termination of less productive matches. Den Haan et al. (2000) model endogenous job destruction within a dynamic general equilibrium setting, while Walsh (2005) builds on this by introducing money and nominal price rigidity.

[4] As will become clear later, when discussing the equilibrium, modelling risk-neutral firm owners separately from workers and assuming that these cannot borrow will deliver high analytical tractability of the model.

t, R_t is the gross real return on assets, w_t is wage income deriving from employment, and δ are unemployment benefits obtained when unemployed.

3.2 Firms

Producers use only labour as input, which is hired in a frictional market. Active employment relationships (matches) produce a_{it} units of output at each period (provided no separation occurs), and a_{it} is composed of a match-specific and an aggregate component

$$a_{it} = a_t \, \varphi_{it}$$

where the match-specific component, φ_{it}, is *iid* both across firms and over time and has CDF $G(\varphi)$ and PDF $g(\varphi)$, while a_t represents a common random productivity disturbance which is orthogonal to φ_{it} and assumed to follow an exogenous AR(1) process (in logs)

$$\ln(a_t) = \gamma_a \, \ln(a_{t-1}) + \xi_t$$

with $\xi_t \sim iid(0, \sigma_\xi^2)$, and $\gamma_a \in [0, 1)$.

Matching Technology. Labour market frictions are summarised by an aggregate matching function, which is assumed to take a Cobb-Douglas form with constant returns to scale,

$$m_t = \mathcal{M} \, e_t^{\alpha} \, v_t^{(1-\alpha)}$$

where m_t denotes the total amount of formed matches, $\mathcal{M}$ is a matching efficiency parameter, $\alpha \in (0, 1)$, v_t is the total amount of vacancies, and $e_t = u_{t-1} + \rho_t \, n_{t-1}$ is the total amount of searching workers, including those already unemployed, u_{t-1}, and those (previously) employed workers, n_{t-1}, that experience separation in the current period (at a rate ρ_t).

Letting market tightness be defined as $\vartheta_t = v_t / e_t$, the matching probability for vacancies and the matching probability for searching workers are given, respectively, by

$$q_t = \frac{m_t}{v_t} = \mathcal{M} \, \vartheta_t^{-\alpha} \,, \qquad f_t = \frac{m_t}{e_t} = \mathcal{M} \, \vartheta_t^{(1-\alpha)}$$

Timing. Aggregate and idiosyncratic productivity shocks are realised at the beginning of each period. Once a_t and φ_{it} are realised, job destruction and job creation occur: first, an endogenously determined fraction of old matches break up; then, new matches are formed, and active producers and employed workers collectively set the wage rate w_t. After this, households make their consumption/saving decisions.

Value Functions. The value of a match for a firm with idiosyncratic productivity φ is

$$J_t(\varphi) = a_t\,\varphi - w_t + \beta\,\mathbb{E}_t\left[(1-\rho^x)\int_{\varphi^*_{t+1}}^{\infty} J_{t+1}(\varphi)\,g(\varphi)\,d\varphi\right] \tag{1}$$

where the wage rate w_t is the same across producers, ρ^x is the exogenous separation rate, and φ^*_{t+1} is the threshold below which a match will become unprofitable, and hence will be endogenously destroyed: since $J_t(\varphi)$ is monotonically increasing in φ, and all firms face the same aggregate shocks, the endogenous job destruction cutoff, φ^*_t, will be determined, at every period, by the condition

$$J_t(\varphi^*_t) = 0$$

and matches with $\varphi_{it} \geq \varphi^*_t$ will be actively producing, while matches with $\varphi_{it} < \varphi^*_t$ will not and break up. Therefore, the total separation rate, associated with φ^*_t, is given by

$$\rho_t := \rho^x + (1-\rho^x)\,G\left(\varphi^*_t\right) \tag{2}$$

When matches break up, inactive producers (which are ex-ante symmetric) post vacancies at a cost of κ units of the final good per vacancy per period, and each vacancy is filled with probability q_t. The value of a vacancy is therefore equal across producers, and given by

$$V_t = -\kappa + q_t\,J_t + [1-q_t]\;\beta\,\mathbb{E}_t\left(V_{t+1}\right) \tag{3}$$

where

$$J_t := \frac{1}{\left[1-G\left(\varphi^*_t\right)\right]}\int_{\varphi^*_t}^{\infty} J_t(\varphi)\,g(\varphi)\,d\varphi$$

Lastly, given the assumptions on the production structure, aggregate dividends collected by firm owners are given by

$$d_t = n_t\,\left[a_t\,\overline{\varphi}_t - w_t\right] - \kappa\,v_t$$

where n_t denotes total employed workers, $\overline{\varphi}_t := \mathbb{E}(\varphi\,|\,\varphi \geq \varphi^*_t)$, and v_t is the total amount of vacancies.

Employment Dynamics. The laws of motion of employment and unemployment are[5]

$$n_{t+1} = [1 - \lambda_{t+1}]\, n_t + f_{t+1}\, u_t \tag{4}$$

$$u_{t+1} = 1 - n_{t+1} = \lambda_{t+1}\, n_t + [1 - f_{t+1}]\, u_t \tag{5}$$

where, since a currently employed worker experiences separation with probability given by the total separation rate ρ_{t+1} and, in that case, finds a new job with probability f_{t+1}, the probability that a currently employed worker is without a job next period is given by

$$\lambda_{t+1} = \rho_{t+1}\, [1 - f_{t+1}] \tag{6}$$

3.3 Equilibrium

Definition 1. *An equilibrium is a set of sequences of optimal household and producer choices such that (i) markets clear, (ii) labour market variables evolve according to (2) and (4)–(6), (iii) wages satisfy the collective wage-setting rule, and (iv) the Job Destruction and Free Entry conditions hold.*

A relevant feature of the equilibrium lies in its zero-liquidity property, allowing good tractability of the precautionary motive within the model: given the zero debt limit households face, the supply of assets is zero in equilibrium, no asset trade actually takes place, and all households turn out to consume their current income. This allows the precautionary motive to be operative without the need to track a full and time-varying wealth distribution.[6]

Intuitively, in standard complete-market models without capital, the consumption smoothing motive for saving or borrowing is operative also when assets are in zero supply: when the real interest rate goes down, households want to bring consumption to the present; with no assets to liquidate or disinvest from, their income adjusts to deliver equilibrium. Similarly, in this incomplete-market setting, when employed workers wish to save for precautionary reasons, this puts downward pressure on the real interest rate, which must fall to ensure that employed workers are not actually willing to save, so that savings are exactly zero at equilibrium. Given this, unemployed workers and firm owners would wish to borrow to bring consumption to the current period but cannot do so due

[5] Given that there are $e_{t+1} = u_t + \rho_{t+1}\, n_t$ searching workers, the law of motion for employed workers can equivalently be stated as $n_{t+1} = (1 - \rho_{t+1})\, n_t + f_{t+1}\, e_{t+1}$.

[6] This feature of the model is directly drawn from Challe (2020) and the earlier literature achieving tractability in incomplete-market models by assuming that no agent can borrow: see, among others, Bilbiie (2019); Krusell et al. (2011); McKay et al. (2017); McKay and Reis (2016, 2021); Ravn and Sterk (2017, 2021); Werning (2015).

to borrowing constraints. Therefore, equilibrium income adjusts accordingly, bringing about the desired reduction in consumption for precautionary motives with no actual saving or borrowing occurring.

How this property formally arises will now be described in more detail, along with the other equilibrium conditions.

3.3.1 Market Clearing

Bonds. The market clearing condition for bonds is given by

$$(1 - n_t)\, b_t^u + n_t\, b_t^n = 0 \tag{7}$$

where superscripts n and u refer to employed and unemployed workers, respectively.

Given that unemployed workers wish to borrow but are liquidity-constrained, we have $b_t^u = 0$; as a result and as already mentioned, even though employed workers wish to precautionarily save, bonds market clearing implies that, at equilibrium, no agent is issuing the bonds that would allow them to do so. As a result, also $b_t^n = 0$, and all households indeed consume all their current income.

Goods. The total supply of the final good is $Y_t + (1 - n_t)\,\delta$, where $Y_t = n_t\, a_t\, \overline{\varphi}_t$, and it provides for household consumption and vacancy posting. Given that all households consume their current income, we have

$$\underbrace{[n_t\, w_t + (1 - n_t)\,\delta]}_{\int_0^1 c_{ht}\, dh} + d_t \,+\, \kappa\, v_t \,=\, Y_t \,+\, (1 - n_t)\,\delta \tag{8}$$

3.3.2 Optimal Household Decisions

Taking into account the fact that all workers consume their current income (be it δ or w_t), Euler conditions for employed workers and unemployed workers are, respectively,

$$1 \geq \beta\, \mathbb{E}_t \left[\frac{(1 - \lambda_{t+1})\, u'(w_{t+1}) + \lambda_{t+1}\, u'(\delta)}{u'(w_t)}\, R_t \right] \tag{9}$$

$$1 \geq \beta\, \mathbb{E}_t \left[\frac{(1 - f_{t+1})\, u'(\delta) + f_{t+1}\, u'(w_{t+1})}{u'(\delta)}\, R_t \right] \tag{10}$$

each holding with strict inequality if the household is liquidity-constrained (i.e. wishing to borrow) and with equality otherwise.

At equilibrium, given that employed workers wish to precautionarily save, their Euler condition in (9) holds with equality. Conversely, unemployed workers wish to borrow but face a binding liquidity constraint; their Euler conditions hence hold with inequality. These equilibrium conditions hold at the steady state, provided that $\delta < w$, as well as in stochastic equilibrium in the steady state neighbourhood, provided that aggregate shocks are not too large.[7] Formally,

Proposition 1. *At steady state, provided that $\delta < w$, Euler conditions for employed workers and unemployed workers are, respectively,*

$$
\begin{aligned}
1 &= \beta \left[\frac{(1-\lambda)\, u'(w) + \lambda\, u'(\delta)}{u'(w)} R \right] \\
1 &> \beta \left[\frac{(1-f)\, u'(\delta) + f\, u'(w)}{u'(\delta)} R \right]
\end{aligned}
$$

Proof. See Appendix B.1. □

It is also worth stressing how a binding liquidity constraint for the unemployed (i.e. their Euler condition holding with inequality) is intimately associated with imperfect insurance against unemployment. If asset trading was not constrained by a borrowing limit, then the employed and the unemployed would trade assets up to the point where their consumption level would be equalised, but this would be at odds with the evidence of consumption dropping upon unemployment. Another limiting case, where consumption still would be equalised but without any asset trading needed, is when $\delta = w$. In any case, a lower consumption level for the unemployed requires that these face a binding liquidity constraint and that their Euler equation holds with inequality.[8] Formally, if that was not the case,

Proposition 2. *Suppose that the Euler conditions of both agents hold with equality at steady state. Then, their consumption is equalised.*

Proof. See Appendix B.2. □

[7] See Ravn and Sterk (2021) and Challe (2020) for more details.

[8] One can, however, argue that zero borrowing is an extreme assumption and that the unemployed could face a binding, but not necessarily zero, borrowing constraint. This possibility is explored numerically in an extension to the quantitative analysis in Section 5, as the presence of a non-zero borrowing constraint makes the model analytically intractable.

3.3.3 Job Destruction and Free Entry Conditions

The exit cutoff φ_t^* is characterised by the following Job Destruction (JD) condition

$$J_t(\varphi_t^*) = 0 \iff a_t\,\varphi_t^* - w_t + \beta\,\mathbb{E}_t\left[(1-\rho^x)\int_{\varphi_{t+1}^*}^{\infty} J_{t+1}(\varphi)\,g(\varphi)\,d\varphi\right] = 0 \tag{JD}$$

With free entry into vacancy posting, the value of posting a vacancy ends up being zero at every period, delivering the following condition

$$\frac{\kappa}{q_t} = J_t \tag{FE}$$

where, combining (1) and (JD), we have $J_t(\varphi) = a_t\,(\varphi - \varphi_t^*)$, for every t, so that

$$\frac{\kappa}{q_t} = \frac{1}{[1-G(\varphi_t^*)]}\int_{\varphi_t^*}^{\infty} J_t(\varphi)\,g(\varphi)\,d\varphi = a_t\,[\overline{\varphi}_t - \varphi_t^*]$$

Moreover, using (FE) into (JD), we get the following expression for the job destruction cutoff

$$a_t\,\varphi_t^* = w_t - \beta\,\mathbb{E}_t\left[(1-\rho_{t+1})\,\frac{\kappa}{q_{t+1}}\right] \tag{11}$$

from this, we can see that ceteris paribus, a higher wage rate is associated with a higher job destruction cutoff, and an expected tighter market is associated with a lower job destruction cutoff.

A higher wage directly implies a higher productivity cutoff above which producers can break even. An expected tighter market implies that vacancies will be harder to fill, and hence producers expect to incur higher costs if they decide to break a match and seek to form another, hopefully more productive one. Hence, this discourages match destruction and is associated with a lower job destruction threshold.

Also, a higher level of aggregate productivity a_t implies a higher production for all matches; therefore, ceteris paribus, matches of lower idiosyncratic productivity can now break even, implying a lower job destruction cutoff. This effect can then amplify the impact of aggregate productivity shocks on output (as emphasised by Den Haan et al., 2000).

However, all these considerations are only valid under partial equilibrium, as aggregate productivity shocks also impact the wage rate as well as the continuation value of the match, κ/q_t.

3.3.4 Wage Setting and Real Wage Rigidity

In the spirit of Jimeno and Thomas (2013), I assume that the wage is the same across producers, resulting from a collective wage-setting rule rather than a match-specific one. This is consistent with the presence of unionised labour markets and simplifies the treatment of the model on both the producer and the household sides.[9]

Moreover, it is assumed that wages adjust sluggishly to shocks. All in all, as noted by Blanchard and Galí (2010), how to formalise real wage rigidity still remains an open research question.[10] Hence, to keep the analysis as simple as possible and clearly highlight the role played by wage rigidity, in what follows, I assume a wage schedule of the form

$$w_t = w\, a_t^{\chi} \tag{12}$$

where $\chi \in [0, \overline{\chi}_w]$ is an index of real wage rigidities, and w is the steady-state wage rate under Nash bargaining. Notice that $\chi = 0$ corresponds to the case of fully rigid wages. $\chi = \overline{\chi}_w$ corresponds instead to the case of flexible wages (under standard Nash bargaining), with the composite parameter $\overline{\chi}_w$ depending on the nature of job separations (exogenous or endogenous) and explicitly outlined in Appendix A.

3.3.5 Summary of the Equilibrium Conditions

I end up with 11 equations determining 11 endogenous variables of interest: λ_t, w_t, R_t, Y_t, ϑ_t, φ_t^*, n_t, u_t, ρ_t, q_t, f_t. The full set of equilibrium conditions is summarised in Table 2, along with the equilibrium conditions of a comparable model with symmetric matches and exogenous separation.

Steady State. The steady state of the two models is summarised in Table 3; these are assumed to differ only in their underlying transitional dynamics while delivering the same steady-state magnitudes.

Proposition 3. *At steady state, for a given job-finding probability f and total separation rate ρ, the wage rate and the job destruction cutoff are given, respectively, by*

$$w = \frac{\left[1 + \frac{\beta\, f\,(1-\rho)}{1-\beta\,(1-\rho)}\right]}{\left[\left(\frac{1-\eta}{\eta}\right)\,\zeta + 1 + \frac{\beta\, f\,(1-\rho)}{1-\beta\,(1-\rho)}\right]}$$

[9] In most continental European countries, wage setting takes place predominantly in the form of collective agreements (Du Caju et al., 2008).

[10] See Appendix A for a more detailed discussion.

Table 2: Model Summary

$1 = \beta\, \mathbb{E}_t \left[\frac{(1-\lambda_{t+1})\, u'(w_{t+1}) + \lambda_{t+1}\, u'(\delta)}{u'(w_t)}\, R_t \right]$	
$w_t = w\, a_t^{\chi}$	
$q_t = \mathcal{M}\, \vartheta_t^{-\alpha}$	
$f_t = \mathcal{M}\, \vartheta_t^{(1-\alpha)}$	
$n_{t+1} = [1 - \lambda_{t+1}]\, n_t + f_{t+1}\, (1 - n_t)$	
$u_{t+1} = 1 - n_{t+1}$	
Endogenous Separation	**Exogenous Separation**
$\rho_t = \rho^x + (1 - \rho^x)\, G\,(\varphi_t^*)$	—
$\lambda_{t+1} = \rho_{t+1}\, [1 - f_{t+1}]$	$\lambda_{t+1} = \rho\, [1 - f_{t+1}]$
$\frac{\kappa}{q_t} = a_t\, [\overline{\varphi}_t - \varphi_t^*]$	$\frac{\kappa}{q_t} = a_t - w_t + \beta\, \mathbb{E}_t \left[(1 - \rho)\, \frac{\kappa}{q_{t+1}} \right]$
$a_t\, \varphi_t^* = w_t - \beta\, \mathbb{E}_t \left[(1 - \rho_{t+1})\, \frac{\kappa}{q_{t+1}} \right]$	—
$Y_t = n_t\, a_t\, \overline{\varphi}_t$	$Y_t = n_t\, a_t$

Notes: $\rho = \rho^x + (1 - \rho^x)\, G\,(\varphi^*)$ is the steady-state separation rate of the endogenous job destruction model, as well as the exogenous (and constant) separation rate of the exogenous job destruction model.

$$\varphi^* = \frac{w - \beta\,(1 - \rho)}{1 - \beta\,(1 - \rho)}$$

where $\zeta := [(w - \delta)/w] \in (0, 1)$. *Moreover, the following inequality holds*

$$\varphi^* < w < 1$$

Proof. See Appendix B.3. □

4 Local Fluctuations

In this section, I study analytically local fluctuations in the neighbourhood of the steady state in response to aggregate productivity shocks. As will become clearer later, it shall be stressed that, unlike standard, complete-market models, focusing on a first-order log approximation does not eliminate the precautionary saving motive from this setting. Indeed, in standard, complete-market models, a precautionary saving motive can arise due to so-called prudence, i.e. convexity of the first derivative of the utility function, and hence disappears when focusing on first-order approximations.

Table 3: Steady State

$1 = \beta\, R\left[1 + \lambda\left(\frac{\zeta}{1-\zeta}\right)\right]$	
$\lambda = \rho\,(1-f)$	
$f = \mathcal{M}\,\vartheta^{(1-\alpha)}$	
$q = \mathcal{M}\,\vartheta^{-\alpha}$	
$u = \frac{\lambda}{\lambda+f}$	
$n = 1-u$	
$Y = n$	
$w = \eta + \eta\,\kappa\,\beta\,(1-\rho)\,\vartheta + (1-\eta)\,\delta$	
Endogenous Separation	**Exogenous Separation**
$\rho = \rho^x + (1-\rho^x)\,G\,(\varphi^*)$	—
$\frac{\kappa}{q} = 1-\varphi^*$	$\frac{\kappa}{q} = 1 - w + \beta\,(1-\rho)\,\frac{\kappa}{q}$
$\varphi^* = w - \beta\,(1-\rho)\,\frac{\kappa}{q}$	—

Notes: Aggregate productivity, a, and average idiosyncratic productivity at steady state, $\overline{\varphi} = \mathbb{E}\,(\varphi\,|\,\varphi \geq \varphi^*)$, are both normalised to 1 so that the two models deliver the same steady-state magnitudes. The parameter $\zeta = [(w-\delta)/w] \in (0,1)$ captures the steady-state amount of unemployment insurance.

By contrast, in this case, the precautionary motive arises due to the presence of liquidity constraints, which imply imperfect insurance against unemployment —as formally shown in propositions 1 and 2— and whose effect persists regardless of the approximation order.

In what follows, I will first formally show how this precautionary saving motive arises in the presence of imperfect unemployment insurance, posing a drag on aggregate demand and exerting downward pressure on the natural rate of interest. I will then move to analytically comparing the precautionary saving motive in the endogenous job destruction model with the exogenous job destruction case, formally showing how it is amplified in the former case and in the presence of real wage rigidity.

The log-linearised model. Let $\widehat{z}_t$ denote log deviations from their steady-state value, z, i.e. $\widehat{z}_t = \ln(z_t) - \ln(z)$. The log-linearised model resulting from first-order (log) approximation around the steady state is summarised in Table 4.

Focusing on the log-linearised Euler equation, we can distinguish —as already highlighted by Challe (2020)— two main forces shaping the response of the (natural) real interest rate: a standard

Table 4: SUMMARY OF THE LOG-LINEAR MODEL

$$\widehat{r}_t = -\left[\frac{\rho\,(1-f)\,\zeta}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right]\mathbb{E}_t\left(\widehat{\lambda}_{t+1}\right) + \left\{(1-\zeta)\left[\frac{1-\rho\,(1-f)}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right]\mathbb{E}_t\left(\widehat{w}_{t+1}\right) - \widehat{w}_t\right\}$$

$$\widehat{q}_t = -\alpha\,\widehat{\vartheta}_t$$

$$\widehat{f}_t = (1-\alpha)\,\widehat{\vartheta}_t$$

$$\widehat{n}_{t+1} = -\lambda\,\widehat{\lambda}_{t+1} + (1-\lambda)\,\widehat{n}_t + \lambda\,\widehat{f}_{t+1} + \lambda\,\widehat{u}_t$$

$$\widehat{u}_{t+1} = -\left(\frac{1-u}{u}\right)\widehat{n}_{t+1}$$

$$\widehat{w}_t = \chi\,\widehat{a}_t$$

$$\widehat{a}_t = \gamma_a\,\widehat{a}_{t-1} + \xi_t$$

Endogenous Separation	Exogenous Separation
$\widehat{y}_t = \widehat{n}_t + \widehat{a}_t + [\tau\,(1-\varphi^*)]\,\widehat{\varphi}^*_t$	$\widehat{y}_t = \widehat{n}_t + \widehat{a}_t$
$\widehat{\rho}_t = \left[\tau\,\left(\frac{1-\rho}{\rho}\right)\right]\widehat{\varphi}^*_t$	—
$\widehat{\lambda}_{t+1} = \widehat{\rho}_{t+1} - \left(\frac{f}{1-f}\right)\widehat{f}_{t+1}$	$\widehat{\lambda}_{t+1} = -\left(\frac{f}{1-f}\right)\widehat{f}_{t+1}$
$\alpha\,\widehat{\vartheta}_t = \widehat{a}_t - \left(\frac{1}{1-\varphi^*}\right)[\varphi^* - \tau\,(1-\varphi^*)]\,\widehat{\varphi}^*_t$	$\alpha\,\widehat{\vartheta}_t = \frac{\widehat{a}_t}{\kappa/q} - \left(\frac{w}{\kappa/q}\right)\widehat{w}_t + \beta\,(1-\rho)\,\mathbb{E}_t\left(\alpha\,\widehat{\vartheta}_{t+1}\right)$
$\widehat{\varphi}^*_t = \left(\frac{w}{\varphi^*}\right)\widehat{w}_t - \widehat{a}_t + \beta\,(1-\rho)\left(\frac{1-\varphi^*}{\varphi^*}\right)\mathbb{E}_t\left(\tau\,\widehat{\varphi}^*_{t+1} - \alpha\,\widehat{\vartheta}_{t+1}\right)$	—

Notes: The parameter $\zeta = [(w-\delta)/w] \in (0,1)$ captures the steady-state amount of unemployment insurance. $\rho = \rho^x + (1-\rho^x)\,G(\varphi^*)$ is the total separation rate in the steady state of the endogenous separation model, as well as the constant separation rate of the exogenous job destruction model. $\tau = \left[\frac{\varphi^*\,g(\varphi^*)}{1-G(\varphi^*)}\right]$, where $g(\varphi^*)$ and $G(\varphi^*)$ are, respectively, the PDF and CDF of the idiosyncratic productivity parameter φ, evaluated at the steady-state job destruction threshold φ^*.

consumption smoothing motive, and a precautionary motive.

$$\hat{r}_t = \underbrace{-\left[\frac{\rho\,(1-f)\,\zeta}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right]\mathbb{E}_t\left(\widehat{\lambda}_{t+1}\right)}_{\text{precautionary motive}} + \underbrace{\left\{(1-\zeta)\left[\frac{1-\rho\,(1-f)}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right]\mathbb{E}_t\left(\widehat{w}_{t+1}\right) - \hat{w}_t\right\}}_{\text{standard consumption smoothing motive}} \quad (13)$$

where the parameter $\zeta = [(w-\delta)/w] \in (0,1)$, representing the percentage loss in equilibrium consumption upon unemployment, captures the steady-state amount of unemployment insurance ($\zeta = 0$ in the limit of full insurance at steady state).

To understand the two opposite forces shaping the response of the natural interest rate, it is useful to consider, in turn, the extreme cases of perfect insurance and constant wages. In the perfect insurance limit ($\zeta \to 0$), the precautionary motive completely disappears, and the response of the natural rate is entirely driven by the standard consumption smoothing motive; as a consequence, if households expect an increasing wage profile, they wish to borrow, and this puts upward pressure on the natural interest rate. By contrast, in the constant wage case ($\chi = 0$), only the precautionary motive is operative: an increase in the risk of losing the current occupation (and not being swiftly able to find another one) increases the desire to hold a buffer stock of savings, putting downward pressure on the natural interest rate.

Coming back to the general case, for a given real wage elasticity χ, the standard consumption smoothing motive is the same in the exogenous job destruction and endogenous job destruction cases. What differs is the precautionary motive, as driven by unemployment risk, $\mathbb{E}_t\left(\widehat{\lambda}_{t+1}\right)$. In the exogenous job destruction case, its only driver is the job-finding probability, as

$$\widehat{\lambda}_{t+1} = -\left(\frac{f}{1-f}\right)\widehat{f}_{t+1}\,.$$

By contrast, in the endogenous job destruction case, unemployment risk is driven both by changes in the probability of losing a job in the first place as well as by changes in the job-finding probability after the job loss, as

$$\widehat{\lambda}_{t+1} = \widehat{\rho}_{t+1} - \left(\frac{f}{1-f}\right)\widehat{f}_{t+1}\,.$$

Therefore, in order to have amplification of a contractionary shock in the endogenous case, compared to the exogenous case, one needs countercyclical variations in the job destruction threshold, as well as procyclical variations in the job-finding probability that are comparable in the two cases. When this occurs, the presence of an endogenous job destruction margin amplifies unemployment risk and strengthens the precautionary motive, making a fall in the natural interest rate (a symptom of demand deficiency in the current period) more likely.

Equilibrium Responses. To formally assess whether and how endogenous job destruction amplifies unemployment risk, strengthening therein the precautionary motive after a contractionary shock, I now solve for local dynamics in the neighbourhood of the steady state. The equilibrium responses to aggregate productivity shocks of the log-linear endogenous job destruction model can be fully characterised starting from those of the job destruction cutoff, $\widehat{\varphi}_t^*$, and market tightness, $\widehat{\vartheta}_t$, from which the dynamics of all the other relevant variables can be determined. In the exogenous separation case, it is instead sufficient to characterise the equilibrium response of market tightness, $\widehat{\vartheta}_t$, to then residually pin down the dynamics of the other variables. These equilibrium responses are summarised in the following proposition.

Proposition 4. *In the endogenous job destruction case, the equilibrium responses to aggregate productivity shocks of the job destruction cutoff and market tightness are given by*

$$\widehat{\vartheta}_t = \mathcal{A}_{\vartheta}^{a}\,\widehat{a}_t \tag{14}$$

$$\widehat{\varphi}_t^* = -\mathcal{A}_\varphi^a \, \widehat{a}_t \tag{15}$$

with

$$\mathcal{A}_\vartheta^a = \frac{1}{\alpha} \left(\frac{1}{1-\varphi^*} \right) \left[\frac{1}{1-\beta\,\gamma_a\,(1-\rho)} \right] \left\{ (1-\mathcal{C}_\vartheta^a) - \chi\, w \left[1 - \tau \left(\frac{1-\varphi^*}{\varphi^*} \right) \right] \right\}$$
$$\mathcal{A}_\varphi^a = \frac{w}{\varphi^*} \left[\frac{1}{1-\beta\,\gamma_a\,(1-\rho)} \right] (\overline{\chi}_c - \chi)$$

where

$$\mathcal{C}_\vartheta^a = \tau \left(\frac{1-\varphi^*}{\varphi^*} \right) w\,\overline{\chi}_c$$
$$\overline{\chi}_c = 1 - \left[\frac{\beta\,(1-\rho)\,(1-\gamma_a)}{1-\beta\,(1-f)\,(1-\rho)} \right] \left(\frac{1-\eta}{\eta} \right) \zeta$$

In the exogenous job destruction case, the equilibrium response to aggregate productivity shocks of market tightness is given by

$$\widehat{\vartheta}_t = \mathcal{B}_\vartheta^a \, \widehat{a}_t \tag{16}$$

where

$$\mathcal{B}_\vartheta^a = \frac{1}{\alpha} \left(\frac{1}{\kappa/q} \right) \left[\frac{1}{1-\beta\,\gamma_a\,(1-\rho)} \right] (1-\chi\, w)$$

We can notice, in particular, that more rigid wages (i.e. a lower χ) amplify the response of both market tightness and the job destruction cutoff. Hence, a lower χ implies higher unemployment risk and a stronger precautionary saving motive. This points towards the fact that below a certain value of χ, the precautionary motive will become so strong to offset the standard consumption smoothing motive, causing the natural interest rate to fall during a productivity-driven downturn. This result is summarised in the following corollary for the $\alpha = \eta$ case.

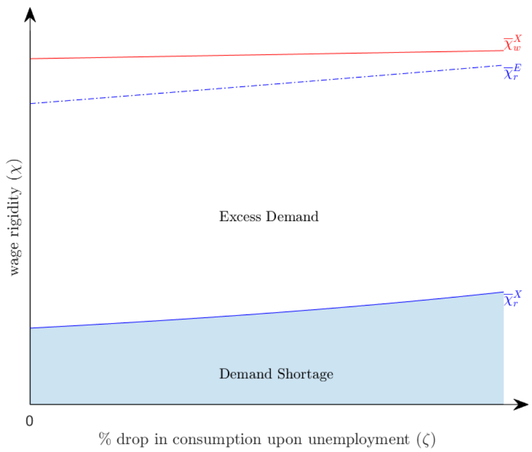
Corollary 4.1. *The natural interest rate responds pro-cyclically to aggregate productivity shocks provided that*

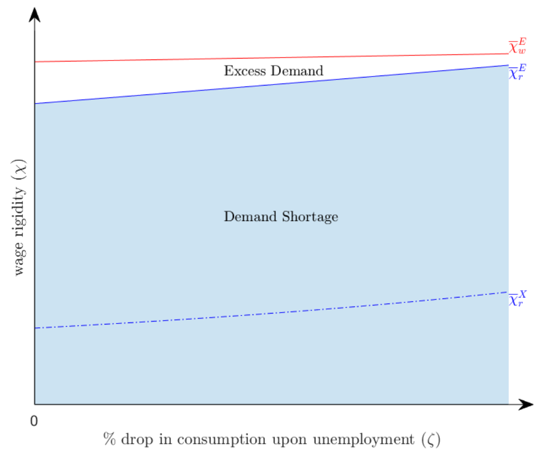
$$\chi < \overline{\chi}_r^X = \frac{1}{w} \left\{ \frac{1}{1 + \left(\frac{1}{\rho\, f\, \gamma_a} \right) \left[\frac{1-\beta\,\gamma_a\,(1-\rho)}{1-\beta\,(1-f)\,(1-\rho)} \right] \{ [(1-\gamma_a) + \gamma_a\,\rho\,(1-f)]\,(1-\zeta) + \rho\,(1-f)\,\zeta \}} \right\}$$

Figure 2: Demand Behavior under a Contractionary Productivity Shock

(a) Exogenous Separation

(b) Endogenous Separation





Notes: The figure reports upper bounds on the wage elasticity χ. $\overline{\chi}_w^j$, $j \in \{X, E\}$, is the maximum value χ can take, corresponding to the flexible wage case. $\overline{\chi}_r^j$, $j \in \{X, E\}$, are bounds below which the precautionary motive dominates and, hence, the natural interest rate falls. On the horizontal axis, $\zeta \in (0, 0.5]$, while the other parameters are $\beta = 0.99$, $\rho = 0.02$, $f = 0.2$, $\alpha = \eta = 0.7$. The sorting of the bounds depicted in the figure is robust to plausible alternative parametrisations.

in the exogenous job destruction case, and provided that

$$\chi < \overline{\chi}_r^E = \frac{\frac{1}{w} + \tau\left(\frac{1-\varphi^*}{\varphi^*}\right)\left[\left(\frac{\alpha}{1-\alpha}\right)\left(\frac{1-f}{f}\right)\left(\frac{1-\rho}{\rho}\right) - 1\right]\overline{\chi}_c}{\frac{1}{w\,\overline{\chi}_r^X} + \tau\left(\frac{1-\varphi^*}{\varphi^*}\right)\left[\left(\frac{\alpha}{1-\alpha}\right)\left(\frac{1-f}{f}\right)\left(\frac{1-\rho}{\rho}\right) - 1\right]}$$

in the endogenous job destruction case. Moreover, $\overline{\chi}_r^X < \overline{\chi}_r^E$*, provided that* $\overline{\chi}_r^X < \overline{\chi}_c$*.*

The requirement $\overline{\chi}_r^X < \overline{\chi}_c$ is, in turn, equivalent to the following parameter restriction

$$\frac{1 - \left[\frac{\beta\,(1-\rho)\,(1-\gamma_a)}{1-\beta\,(1-f)\,(1-\rho)}\right]\left(\frac{1-\eta}{\eta}\right)\zeta}{1 + \left[\frac{1-\beta\,\gamma_a\,(1-\rho)}{1-\beta\,(1-f)\,(1-\rho)}\right]\left(\frac{1-\eta}{\eta}\right)\zeta}$$
$$> \frac{1}{1 + \left(\frac{1}{\rho\,f\,\gamma_a}\right)\left[\frac{1-\beta\,\gamma_a\,(1-\rho)}{1-\beta\,(1-f)\,(1-\rho)}\right]\{[(1-\gamma_a) + \gamma_a\,\rho\,(1-f)]\,(1-\zeta) + \rho\,(1-f)\,\zeta\}}$$

which holds for plausible parameter values and targets.

Figure 2 illustrates these results. We can notice that, first, the fully flexible wage case ($\chi = \overline{\chi}_w$) is always characterised by excess rather than deficient demand. Most prominently, we can notice that regardless of the amount of incomplete insurance, as captured by ζ, a lighter extent of real wage rigidity —i.e., a lower χ— is sufficient, in the endogenous separation case, to have the precautionary motive dominating on the standard consumption smoothing motive, with a resulting demand shortage.

Intuitively, with endogenous and countercyclical job destruction, unemployment risk is amplified, as a contractionary productivity shock implies not only a reduction in the job-finding probability (as happens in the exogenous job destruction case) but also a higher probability of losing the job in the first place. As a result, it is much more plausible that a contractionary supply shock causes a demand shortage through the precautionary motive compared to the exogenous job destruction case. In particular, wages do not need to be as rigid as in the case of exogenous job destruction to have a fall in the natural interest rate in response to a contractionary aggregate productivity shock.

4.1 Nominal Price Rigidity

So far, the issue of the presence of demand shortages has been analysed under the assumption of flexible prices. However, this implies that output is supply-determined; hence there is no feedback from demand shortages to depressed output at equilibrium. Introducing nominal price rigidity allows to uncover how demand deficiencies, whose symptom is a falling natural interest rate, actually translate into making a recession even worse. Falling natural rates imply indeed a positive unemployment gap under simple inflation targeting, as will be formalised in this section.

With nominal price rigidity (à la Calvo),[11] the log-linear model is first of all characterised by the following Euler condition and Phillips curve[12]

$$
\begin{aligned}
i_t - \mathbb{E}_t\left(\pi_{t+1}\right) &= -\left[\frac{\rho\,(1-f)\,\zeta}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right]\mathbb{E}_t\left(\widehat{\lambda}_{t+1}\right) + \left\{\frac{(1-\zeta)\,\left[1-\rho\,(1-f)\right]}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right\}\mathbb{E}_t\left(\widehat{w}_{t+1}\right) - \widehat{w}_t \\
\pi_t &= \beta\,\mathbb{E}_t\left(\pi_{t+1}\right) + \Omega\,\widehat{x}_t
\end{aligned}
$$

where i_t is the nominal interest rate, π_t is the inflation rate, $\Omega = (1-\omega)\,(1-\beta\,\omega)/\omega$, with ω being the probability that price setters cannot reset their price, and x_t is the real marginal cost. Additionally, in the exogenous separation case, the job creation condition becomes

$$
\alpha\,\widehat{\vartheta}_t = \frac{1}{\kappa/q}\,\left(\widehat{a}_t + \widehat{x}_t\right) - \left(\frac{w}{\kappa/q}\right)\widehat{w}_t + \beta\,(1-\rho)\,\mathbb{E}_t\left[\alpha\,\widehat{\vartheta}_{t+1}\right]
$$

[11] How the structure of the production side of the model is amended to formally introduce price rigidity is outlined in full detail in Appendix C.

[12] Log-linearisation is performed around the (zero-inflation) steady state already outlined in Table 3.

whereas, in the endogenous separation case, the job creation and job destruction conditions become

$$
\begin{aligned}
\alpha\,\widehat{\vartheta}_t &= \widehat{a}_t + \widehat{x}_t - \left(\frac{1}{1-\varphi^*}\right)\,[\varphi^* - \tau\,(1-\varphi^*)]\;\widehat{\varphi}_t^* \\
\widehat{\varphi}_t^* &= \left(\frac{w}{\varphi^*}\right)\,\widehat{w}_t - \widehat{a}_t - \widehat{x}_t + \tau\,\left(\frac{1-\varphi^*}{\varphi^*}\right)\,\beta\,(1-\rho)\,\mathbb{E}_t\left(\widehat{\varphi}_{t+1}^*\right) - \left(\frac{1-\varphi^*}{\varphi^*}\right)\,\beta\,(1-\rho)\,\mathbb{E}_t\left(\alpha\,\widehat{\vartheta}_{t+1}\right)
\end{aligned}
$$

while the other log-linear model equations remain the same as those in Table 4. Lastly, the model is closed by a Taylor rule, assumed to take a simple inflation-targeting form

$$
i_t = \phi\,\pi_t\,.
$$

It is useful to express the model with nominal price rigidity in terms of gaps with respect to the flexible prices benchmark summarised in Table 4. Let $\Theta_t = \widehat{\vartheta}_t - \widehat{\vartheta}_t^l$ and $\Phi_t = \widehat{\varphi}_t - \widehat{\varphi}_t^l$, where the l superscript refers to the flexible price benchmark. Then we have

$$
\begin{aligned}
\alpha\,\Theta_t^X &= \left(\frac{1}{\kappa/q}\right)\,\widehat{x}_t + \beta\,(1-\rho)\,\mathbb{E}_t\left(\alpha\,\Theta_{t+1}^X\right) \\
\phi\,\pi_t - \mathbb{E}_t\,(\pi_{t+1}) - \hat{r}_t^l &= \left[\frac{\rho\,(1-f)\,\zeta}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right]\,\left(\frac{f}{1-f}\right)\,(1-\alpha)\;\mathbb{E}_t\left(\Theta_{t+1}^X\right)
\end{aligned}
$$

in the exogenous separation case, and

$$
\begin{aligned}
\alpha\,\Theta_t^E &= \widehat{x}_t - \left(\frac{1}{1-\varphi^*}\right)\,[\varphi^* - \tau\,(1-\varphi^*)]\;\Phi_t \\
\Phi_t &= -\widehat{x}_t - \left(\frac{1-\varphi^*}{\varphi^*}\right)\,\beta\,(1-\rho)\,\mathbb{E}_t\,(x_{t+1}) + \beta\,(1-\rho)\,\mathbb{E}_t\,(\Phi_{t+1}) \\
\phi\,\pi_t - \mathbb{E}_t\,(\pi_{t+1}) - \hat{r}_t^l &= \left[\frac{\rho\,(1-f)\,\zeta}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right]\left\{\left(\frac{f}{1-f}\right)\,(1-\alpha)\;\mathbb{E}_t\left(\Theta_{t+1}^E\right) - \tau\,\left(\frac{1-\rho}{\rho}\right)\,\mathbb{E}_t\,(\Phi_{t+1})\right\}
\end{aligned}
$$

in the endogenous separation case. The equilibrium behaviour of the gaps can then be expressed in terms of the response of the natural interest rate, $\hat{r}_t^l$.[13] In the exogenous separation case,

$$
\Theta_t^X = \left(\frac{1}{\alpha}\right)\,\left(\frac{1}{\kappa/q}\right)\,\left[\frac{1}{1-\beta\,\gamma_a\,(1-\rho)}\right]\,\left(\frac{1}{\mathcal{D}^X}\right)\,\hat{r}_t^l
$$

[13]The theoretical results are derived under the simplifying assumption that $\phi = 1/\beta$, allowing to tractably investigate the local determinacy properties of the two models, which are discussed in more detail in Appendix D. The quantitative analysis in Section 5 will deal with the more general case of ϕ not necessarily equal to $1/\beta$.

where

$$\mathcal{D}^X = \frac{\Omega}{\beta} - \left[\frac{\gamma_a}{1-\beta\,\gamma_a\,(1-\rho)}\right]\left[\frac{\rho\,f\,\zeta}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right]\left(\frac{1-\alpha}{\alpha}\right)\left(\frac{1}{\kappa/q}\right).$$

In the endogenous separation case,

$$\Theta_t^E = \frac{1}{\alpha}\left[\frac{1}{1-\beta\,\gamma_a\,(1-\rho)}\right]\left(\frac{1}{1-\varphi^*}\right)\left[1-\tau\left(\frac{1-\varphi^*}{\varphi^*}\right)w\,\overline{\chi}_c\right]\left(\frac{1}{\mathcal{D}^E}\right)\hat{r}_t^l$$
$$\Phi_t = -\left[\frac{1}{1-\beta\,\gamma_a\,(1-\rho)}\right]\left(\frac{w\,\overline{\chi}_c}{\varphi^*}\right)\left(\frac{1}{\mathcal{D}^E}\right)\hat{r}_t^l$$

where

$$\mathcal{D}^E = \frac{\Omega}{\beta} - \left[\frac{\gamma_a}{1-\beta\,\gamma_a\,(1-\rho)}\right]\left[\frac{\rho\,f\,\zeta}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right]\left(\frac{1-\alpha}{\alpha}\right)\left(\frac{1}{1-\varphi^*}\right)\left[1-\tau\left(\frac{1-\varphi^*}{\varphi^*}\right)w\,\overline{\chi}_c\right]$$
$$- \left[\frac{\gamma_a}{1-\beta\,\gamma_a\,(1-\rho)}\right]\left[\frac{\rho\,(1-f)\,\zeta}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right]\tau\left(\frac{1-\rho}{\rho}\right)\left(\frac{1}{\varphi^*}\right)w\,\overline{\chi}_c\,.$$

Local determinacy ensures that $\mathcal{D}^X > 0$ and $\mathcal{D}^E > 0$, implying, in turn, that in the presence of nominal price rigidity, a falling natural interest rate is associated with a larger separation rate and a smaller job-finding rate.

Focusing now on the unemployment gap, $\mathcal{U}_t = \hat{u}_t - \hat{u}_t^l$, we have

$$\mathcal{U}_t^X = -\left(\frac{f}{1-f}\right)(1-\alpha)\,\Theta_t^X + (1-\rho)\,(1-f)\,\mathcal{U}_{t-1}^X$$
$$\mathcal{U}_t^E = \tau\left(\frac{1-\rho}{\rho}\right)f\,\Phi_t - \left(\frac{f}{1-f}\right)(1-\alpha)\,\Theta_t^E + (1-\rho)\,(1-f)\,\mathcal{U}_{t-1}^E$$

in the exogenous and endogenous separation cases, respectively. It is then straightforward to see that a falling (rising) natural interest rate is associated with a positive (negative) unemployment gap. In other words, in the presence of nominal price rigidity, a demand-deficient recession (expansion) would be characterised by a falling (rising) natural interest rate as well as a larger (smaller) surge in unemployment.

5 Quantitative Analysis

5.1 Calibration

The baseline calibration of the parameters is summarised in Table 5. The exogenous and endogenous separation models are calibrated to deliver the same steady-state magnitudes but will differ in their

Table 5: Baseline Calibration

Targets			
Variable/Parameter	Notation	Value	Source
Steady state total separation rate	ρ	0.02	Jimeno and Thomas (2013)
Exogenous separation rate	ρ^x	0.014	$= 0.7\,\rho$, Jimeno and Thomas (2013)
Steady state job finding probability	f	0.20	Jimeno and Thomas (2013)
Steady state market tightness	ϑ	0.25	Jimeno and Thomas (2013)

Externally Calibrated Parameters			
Parameter	Notation	Value	Source
Discount rate	β	0.99	Quarterly calibration
Matching function parameter	α	0.7	Fujita and Ramey (2012)
Worker surplus share	η	0.7	Hosios condition
% loss in consumption upon unemployment	ζ	0.2	Chodorow-Reich and Karabarbounis (2016)
Persistence of aggregate productivity shocks	γ_a	0.95	Den Haan et al. (2000)
Std. dev. of aggregate productivity shocks	σ_ξ	0.01	Den Haan et al. (2000)

Internally Calibrated Parameters			
Parameter	Notation	Value	Target
Standard deviation of $\ln(\varphi) \sim \mathcal{N}(\mu_\varphi, \sigma_\varphi)$	σ_φ	0.1822	φ^* (Proposition 3) & $\overline{\varphi} = 1$
Mean of $\ln(\varphi) \sim \mathcal{N}(\mu_\varphi, \sigma_\varphi)$	μ_φ	-0.0191	φ^* (Proposition 3) & $\overline{\varphi} = 1$
Matching efficiency	$\mathcal{M}$	0.3031	α, f, and ϑ
Vacancy cost	κ	0.3029	steady state FE

response to aggregate productivity shocks.

Each time period is intended to be a quarter, so I set $\beta = 0.99$. Moreover, I assume log-utility for workers (as in Challe, 2020). The matching function parameter is set to $\alpha = 0.7$, as in Fujita and Ramey (2012) and close to the 0.72 of Shimer (2005), and $\eta = \alpha$. As for aggregate shocks, I set $\sigma_\xi = 0.01$ and $\gamma_a = 0.95$ as in Den Haan et al. (2000). Following Chodorow-Reich and Karabarbounis (2016), consumption is assumed to drop by 20% upon job loss, implying that $\delta = 0.8\,w$.

The main targets of the calibration are the steady-state total separation rate and job-finding rate, which are aimed at capturing the characteristics of an average continental European labour market. As in Jimeno and Thomas (2013), the steady-state total separation rate is set to be equal to 0.02

$$\rho = \rho^x + (1 - \rho^x)\, G\,(\varphi^*) = 0.02$$

and the exogenous separation rate is set to be equal to 0.7 of the total separation rate at steady state. The steady-state job-finding rate is set to be $f = 0.20$ and the steady-state market tightness to be $\vartheta = 0.25$. Given $\lambda = \rho\,(1 - f)$, the targeted total separation rate and job-finding probability imply a steady-state unemployment rate

$$u = \frac{\lambda}{\lambda + f}$$

amounting to approximately 7%. Also, given the targets, I can accordingly calibrate the matching efficiency parameter $\mathcal{M} = f/\vartheta^{(1-\alpha)} = 0.3093$, and compute the vacancy-filling rate as $q = f/\vartheta$.

The steady-state wage, w, exit cutoff, φ^*, and continuation value, $\kappa/q = 1 - \varphi^*$, can then be derived from the result in Proposition 3, and the vacancy cost parameter κ can be pinned down from the steady-state free entry condition, which implies $\kappa = q\,[1 - \varphi^*] = 0.1852$.

Lastly, the idiosyncratic productivity term φ is assumed to follow a log-normal distribution with mean μ_φ and standard deviation σ_φ. Given φ^*, ρ and ρ^x, σ_φ and μ_φ are jointly calibrated to normalise $\overline{\varphi} := \mathbb{E}\,(\varphi\,|\,\varphi \geq \varphi^*) = 1$ at steady state.

5.1.1 Sensitivity

I now perform some sensitivity checks of the results on the interaction between wage rigidity, job destruction, and unemployment risk in their implications for aggregate demand shortages.

The first dimension along which sensitivity checks are performed regards the persistence of aggregate productivity shocks: I consider, alternatively, $\gamma_a = 0$ (i.e. a purely transitory shock) and shocks of different persistence ($\gamma_a = 0.9$, or 0.95 as in the baseline calibration).

The second parameter involved in the sensitivity checks is the matching function parameter, α.[14] While Shimer (2005) estimates it at 0.72, Mortensen and Nagypal (2007) argue that this value is empirically too high, estimating it at 0.45. Brügemann (2008) proposes, instead, estimates between 0.54 and 0.63. Therefore, I follow Fujita and Ramey (2012) in setting $\alpha = 0.7$ as a benchmark and considering $\alpha = 0.5$ as an alternative parametrisation.

Table 6 summarises what happens, under alternative parametrisations, to wage responsiveness thresholds for aggregate demand shortages. A more detailed comment on the impulse responses of the model under the baseline calibration is instead the focus of section 5.2.

[14] A comprehensive survey on matching functions can be found in Petrongolo and Pissarides (2001).

Table 6: Wage Responsiveness Threshold for Procyclical Natural Interest Rates

Shock persistence (γ_a)	$\overline{\chi}_r^E$ (Endogenous Separation)		$\overline{\chi}_r^X$ (Exogenous Separation)	
	$\alpha = 0.5$	$\alpha = 0.7$	$\alpha = 0.5$	$\alpha = 0.7$
0	0	0	0	0
0.9	0.6307	0.6251	0.0645	0.0636
0.95	0.8300	0.8286	0.1684	0.1659

Notes: The table reports upper bounds on the wage elasticity χ under alternative parametrisations: when $\chi < \overline{\chi}^j$, $j \in \{X, E\}$, the precautionary motive dominates and, hence, the natural interest rate behaves procyclically, i.e. there is deficient (excess) aggregate demand after a contractionary (expansionary) productivity shock.

First of all, as far as shock persistence is concerned, purely transitory contractionary shocks cannot possibly cause a demand shortage under the assumed timing: as the shock is unanticipated and purely transitory, it has no impact on expected unemployment risk, $\mathbb{E}_t(\lambda_{t+1})$. Hence, only the standard consumption smoothing motive is operative. As shock persistence increases, so do the prospects of income losses due to unemployment, and hence the precautionary saving behaviour. As a consequence, demand shortages become a more likely outcome. Given that in the data χ is in the ballpark of 1/3, such an outcome occurs in the endogenous job destruction, but not in the exogenous job destruction case, under the chosen parametrisation and when shocks are sufficiently persistent.

Lastly, different calibrations of the matching function do not substantially alter the results.

5.2 Baseline Results

Figure 3 reports impulse responses to a 1% fall in aggregate productivity under the baseline calibration summarised in Table 5. In order to better understand the role played by the endogenous job destruction margin, I compare the impulse responses of the endogenous job destruction model with those of the standard S&M model with symmetric matches and exogenous separation summarised in Table 2. For both models, I consider the case of flexible wages as well as that of inertial wages. As can be seen from Figure 3, both models generate an unrealistically strong response of wages to productivity (almost 1:1) in the flexible wage case, a common feature of S&M models first highlighted by Shimer (2005) and Hall (2005). Therefore, I set the real wage elasticity to $\chi = 1/3$, as suggested by Challe (2020) with reference to the empirical evidence.

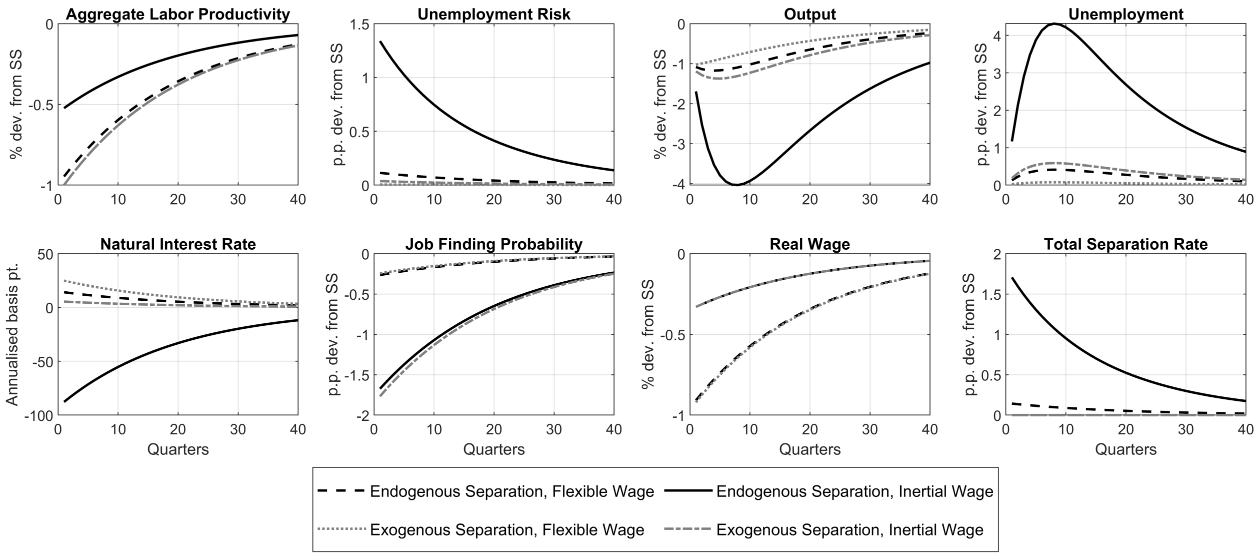
With inertial wages, there is a cleansing effect preventing aggregate labour productivity from falling as much as in the flexible wage case: as more unproductive jobs are endogenously destroyed, the average idiosyncratic productivity of a match is higher, and this partly offsets the aggregate shock (a_t falls while $\overline{\varphi}_t$ rises). However, since more jobs are destroyed, a contained fall in aggregate labour productivity is not enough to prevent a larger fall in output than in the flexible-wage case.

Focusing on the inertial wage case, the exogenous and endogenous job destruction models give an almost identical drop in the job-finding probability, but only the endogenous job destruction model can generate a rise in the total separation rate (of about 1.8 percentage points above the steady-state level). Given that there is a sizeable increase in unemployment risk only in the endogenous job destruction model, this seems to validate the ability of the model to capture the conventional wisdom that increased unemployment during recessions stems primarily from increased job destruction rates rather than from reduced job creation rates. As a result, unemployment rises, reaching a peak of around 4.5 percentage points above its steady-state level, and there is also a sizeable fall in aggregate output (with a through of about -4%), which is proportionally much larger than the size of the initial negative supply shock of 1%.

As unemployment rises, due to incomplete markets workers cannot fully insure against the increased income risk from losing their jobs; as a consequence, they wish to precautionarily save and cut consumption, potentially inducing an aggregate demand shift larger than the aggregate supply shift, which would manifest as a reduction in the natural interest rate. Indeed, as discussed above, two main forces shape the response of the natural interest rate: standard consumption smoothing and the precautionary motive. Following a contractionary productivity shock, these two forces push in opposite directions; on the one hand, better future wage prospects induce to smooth consumption by moving it to the present, implying a desire to borrow and, hence, upward pressure on the natural interest rate; on the other hand, heightened unemployment risk increases the desire to precautionarily save in light of the prospect of becoming unemployed and hence be forced to reduce consumption. This latter force, which puts downward pressure on the natural interest rate, dominates in the endogenous separation and inertial wage case; as a result, the natural interest rate falls by about 100 annualised basis points. Moreover, the precautionary motive is sufficiently strong to cause a fall in the natural interest rate only when the interaction between wage rigidity and endogenous job destruction is at work: when one or both of these two channels are absent, it is the standard consumption smoothing motive that dominates, and there is a rise in the natural interest rate, suggesting the presence of excess rather than depressed demand.

Second moments obtained from stochastic simulations, reported in Table 7, confirm these results.

Figure 3: Impulse Responses to a Contractionary Productivity Shock



Notes: The figure reports model-based impulse responses to a 1% decline in productivity under the parametrisation summarised in Table 5. Aggregate Labor Productivity refers to $Y_t/n_t = a_t$ in the exogenous separation case and $Y_t/n_t = a_t\,\overline{\varphi}_t$ in the endogenous separation case. Unemployment Risk refers to $\mathbb{E}_t\left(\widehat{\lambda}_{t+1}\right)$.

Unemployment is more volatile with endogenous job destruction and even more so with rigid real wages. Looking at the correlation between output and the natural interest rate, it is also confirmed that the natural interest rate behaves procyclically only in the endogenous job destruction model with inertial wages, whereas it exhibits a countercyclical behaviour in all the other cases.

5.3 Extensions

5.3.1 Nominal Price Rigidity

As shown analytically, nominal price rigidity implies that deficient (excess) demand, whose symptom is a falling (rising) natural interest rate, makes a recession more (less) severe, being associated with a positive (negative) unemployment gap and hence a larger (smaller) surge in unemployment.

In order to quantitatively explore this issue, the fraction of unchanged prices is conventionally set to $\omega = 0.75$ and the Taylor rule parameter to $\phi = 1.5$, while the other parameters and targets are as before, in the baseline calibration summarised in Table 5.

Considering the case of inertial wages under both separation regimes, we can see from the impulse responses in Figure 4 that the exogenous separation model is indeed characterised by excess

Table 7: Second Moments

	Endogenous Separation		Exogenous Separation	
	Flexible Wage	Inertial Wage	Flexible Wage	Inertial Wage
$\sigma_{\widehat{y}}$	0.016	0.045	0.014	0.018
$\sigma_{\widehat{w}} \,/\, \sigma_{\widehat{y}}$	0.742	0.096	0.879	0.235
$\sigma_{\widehat{u}} \,/\, \sigma_{\widehat{y}}$	3.681	11.105	0.806	4.538
$\rho_{\widehat{y},\widehat{r}}$	-0.977	0.769	-0.999	-0.965

Notes: The table reports standard deviations of the real wage and unemployment relative to the standard deviation of output, and correlations between output and the natural interest rate. These second moments are obtained from stochastic simulations of the model. The simulated data are HP-filtered with a smoothing parameter of 1600.

demand in terms of a rising natural interest rate as well as a negative unemployment gap, even though of small magnitude, as the fact that the rise in the natural interest rate is contained implies, in turn, small feedback from this slight excess demand to sustained economic activity. By contrast, in the endogenous separation case, the demand-deficient nature of the recession manifests both as a falling natural interest rate and a positive unemployment gap.

The second moments reported in Table 8 confirm these results. While with endogenous job destruction the relative volatility of unemployment is higher in the presence of nominal price rigidity compared to flexible prices (Table 7), it is lower with exogenous job destruction. Indeed, while in the former case demand-deficient recessions and demand-abundant expansions amplify business cycle fluctuations, the reverse is true in the latter case, where recessions are demand-abundant and expansions are demand-deficient. Looking at the correlation between output and inflation, we can also notice how only the endogenous job destruction model exhibits a procyclical inflation rate.

5.3.2 Non-zero Liquidity

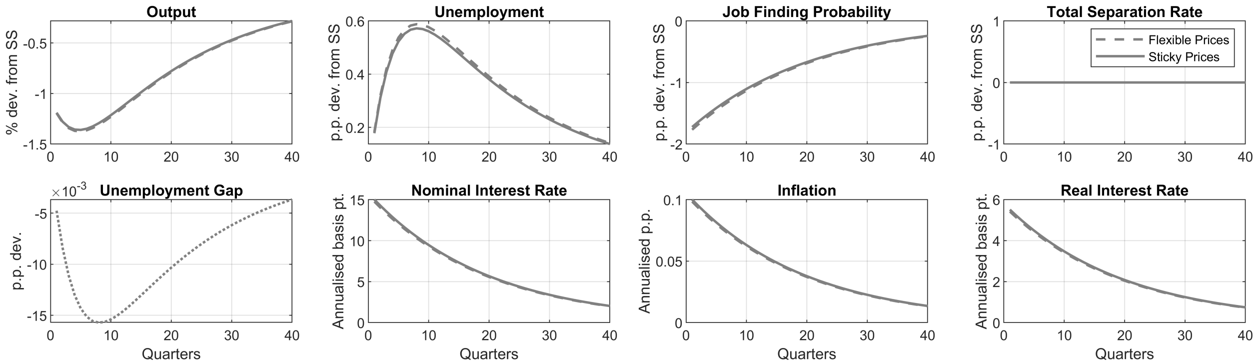
The model can be extended further by allowing workers to actually hold assets for precautionary motives. Following Challe et al. (2017), I do so by making two key assumptions: i) imperfect risk sharing between the unemployed and the employed due to a debt limit $\underline{b} > 0$, which is non-zero but still tighter than the natural debt limit,[15] and ii) full risk sharing among the employed.

As for the first assumption, a non-zero borrowing limit implies that the unemployed, who have lower income, can borrow from the employed, who in turn precautionarily hold assets for self-insuring

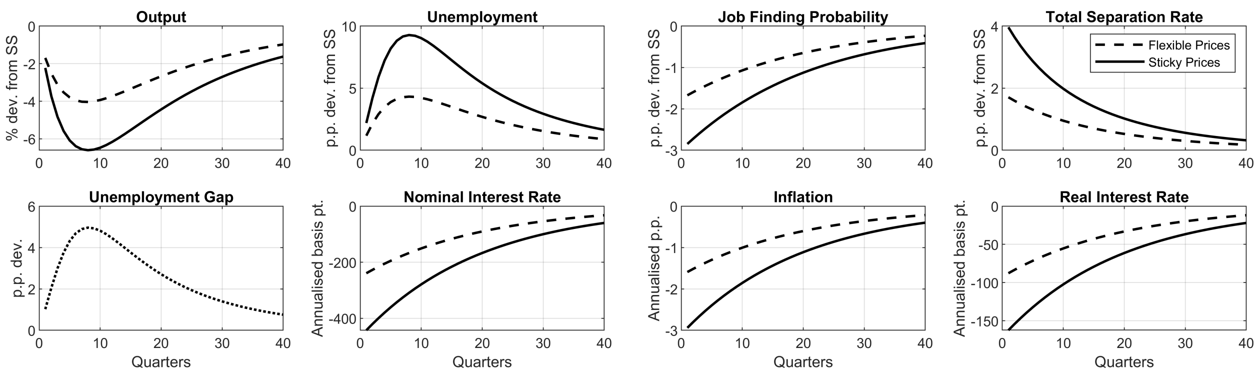
[15]The natural debt limit is the maximum amount a household could borrow while still being able to repay in the worst-case scenario income history (corresponding to permanent unemployment, in this setting).

Figure 4: Effect of a Contractionary Productivity Shock with Nominal Price Rigidity

(a) Exogenous Separation



(b) Endogenous Separation



Notes: The figure reports model-based impulse responses to a 1% decline in productivity under the parametrisation summarised in Table 5; additionally, $\omega = 0.75$ and $\phi = 1.5$.

Table 8: Second Moments from the Models with Nominal Rigidity

	Endogenous Separation		Exogenous Separation	
	Flexible Wage	Inertial Wage	Flexible Wage	Inertial Wage
$\sigma_{\widehat{y}}$	0.016	0.072	0.014	0.018
$\sigma_{\widehat{w}} \,/\, \sigma_{\widehat{y}}$	0.716	0.060	0.818	0.237
$\sigma_{\widehat{u}} \,/\, \sigma_{\widehat{y}}$	3.555	12.252	0.750	4.457
$\rho_{\widehat{y},\pi}$	-0.979	0.709	-0.999	-0.967

Notes: The table reports standard deviations of the real wage and unemployment relative to the standard deviation of output, and correlations between output and inflation. These second moments are obtained from stochastic simulations of the model. The simulated data are HP-filtered with a smoothing parameter of 1600.

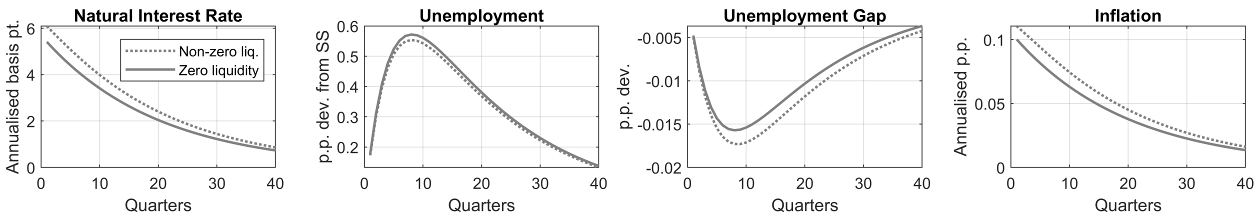
themselves against the drop in income that would occur upon unemployment. Furthermore, to be consistent with the fact that the unemployed consume less than the employed, it is assumed (and later checked) that the borrowing constraint is always binding. As a consequence, the asset market clearing condition in (7) now implies $n_t \, b_t^n = (1 - n_t) \, \underline{b}$, i.e. a non-degenerate (but still finite-dimensional) wealth distribution, differently from the zero-liquidity case where $\underline{b} = 0$. In sum, this first assumption implies partial risk sharing between the employed and the unemployed via the asset market. The second assumption of full risk sharing among the employed implies instead, in practice, that those becoming employed pool their debt with the assets of those remaining employed. These model extensions allowing for non-zero liquidity at equilibrium are described in more detail in Appendix E, along with the (re)calibration strategy —aimed at targeting the same steady-state consumption decline for the unemployed of the zero liquidity model ($\zeta = 0.2$).

Figure 5 compares the impulse responses of key variables (the natural interest rate, unemployment, and the unemployment gap) in the non-zero and zero liquidity cases and for both separation regimes. Qualitatively, the main result is unchanged when allowing for self-insurance via non-zero asset holdings: only the endogenous separation case is characterised by demand deficiency in response to a contractionary productivity shock, while the exogenous separation case still depicts excess demand. Quantitatively, (partial) self-insurance allows workers to contain the fall in consumption upon unemployment, dampening their unmet precautionary saving desire. As a result, in the endogenous separation model the natural interest rate falls by around 20 annualised basis points less with non-zero liquidity than with zero liquidity. Since the fall in demand is partially contained, the increase in the unemployment gap is two percentage points smaller, implying a correspondingly smaller surge in unemployment. The quantitative results are, instead, almost unchanged in the exogenous separation case: as demand is partially more sustained, the natural interest rate rises by around one annualised basis point more than in the zero-liquidity case, implying, in turn, a marginally lower increase in the unemployment rate, due to a slightly larger decline in the unemployment gap.

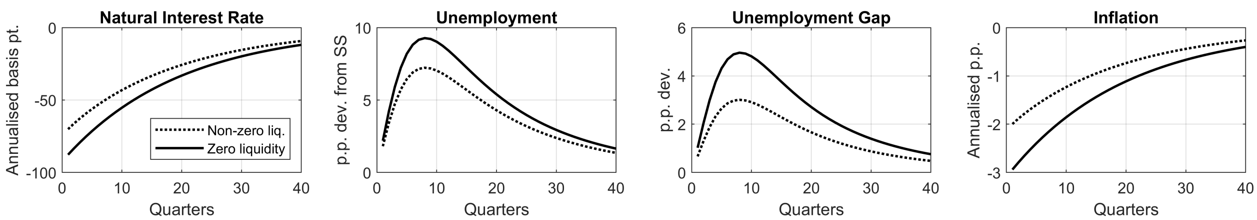
Table 9 reports second moments from stochastic simulation of the non-zero liquidity model, confirming how its business cycle properties are essentially in line with those of the zero liquidity model considered in the baseline analysis.

Figure 5: Effect of a Contractionary Productivity Shock with Non-zero Liquidity

(a) Exogenous Separation



(b) Endogenous Separation



Notes: The figure reports model-based impulse responses to a 1% decline in productivity under the parametrisation summarised in Table 5 and Appendix E.

Table 9: Second Moments from the Models with Non-zero Liquidity

	Endogenous Separation		Exogenous Separation	
	Non-zero Liquidity	Zero Liquidity	Non-zero Liquidity	Zero Liquidity
$\sigma_{\widehat{y}}$	0.062	0.072	0.018	0.018
$\sigma_{\widehat{w}} \,/\, \sigma_{\widehat{y}}$	0.070	0.060	0.239	0.237
$\sigma_{\widehat{u}} \,/\, \sigma_{\widehat{y}}$	12.002	12.252	4.361	4.457
$\rho_{\widehat{y},\pi}$	0.717	0.709	-0.976	-0.967

Notes: the table reports standard deviations of the real wage and unemployment relative to the standard deviation of output, and correlations between output and inflation. These second moments are obtained from stochastic simulations of the model. The simulated data are HP-filtered with a smoothing parameter of 1600.

6 Conclusions

Can negative supply shocks induce sizeable falls in demand, making a recession worse? The answer is typically negative in models with complete markets, as a standard consumption smoothing desire induces households to sustain aggregate demand during a recession by wishing to borrow in light of improving income prospects. Introducing incomplete markets in the form of uninsurable unemployment risk allows for a precautionary saving motive that can end up offsetting this desire to borrow, making therein a fall in the natural interest rate —a symptom of demand deficiency— a possible outcome, although not necessarily the likely one as long as unemployment risk stems only from reduced job creation, as it has so far most often been assumed (e.g. by Ravn and Sterk, 2021). As shown analytically in this paper, if heightened unemployment risk stems not only from reduced job-finding prospects but also from endogenous job destruction, a fall in the natural interest rate after a negative productivity shock becomes not merely a possible outcome but a most likely one. Quantitatively, it is then crucial to account for the endogenous job destruction channel in models with uninsurable unemployment risk in order to capture the demand-deficient nature of supply-driven recessions.

Appendix

A Real Wage Rigidity

Since the work of Shimer (2005), rigid wages have been shown to be a key feature for S&M models to match the empirical volatility of unemployment. The fact that wage stickiness vastly increases the sensitivity of these models to driving forces was also noticed by Hall (2005). Firstly, he showed that *any* wage rule involving a positive surplus for both parties (workers and producers) can be an equilibrium in the Nash sense, not only the constant surplus splitting scheme commonly known as Nash bargaining. This latter, traditionally adopted by the S&M literature, was, however, shown by Shimer (2005) to involve excessively flexible wages and, hence, too much unemployment volatility compared to the data. While focusing in particular on the subset of constant wages in his quantitative assessment, Hall (2005) also emphasised that other possible equilibrium wage rules are consistent with inertial —but not necessarily constant— wages. One such possibility is a wage smoothing norm (as adopted e.g. by Challe, 2020, , among others),[16]

$$w_t = (w_t^n)^\Gamma w^{1-\Gamma} \tag{A.1}$$

where Γ acts as a smoothing parameter, with $\Gamma = 0$ corresponding to the constant wage case and $\Gamma = 1$ to the flexible wage case, and w_t^n is a notional wage, usually assumed to coincide with the Nash-bargained wage.

As shown in subsection A.1 below, a collective surplus splitting scheme between workers and producers gives the following notional wage rate, in this setting,

$$w_t^n = \eta \left\{ a_t \, \overline{\varphi}_t + \kappa \, \beta \, \mathbb{E}_t \left[(1 - \rho_{t+1}) \, \vartheta_{t+1} \right] \right\} + (1 - \eta) \, \delta \tag{A.2}$$

where η is the fraction of the collective surplus going to workers, with the remaining fraction $(1 - \eta)$ going to producers.

Conceptually, the wage schedule in (12) is essentially the same as the wage norm in (A.1), in

[16] Another possibility emphasised by Hall (2005) —with the analytical shortcoming that the wage becomes a state variable of the model— is a wage norm depending on past wages, $w_t = \gamma_w \, w_t^n + (1 - \gamma_w) \, w_{t-1}$, where γ_w captures the degree of wage rigidity, and can be interpreted as the fraction of wages renegotiated each period (see Gertler and Trigari, 2009). In the context of unionised labour markets, it actually takes time to renegotiate collective bargaining agreements. Hence, wages will respond sluggishly to shocks: collective bargaining coverage has been shown to be positively related to downward real wage rigidity both from an empirical perspective (Du Caju et al., 2008; Babecky et al., 2009) and a theoretical perspective (Morin, 2017).

first-order approximations. Formally, in the log-linear model, there is a strictly increasing mapping between the wage norm parameter Γ and the wage elasticity χ.

$$\chi^E = \frac{1}{w} \left\{ \frac{\alpha + \left[\frac{\beta\,\gamma_a\, f\,(1-\rho)}{1-\beta\,\gamma_a\,(1-\rho)}\right] - \tau\,\left(\frac{1-\varphi^*}{\varphi^*}\right)\,\left[\frac{\alpha+(1-\alpha)\,\beta\, f\,\gamma_a\,(1-\rho)}{1-\beta\,\gamma_a\,(1-\rho)}\right]\,\overline{\chi}_c^*}{\frac{\alpha/\eta}{\Gamma} + \left[\frac{\beta\,\gamma_a\, f\,(1-\rho)}{1-\beta\,\gamma_a\,(1-\rho)}\right] - \tau\,\left(\frac{1-\varphi^*}{\varphi^*}\right)\,\left[\frac{\alpha+(1-\alpha)\,\beta\, f\,\gamma_a\,(1-\rho)}{1-\beta\,\gamma_a\,(1-\rho)}\right]} \right\}$$

and

$$\chi^X = \frac{1}{w} \left\{ \frac{\alpha + \left[\frac{\beta\,\gamma_a\, f\,(1-\rho)}{1-\beta\,\gamma_a\,(1-\rho)}\right]}{\frac{\alpha/\eta}{\Gamma} + \left[\frac{\beta\,\gamma_a\, f\,(1-\rho)}{1-\beta\,\gamma_a\,(1-\rho)}\right]} \right\}$$

in the endogenous and exogenous separation cases, respectively, where $\tau := \varphi^*\, g(\varphi^*)/[1-G(\varphi^*)]$ and $\overline{\chi}_c^* = \varphi^* + (1-\varphi^*)\,\beta\,\gamma_a\,(1-\rho)$.

When $\Gamma = 0$, $\chi = 0$. When $\Gamma = 1$, χ is equal to (hence bounded above by)

$$\overline{\chi}_w^E = \frac{1}{w} \left\{ \frac{\alpha + \left[\frac{\beta\,\gamma_a\, f\,(1-\rho)}{1-\beta\,\gamma_a\,(1-\rho)}\right] - \tau\,\left(\frac{1-\varphi^*}{\varphi^*}\right)\,\left[\frac{\alpha+(1-\alpha)\,\beta\, f\,\gamma_a\,(1-\rho)}{1-\beta\,\gamma_a\,(1-\rho)}\right]\,\overline{\chi}_c^*}{\frac{\alpha}{\eta} + \left[\frac{\beta\,\gamma_a\, f\,(1-\rho)}{1-\beta\,\gamma_a\,(1-\rho)}\right] - \tau\,\left(\frac{1-\varphi^*}{\varphi^*}\right)\,\left[\frac{\alpha+(1-\alpha)\,\beta\, f\,\gamma_a\,(1-\rho)}{1-\beta\,\gamma_a\,(1-\rho)}\right]} \right\}$$

in the endogenous separation case, and

$$\overline{\chi}_w^X = \frac{1}{w} \left\{ \frac{\alpha + \left[\frac{\beta\,\gamma_a\, f\,(1-\rho)}{1-\beta\,\gamma_a\,(1-\rho)}\right]}{\frac{\alpha}{\eta} + \left[\frac{\beta\,\gamma_a\, f\,(1-\rho)}{1-\beta\,\gamma_a\,(1-\rho)}\right]} \right\}$$

in the exogenous separation case.

Indeed, the wage schedule in (12) can be, on its own, an equilibrium wage in Hall's (2005) sense once it is ensured that the match surplus remains positive for both workers and producers. As for producers, such a circumstance is always satisfied when φ has positive support since those matches involving a negative match surplus for the firm will be terminated according to the (JD) condition. As for workers, it is instead sufficient that $w_t > \delta$ in the current period and in expectations.

A.1 Real Wage Rate Under Nash Bargaining

The notional wage, w_t^n, is assumed to be determined by standard Nash Bargaining, involving a constant surplus splitting scheme between workers and producers.

The asset value of a match for a firm with idiosyncratic productivity φ is given by $J_t(\varphi)$ as already expressed in (1). The asset value to active producers is then given by

$$J_t := \mathbb{E}_t \left[J_t(\varphi) \,|\, \varphi \geq \varphi_t^* \right] = a_t \, \overline{\varphi}_t - w_t + \beta \, \mathbb{E}_t \left[(1 - \rho_{t+1}) \, \frac{\kappa}{q_{t+1}} \right]$$

given free entry into vacancy posting, implying $V_t = 0$, this also coincides with the average surplus to active producers.

The asset value of employment is

$$W_t = w_t + \beta \, \mathbb{E}_t \left\{ (1 - \lambda_{t+1}) \, W_{t+1} + \lambda_{t+1} \, U_{t+1} \right\}$$

and the asset value of unemployment is

$$U_t = \delta + \beta \, \mathbb{E}_t \left\{ f_{t+1} \, W_{t+1} + (1 - f_{t+1}) \, U_{t+1} \right\}$$

therefore, the surplus enjoyed by an employed worker is

$$W_t - U_t = w_t - \delta + \beta \, \mathbb{E}_t \left[(1 - f_{t+1}) \, (1 - \rho_{t+1}) \, (W_{t+1} - U_{t+1}) \right]$$

and the aggregate surplus arising from all active matches is given by

$$n_t \, \left[(W_t - U_t) + J_t \right]$$

The aggregate surplus is collectively split by firm owners and workers, with a fraction η going to workers and the remaining fraction $(1 - \eta)$ going to firm owners. This implies the following collective surplus splitting rule

$$W_t - U_t = \left(\frac{\eta}{1 - \eta} \right) \, J_t$$

which, combined with free entry, gives the following wage rate

From the FE condition, we have

$$\frac{\kappa}{q_t} = J_t$$

where

$$J_t := \frac{1}{[1 - G(\varphi_t^*)]} \int_{\varphi_t^*}^{\infty} J_t(\varphi) \, g(\varphi) \, d\varphi$$

Combining the FE condition with the surplus splitting rule and leading one period ahead gives

$$(W_{t+1} - U_{t+1}) = \left(\frac{\eta}{1-\eta}\right) \frac{\kappa}{q_{t+1}} \tag{A.3}$$

Also, from the surplus splitting rule,

$$W_t - U_t = \left(\frac{\eta}{1-\eta}\right) J_t = \left(\frac{\eta}{1-\eta}\right) \left\{a_t\, \overline{\varphi}_t - w_t^n + \beta\, \mathbb{E}_t \left[(1-\rho_{t+1}) \frac{\kappa}{q_{t+1}}\right]\right\} \tag{A.4}$$

Using (A.3) and (A.4) in the recursion for worker surplus,

$$W_t - U_t = w_t^n - \delta + \beta\, \mathbb{E}_t \left[(1-f_{t+1})\,(1-\rho_{t+1})\,(W_{t+1} - U_{t+1})\right]$$

gives

$$\left(\frac{\eta}{1-\eta}\right) \left\{a_t\, \overline{\varphi}_t - w_t^n + \beta\, \mathbb{E}_t \left[(1-\rho_{t+1}) \frac{\kappa}{q_{t+1}}\right]\right\} \\ = w_t^n - \delta + \beta\, \mathbb{E}_t \left[(1-f_{t+1})\,(1-\rho_{t+1}) \left(\frac{\eta}{1-\eta}\right) \frac{\kappa}{q_{t+1}}\right]$$

which gives, upon rearranging and since $f_{t+1} = \vartheta_{t+1}\, q_{t+1}$, the wage rate as expressed in (A.2).

B Proofs

B.1 Proof of Proposition 1

Starting from the Euler condition of employed workers

$$\frac{1}{\beta} = \left[\frac{(1-\lambda)\, u'(w) + \lambda\, u'(\delta)}{u'(w)}\right] R$$

since $\lambda \in (0,1)$, and $\delta < w$ implies in turn $u'(\delta) > u'(w)$, the term in square brackets is

$$\frac{(1-\lambda)\, u'(w) + \lambda\, u'(\delta)}{u'(w)} = (1-\lambda) + \lambda\, \frac{u'(\delta)}{u'(w)} > 1$$

giving, in turn, that

$$\frac{1}{\beta} > R$$

Since $f \in (0,1)$,

$$\frac{(1-f)\,u'(\delta)+f\,u'(w)}{u'(\delta)} = (1-f)+f\,\frac{u'(w)}{u'(\delta)} < 1 < \frac{(1-\lambda)\,u'(w)+\lambda\,u'(\delta)}{u'(w)}$$

implying, in turn,

$$\left[\frac{(1-f)\,u'(\delta)+f\,u'(w)}{u'(\delta)}\right] R < \left[\frac{(1-\lambda)\,u'(w)+\lambda\,u'(\delta)}{u'(w)}\right] R = \frac{1}{\beta}$$

which establishes that the Euler condition for unemployed workers holds indeed with inequality.

B.2 Proof of Proposition 2

Let $\Omega := \frac{u'(c^n)}{u'(c^u)}$ be a measure of consumption inequality at steady state. If the Euler conditions of the employed and the unemployed both hold with equality, these would read, respectively,

$$1 = \beta\left[(1-\lambda)+\lambda\,\frac{1}{\Omega}\right]$$
$$1 = \beta\,[f\,\Omega+(1-f)]$$

Therefore,

$$(1-\lambda)+\lambda\,\frac{1}{\Omega} = f\,\Omega+(1-f)$$

But this necessarily implies that $\Omega = 1$, i.e. consumption is equalised. Indeed, suppose that $\Omega > 1$, then since $\lambda, f \in (0,1)$,

$$f\,\Omega+(1-f) > (1-\lambda)+\lambda\,\frac{1}{\Omega}\,.$$

Similarly, if instead $\Omega < 1$,

$$f\,\Omega+(1-f) < (1-\lambda)+\lambda\,\frac{1}{\Omega}\,.$$

B.3 Proof of Proposition 3

Starting from the Free Entry Condition,

$$\frac{\kappa}{q} = \left[1-w+\beta\,(1-\rho)\,\frac{\kappa}{q}\right]$$

we have

$$\frac{\kappa}{q} = \left[\frac{1}{1-\beta\,(1-\rho)}\right]\,[1-w]$$

From the wage equation,

$$w = \eta + \eta\,\kappa\,\beta\,\vartheta\,(1-\rho) + (1-\eta)\,\delta$$

where $\kappa\,\vartheta = \frac{\kappa}{q}\,f$. Therefore,

$$w = \eta + \eta\,\frac{\kappa}{q}\,f\,(1-\rho) + (1-\eta)\,\delta$$

Letting $\zeta := 1 - \delta/w$, we have $\delta = (1-\zeta)\,w$, hence

$$w = \eta + \eta\,\frac{\kappa}{q}\,f\,(1-\rho) + (1-\eta)\,(1-\zeta)\,w$$

Exploiting the result from the FE condition,

$$w = \eta + \eta\,\left[\frac{\beta\,f\,(1-\rho)}{1-\beta\,(1-\rho)}\right]\,[1-w] + (1-\eta)\,(1-\zeta)\,w$$

Solving for w,

$$w = \frac{\left[1 + \frac{\beta\,f\,(1-\rho)}{1-\beta\,(1-\rho)}\right]}{\left[\left(\frac{1-\eta}{\eta}\right)\,\zeta + 1 + \frac{\beta\,f\,(1-\rho)}{1-\beta\,(1-\rho)}\right]} < 1$$

Turning now to φ^*, combining the Job Destruction condition with the previous result on κ/q from FE, we have

$$\varphi^* = w - \beta\,(1-\rho)\,\frac{\kappa}{q} = w - \left[\frac{\beta\,(1-\rho)}{1-\beta\,(1-\rho)}\right]\,[1-w] = w\,\left[\frac{1}{1-\beta\,(1-\rho)}\right] - \left[\frac{\beta\,(1-\rho)}{1-\beta\,(1-\rho)}\right] < w$$

where the inequality holds in virtue of the fact that $w < 1$.

C The Producer Side with Nominal Price Rigidity

Production consists of three layers: a final (consumption) good is assembled with CES technology, by aggregating differentiated goods from a monopolistically competitive wholesale sector; each wholesale producer uses in turn, as input, a homogeneous intermediate good; this latter is produced by firms differing in their productivity, using only labour, which is hired in a frictional labour market.[17]

Final Good

The final good is produced under perfect competition, by aggregating a continuum of wholesale goods with CES technology

$$Y_t = \left(\int_0^1 y_t(k)^{\frac{\varepsilon-1}{\varepsilon}} dk \right)^{\frac{\varepsilon}{\varepsilon-1}}$$

Given the CES structure, demand for variety k from the wholesale sector is given by

$$y_t(k) = Y_t \left[\frac{p_t(k)}{P_t} \right]^{-\varepsilon}$$

where, given perfect competition in the final good sector, $P_t = \left(\int_0^1 p_t(k)^{1-\varepsilon} dk \right)^{1/(1-\varepsilon)}$.

Wholesale Firms

Wholesale producers turn intermediate goods into wholesale differentiated products according to a simple linear technology with symmetric productivity

$$y_t(k) = s_t(k)$$

where $y_t(k)$ is the amount of variety k produced, and $s_t(k)$ is the amount of intermediate inputs used in production by wholesaler k.

Each wholesaler is a monopolistic supplier of the variety k it produces. The profit of wholesale firm k is, therefore,

$$D_t^W(k) = y_t(k) \; [p_t(k) - X_t] = Y_t \left[\frac{p_t(k)}{P_t} \right]^{-\varepsilon} [p_t(k) - X_t]$$

where X_t is the nominal marginal cost faced by wholesale firms (i.e. the price of the intermediate goods used in production).

Moreover, wholesale firms are assumed to face Calvo pricing frictions, with ω being the probability that a wholesale firm cannot reset its price.

[17] Krause and Lubik (2007) embed the price-setting and employment adjustment decisions within a single, representative, monopolistically competitive producer. By contrast, Trigari (2009) separates price-setting and employment adjustment decisions into two distinct sectors.

Therefore, the pricing problem solved by wholesale firm k at time t, determining its optimal reset price, is

$$\max_{p_t(k)} \mathbb{E}_t \left\{ \sum_{j=0}^{\infty} \omega^j \beta^j \left(\frac{P_t}{P_{t+j}} \right) Y_{t+j} \left[\frac{p_t(k)}{P_{t+j}} \right]^{-\varepsilon} [p_t(k) - X_{t+j}] \right\}$$

Also, I assume that an optimal subsidy to wholesalers is in place, so that the steady-state distortion of monopolistic competition is offset, and the rigid prices model delivers the same (zero inflation) steady state already outlined in table 3.

Intermediate Good Producers

Production in the intermediate goods sector occurs using only labour as input, which is hired in a frictional market. The value of a match for a producer with idiosyncratic productivity φ is

$$J_t(\varphi) = x_t \, a_t \, \varphi - w_t + \beta \, \mathbb{E}_t \left[(1 - \rho^x) \int_{\varphi^*_{t+1}}^{\infty} J_{t+1}(\varphi) \, g(\varphi) \, d\varphi \right]$$

D Local Determinacy Properties

Exogenous Job Destruction

Under the simplifying assumption that $\phi_\pi = 1/\beta$, we get the following forward-looking equation for the tightness gap, Θ^X_t,

$$\Theta^X_t = H^X \, \mathbb{E}_t \left(\Theta^X_{t+1} \right) + \left(\frac{1}{\kappa/q} \right) \left(\frac{\beta}{\alpha} \right) \frac{1}{\Omega} \, \hat{r}^f_t$$

hence determinacy requires

$$H^X = \beta \, (1 - \rho) + \left(\frac{1}{\kappa/q} \right) \left[\frac{\rho \, (1 - f) \, \zeta}{(1 - \zeta) + \rho \, (1 - f) \, \zeta} \right] \left(\frac{f}{1 - f} \right) \left(\frac{1 - \alpha}{\alpha} \right) \frac{1}{\Omega} < 1$$

which implies in turn $\mathcal{D}^X > 0$ as $\gamma_a < 1$.

Endogenous Job Destruction

In the endogenous job destruction case, the model can be expressed in the following matrix form

$$\mathbf{A}\begin{bmatrix}\Theta_t^E \\ \\ \Phi_t\end{bmatrix} = \mathbf{B}\begin{bmatrix}\mathbb{E}_t\left(\Theta_{t+1}^E\right) \\ \\ \mathbb{E}_t\left(\Phi_{t+1}\right)\end{bmatrix} + \begin{bmatrix}1 \\ \\ 0\end{bmatrix}\hat{r}_t^f$$

where

$$\mathbf{A} = \begin{bmatrix}\frac{\alpha}{\beta}\,\Omega & \frac{1}{\beta}\,\Omega\left(\frac{1}{1-\varphi^*}\right)\left[1-\tau\left(1-\varphi^*\right)\right] \\ \\ \alpha & \left(\frac{1}{1-\varphi^*}\right)\left[1-\tau\left(1-\varphi^*\right)\right]\end{bmatrix}$$

$$\mathbf{B} = \begin{bmatrix}\left[\frac{\rho\, f\, \zeta}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right]\left(\frac{1-\alpha}{\alpha}\right) & -\left[\frac{\rho\,(1-f)\,\zeta}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right]\tau\left(\frac{1-\rho}{\rho}\right) \\ \\ -\left(\frac{1-\varphi^*}{\varphi^*}\right)\beta\,(1-\rho)\,\alpha & \tau\left(\frac{1-\varphi^*}{\varphi^*}\right)\beta\,(1-\rho)\end{bmatrix}$$

Determinacy then requires that the matrix $\mathbf{A}^{-1}\mathbf{B}$ has both eigenvalues within the unit circle. This gives the following parameter restriction

$$\begin{aligned}\frac{\Omega}{\beta} - \left[\frac{1}{1-\beta\,(1-\rho)}\right]\left[\frac{\rho\, f\,\zeta}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right]\left(\frac{1-\alpha}{\alpha}\right)\left(\frac{1}{1-\varphi^*}\right)\left[1-\tau\left(\frac{1-\varphi^*}{\varphi^*}\right)\widetilde{\chi}_c^*\right] \\ - \left[\frac{1}{1-\beta\,(1-\rho)}\right]\left[\frac{\rho\,(1-f)\,\zeta}{(1-\zeta)+\rho\,(1-f)\,\zeta}\right]\tau\left(\frac{1-\rho}{\rho}\right)\left(\frac{1}{\varphi^*}\right)\widetilde{\chi}_c^* > 0\end{aligned}$$

where $\widetilde{\chi}_c^* = \varphi^* + (1-\varphi^*)\,\beta\,(1-\rho)$. Then, as $\gamma_a < 1$, the parameter restriction above implies in turn that $\mathcal{D}^E > 0$.

E The Non-zero Liquidity Model

The non-zero liquidity model entails two extensions compared to the baseline, zero liquidity model. First, it is assumed that households face a non-zero borrowing limit, i.e. the borrowing constraint becomes $b_{ht} \geq -\underline{b}$, with the zero borrowing (and zero liquidity equilibrium) case nested by $\underline{b} = 0$.

Furthermore, it is assumed that there is perfect risk sharing among the employed but not between the employed and the unemployed, as $\underline{b}$ is tighter than the natural borrowing limit.

As argued in detail by Challe et al. (2017), such a non-zero liquidity economy still retains numerical tractability as workers, once becoming unemployed, start liquidating the assets they have set aside for self-insurance motives when employed, eventually facing a binding borrowing constraint in a finite number of subsequent periods of unemployment. Challe et al. (2017), supported by the data, favour a specification where the borrowing constraint is hit immediately in the first period of unemployment. Hence, unemployed workers remain liquidity-constrained thereafter as long as they do not find a job. In such equilibrium, there are three types of workers, differing in their consumption levels: i) the employed, whose consumption level is denoted by c^n in equation (E.2), precautionarily hold the amount of assets b_t, and earn interest payments on those assets that are left after the fraction $\lambda_t\, n_{t-1}$ of previously employed workers becomes jobless —bringing with them the assets they set aside for self-insurance— and the fraction $f_t\,(1-n_{t-1})$ of previously unemployed workers joins with their outstanding debt the pool of mutually insured employed workers; ii) the short-term unemployed, who were employed in the previous period and still retain the assets that were precautionarily set aside, and whose consumption level is denoted by c^{nu} in equation (E.3); iii) the long-term unemployed, whose consumption level is denoted by c^{uu} in equation (E.4), have already liquidated all their assets and remain liquidity-constrained as long as they do not find a job, hence having to pay interests on their outstanding debt from the previous period.

$$1 = \beta\,\mathbb{E}_t\left[\frac{(1-\lambda_{t+1})\,u'\left(c^n_{t+1}\right)+\lambda_{t+1}\,u'\left(c^{nu}_{t+1}\right)}{u'\left(c^n_t\right)}\,R_t\right] \tag{E.1}$$

$$c^n_t = w_t - b_t + R_{t-1}\,b^n_{t-1} \tag{E.2}$$

$$c^{nu}_t = \delta + \underline{b} + R_{t-1}\,b_{t-1} \tag{E.3}$$

$$c^{uu}_t = \delta + \underline{b} - R_{t-1}\,\underline{b} \tag{E.4}$$

$$n_t\,b_t = (1-n_t)\,\underline{b} \tag{E.5}$$

$$n_t\,b^n_{t-1} = (1-\lambda_t)\;n_{t-1}\,b_{t-1} - f_t\,(1-n_{t-1})\,\underline{b} \tag{E.6}$$

In an equilibrium with liquidity-constrained (short- and long-term) unemployed workers, it must also be the case that

$$b_t > 0 \tag{E.7}$$

$$1 > \beta\,\mathbb{E}_t\left[\frac{f_{t+1}\,u'\left(c^n_{t+1}\right) + (1-f_{t+1})\,u'\left(c^{uu}_{t+1}\right)}{u'\left(c^{nu}_t\right)}\,R_t\right] \tag{E.8}$$

$$1 > \beta\,\mathbb{E}_t\left[\frac{f_{t+1}\,u'\left(c^n_{t+1}\right) + (1-f_{t+1})\,u'\left(c^{uu}_{t+1}\right)}{u'\left(c^{uu}_t\right)}\,R_t\right] \tag{E.9}$$

E.1 Calibration

At the steady state,

$$c^n = w - b + R\,b^n \tag{E.10}$$

$$c^{nu} = \delta + \underline{b} + R\,b \tag{E.11}$$

$$c^{uu} = \delta + \underline{b} - R\,\underline{b} \tag{E.12}$$

$$n\,b = (1-n)\,\underline{b} \tag{E.13}$$

$$b^n = (1-\rho)\,(1-f)\,b \tag{E.14}$$

Therefore, two additional parameters need to be (re)calibrated in the non-zero liquidity model: the borrowing limit $\underline{b}$ and the steady state replacement ratio $\delta_w := \delta/w$. In order to nest the zero liquidity model as a special case of the non-zero liquidity model, it is assumed that the average consumption loss upon unemployment, ζ, is the same in the two models. In the zero liquidity model, this maps exactly to the replacement ratio:

$$\frac{c^{u,0}}{c^{n,0}} = \frac{\delta}{w} = 1 - \zeta\,.$$

In the non-zero liquidity model, we have, instead,

$$\frac{c^u}{c^n} = \frac{\delta_w\,w + [1 - R\,(1-\rho)\,(1-f)]\,\underline{b}}{w - [1 - R\,(1-\rho)\,(1-f)]\,b} = 1 - \zeta$$

where $c^u := \frac{\lambda\,n}{1-n}\,c^{nu} + \left(1 - \frac{\lambda\,n}{1-n}\right)\,c^u = f\,c^{nu} + (1-f)\,c^{uu}$ is the average consumption level of the unemployed at the steady state. Exploiting the fact that $b = \frac{1-n}{n}\,\underline{b} = \frac{\lambda}{f}\,\underline{b}$, we then have

$$\underline{b} = w\,\frac{(1-\zeta)-\delta_w}{\left[1-R\,(1-\rho)\,(1-f)\right]\left[1+(1-\zeta)\,\frac{\lambda}{f}\right]}\,. \tag{E.15}$$

δ_w (and consequently $\underline{b}$) is then chosen to amount to the minimal value consistent with having liquidity-constrained unemployed households, i.e. the Euler conditions in (E.8) and (E.9) holding both with inequality. Given the baseline calibration, this corresponds to $\delta_w = 0.793$ and $\underline{b}/w = 0.03$, i.e. the unemployed can borrow up to $\underline{b}/\delta = 3.8\%$ in excess of their income. The zero liquidity case is then nested by $\delta_w = 1-\zeta$, which implies, in turn, $\underline{b} = 0$ in (E.15).

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