Unemployment (Fears) and Deflationary Spirals

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Abstract

The *interaction* of incomplete markets and sticky nominal wages is shown to magnify business cycles even though these two features – in isolation – dampen them. During recessions, fears of unemployment stir up precautionary sentiments which induces agents to save more. The additional savings may be used as investments in both a productive asset (equity) and an unproductive asset (money). The rise in money demand has important consequences. The desire to hold money puts deflationary pressure on the economy, which, provided that nominal wages are sticky, increases labor costs and reduces firm profits. Lower profits repress the desire to save in equity, which increases (the fear of) unemployment, and so on. This is a powerful mechanism which causes the model to behave differently from its complete markets version. In our framework, deflationary pressure means a reduction the price level, but goes together with an increase in expected inflation and a *decrease* in the real interest rate. Thus, our mechanism is quite different from the one emphasized in the zero-lower-bound literature. Due to deflationary spirals our model behaves differently from its incomplete market version without aggregate uncertainty especially in terms of the impact of unemployment insurance on average employment levels. **This version differs substantially from the previous version in terms of having responsive monetary policy and the use of individual wealth data from the HFCS to calibrate. It still needs some polishing.**

Keywords: Keynesian unemployment, business cycles, search friction, magnification, propagation, heterogeneous agents.

JEL Classification: E12, E24, E32, E41, J64, J65.

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1 Introduction

The empirical literature documents that workers suffer substantial losses in both earnings and consumption levels during unemployment. For instance, Kolsrud, Landais, Nilsson, and Spinnewijn (2015) use Swedish data to document that consumption expenditures drop on average by 4.52% during the first year of an unemployment spell.[1] This observed inability to insure against unemployment spells has motivated several researchers to develop business cycle models with a focus on incomplete markets. The hope (and expectation) has been that such models would not only generate more realistic behavior for individual variables, but also be able to generate volatile and prolonged business cycles without relying on large and persistent exogenous shocks. While in existing models, *individual* consumption is indeed much more volatile than aggregate consumption, aggregate variables are often not substantially more volatile than their counterparts in the corresponding complete markets (or representative-agent) version. Krusell, Mukoyama, and Sahin (2010), for instance, find that imperfect risk sharing does not help in generating more volatile business cycles. McKay and Reis (2016) document that a decrease in unemployment benefits – which exacerbates market incompleteness – actually *decreases* the volatility of aggregate consumption. The reason is that a decrease in unemployment benefits increases precautionary savings, investment, the capital stock, and ultimately makes the economy *as a whole* better equipped to smooth consumption.

We develop a model in which the inability to insure against unemployment risk generates business cycles which are much more volatile than the corresponding complete markets version. Moreover, although the only aggregate exogenous shock has a small standard deviation, the outcome of key exercises such as changes in unemployment benefits depends crucially on whether there is aggregate uncertainty. This result is obtained by combining incomplete asset markets with incomplete adjustments of the nominal wage rate to changes in the price level.[2] Markets are incomplete because agents can invest in only two assets, both with payoffs that only depend on aggregate outcomes. Those are a productive asset (equity) and an unproductive asset (money). Our mechanism operates when the unproductive asset earns interest and when it does not. In our model it does. Key is that nominal wages are expressed in units of this (unproductive) asset. The impact of shocks is prolonged by Diamond-Mortensen-Pissarides search frictions in the labor market.

Before explaining why the *combination* of incomplete markets and sticky nominal wages amplifies business cycles, we first explain why these features by themselves *dampen* business cycles in our model in which aggregate fluctuations are caused by productivity shocks. First, consider a model in which there are complete markets, but nominal wages do not respond one-for-one to price level changes. A negative productivity shock induces agents to reduce their demand for money, since

[1] Appendix A provides a more detailed discussion of the empirical literature investigating the behavior of individual consumption during unemployment spells.

[2] We discuss the empirical motivation for these assumptions in section 2 and appendix A.

the present is worse than the future and agents would like to smooth consumption. Moreover, less money is needed at lower activity levels. The decline in money demand puts upward pressure on the price level. Provided that nominal wages are sticky, the resulting downward pressure on real wages mitigates the reduction in profits caused by the direct negative effect of a decline in productivity. The result is a muted aggregate downturn, since a smaller reduction in profits implies a smaller drop in employment. Next, consider a model in which nominal wages are flexible, but workers cannot fully insure themselves against unemployment risk. Forward-looking agents understand that a persistent negative productivity shock increases the risk of being unemployed in the near future. If workers are not fully insured against this risk, the desire to save increases for precautionary reasons. However, increased savings leads to an increase in demand for all assets, including productive assets such as firm ownership. This counteracting effect alleviates the initial reduction in demand for productive assets which was induced by the direct negative effect of a reduced productivity level, and therefore *dampens* the increase in unemployment. In either case, sticky nominal wages or incomplete markets lead – in isolation – to a muted business cycle.

Why does the combination of incomplete markets and sticky nominal wages lead to the opposite results? As before, the increased probability of being unemployed in the near future increases agents' desire to save more in all assets. However, the increased desire to hold money puts downward pressure on the price level, which in turn increases real labor costs and reduces profits. This latter effect counters any positive effect that increased precautionary savings might have on the demand for productive investments. Once started, this channel will reinforce itself. That is, if precautionary savings lead – through downward pressure on prices – to increased unemployment, then this will in turn lead to a further increase in precautionary savings, and so on. When does this process come to an end? At some point, the expanding number of workers searching for a new job reduces the expected cost of hiring, which makes it attractive to resume job creating investments.

In addition to endogenizing unemployment, the presence of search frictions in the labor market adds further dynamics to this propagation mechanism. First, the value of a firm – i.e. the price of equity – is forward-looking. As a consequence, a prolonged increase in real labor costs leads to a sharp reduction in economic activity already in the present, with an associated higher risk of unemployment. Second, with low job-finding rates unemployment becomes a slow moving variable. Thus, the increase in unemployment is more persistent than the reduction in productivity itself.

Our mechanism is quite different from the one emphasized in the zero-lower-bound literature. Key in the zero-lower-bound literature is deflationary pressure that manifests itself in a reduction in expected inflation and possibly even deflation combined with the inability to reduce the policy rate to values below zero. This leads to an increase in the real interest rate, which in turn leads to a deterioration of the economy and further deflationary pressure. In our framework, however, deflationary pressure means a reduction in the price *level* that actually goes together with an increase in expected inflation and a substantial *decrease* in the real interest rate.

We use our framework to study the advantages of alternative unemployment insurance (UI) policies. Specifically, we document that the effects of changes in unemployment benefits on the behavior of aggregate variables differ from the effects in other models. In the existing literature, increased unemployment benefits brings forth adverse aggregate consequences that eclipse the gains of reduced income volatility (e.g. Young (2004) and Krusell, Mukoyama, and Sahin (2010)). In particular, with lower fluctuations in individual income the precautionary motive weakens, and aggregate investment falls. The result is a decline in average employment and output, with adverse effects on welfare. This channel is important in our model as well. However, in the version of our model *with* aggregate uncertainty, there are two quantitatively important factors that push average employment in the opposite direction, and can overturn the negative effect associated with the reduction in precautionary savings. The first is that the demand for the productive asset can *increase*, because an increase in the level of unemployment benefits stabilizes asset prices as well as business cycles. The second is that the nonlinearity in the matching process is such that increases in employment during expansions are smaller than reductions during recessions. Consequently, a reduction in volatility can lead to an increase in *average* employment (cf. Jung and Kuester (2011)).

An important aspect of our model is that precautionary savings can be used for investments in both the productive asset (firm ownership) and the unproductive asset (money). This complicates the analysis, because the numerical procedure requires a simultaneous solution for a portfolio choice problem for each agent, and for equilibrium prices. Our numerical analysis ensures that the market for firm ownership (equity) is in equilibrium and all agents owning equity discount future equity returns with the correct, that is, their own individual-specific, intertemporal marginal rate of substitution (MRS). By contrast, a typical set of assumptions in the literature is that workers jointly own the productive asset at equal shares, that these shares cannot be sold, and that discounting of the returns of this asset occurs with some average MRS or an MRS based on aggregate consumption.[3,4] One exception is Krusell, Mukoyama, and Sahin (2010) who – like us – allow trade in the productive asset and discount agents' returns on this asset with the correct marginal rate of substitution.[5]

In section 2, we provide empirical motivation for the key assumptions underlying our model:

[3]Examples are Shao and Silos (2007), Nakajima (2010), Gorneman, Kuester, and Nakajima (2012), Favilukis, Ludvigson, and Van Nieuwerburgh (2013), Jung and Kuester (2015), and Ravn and Sterk (2015).

[4]An alternative simplifying assumption is that the only agents who are allowed to invest in the productive asset are agents that are not affected by idiosyncratic risk (of any kind). Examples are Rudanko (2009), Bils, Chang, and Kim (2011), Challe, Matheron, Ragot, and Rubio-Ramirez (2014), and Challe and Ragot (2014). Bayer, Luetticke, Pham-Dao, and Tjaden (2014) analyze a more challenging problem than ours, in which firms are engaged in intertemporal decision making. However, in contrast to our model, these firms are assumed to be risk neutral, consume their own profits, and discount the future at a constant geometric rate.

[5]The procedure in Krusell, Mukoyama, and Sahin (2010) is only exact if the aggregate shock can take on as many realizations as there are assets and no agents are at the short-selling constraint. Our procedure does not require such restrictions, which is important, because the fraction of agents at the constraint is nontrivial in our model.

sticky nominal wages and workers' inability to insure against unemployment risk. We also discuss the relationship between savings and idiosyncratic uncertainty. In section 3, we describe the model. In section 4, we discuss the calibration of our model. In sections 5 and 6, we describe the behavior of individual and aggregate variables, respectively. In section 8, we discuss how business cycle behavior is affected by alternative UI policies.

2 Empirical motivation

Figure 1 displays the behavior of GDP, the unemployment rate, and stock prices for the Eurozone during the great recession.[6] What are the factors behind the observed large and persistent drops in real activity and stock prices? The mechanism proposed in this paper is motivated by the behavior of prices, nominal wages, and unit labor costs in the Eurozone during this economic downturn. The first observation is that the growth in the price level slowed considerably during the crisis relative to the trend. This is documented in the top panel of figure 2, which plots the GDP deflator for the Eurozone alongside its pre-crisis trend.[7] To investigate whether nominal wages followed the slowdown in inflation, the second panel of figure 2 displays nominal hourly earnings together with its pre-crisis trend. We find that nominal wages continued to grow at pre-crisis rates or above, despite a substantial reduction in inflation rates. This means that real wages *increased* relative to trend.[8]

[6]Details on data sources are given in appendix B.

[7]The pre-crisis trend is defined as the time path the variable would have followed if its growth rate before and beyond the fourth quarter of 2007 had been equal to the average growth rate over the five years preceding 2007.

[8]Similarly, Daly, Hobijn, and Lucking (2012) and Daly and Hobijn (2013) document that real wages increased during the recent recession in the US.

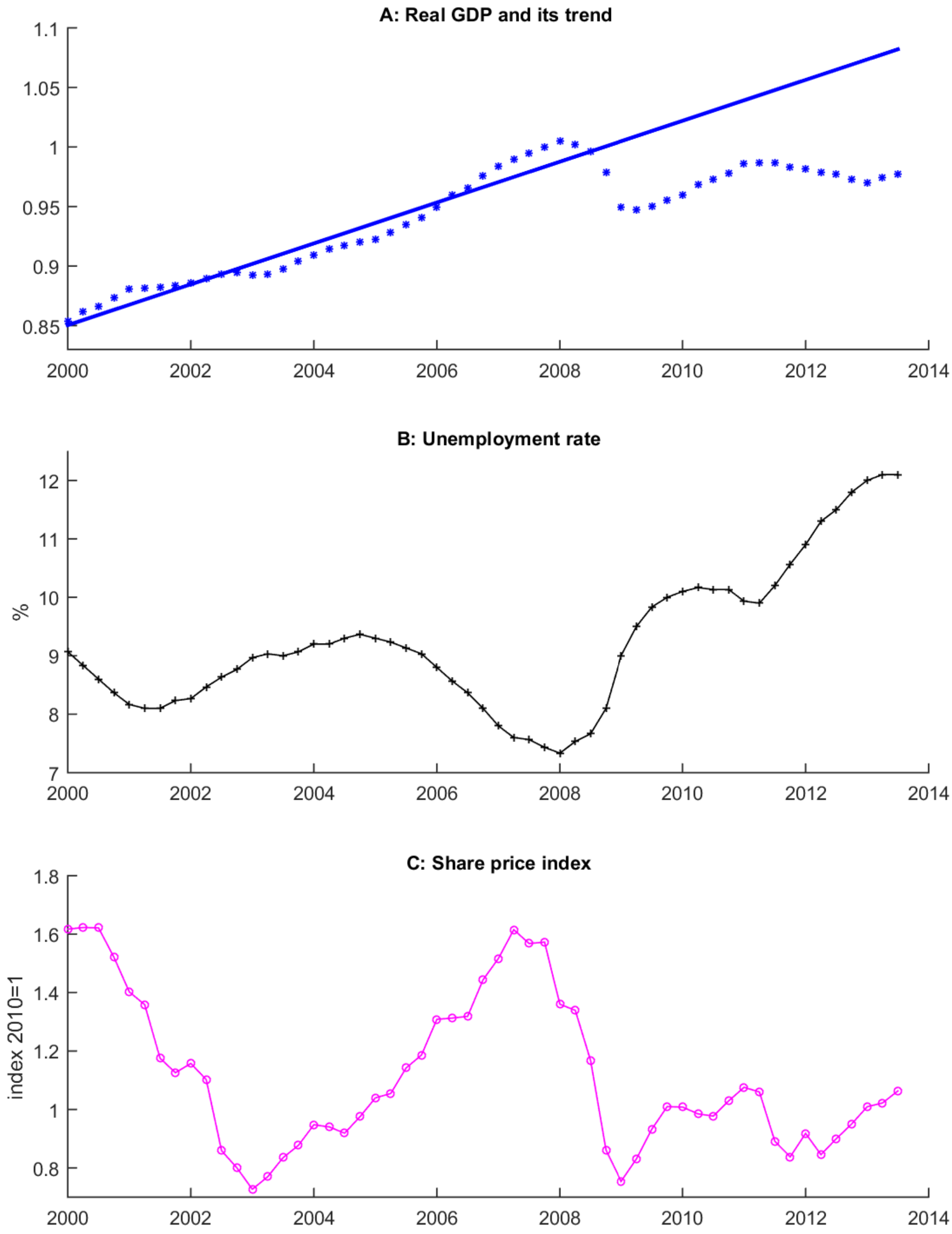

Figure 1: Key Eurozone variables.

Notes. The pre-crisis trend is defined as the time path the variable would have followed if its growth rate before and beyond the fourth quarter of 2007 had been equal to the average growth rate over the five years preceding 2007. Data sources are given in appendix B.

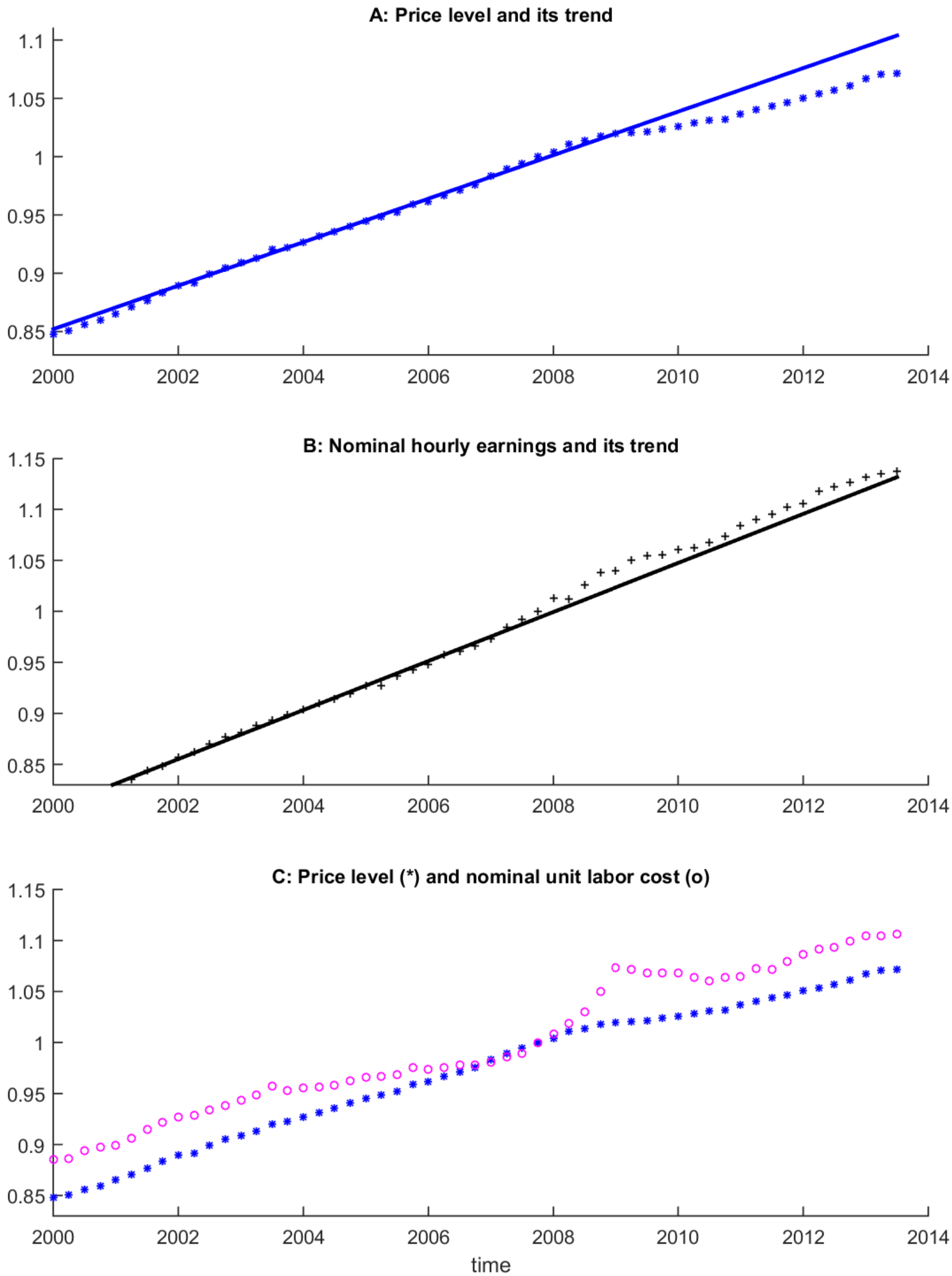

Figure 2: Key Eurozone variables.

Notes. The pre-crisis trend is defined as the time path the variable would have followed if its growth rate before and beyond the fourth quarter of 2007 had been equal to the average growth rate over the five years preceding 2007. Data sources are given in B.

The observed increases in real wages are not necessarily due to a combination of low inflation and downward nominal wage rigidity. It is possible that solid real wage growth reflects an increase in labor productivity, for example, because workers that are laid off are less productive than those that are not. To shed light on this possibility, we compare the nominal unit labor cost with the price level.[9] The results are shown in the bottom panel of figure 2. The panel shows that nominal unit labor costs have grown faster than prices since the onset of the crisis, whereas the opposite was true before the crisis. This indicates that real labor costs increased during the crisis even if one corrects for productivity.[10]

These observations are consistent with the hypothesis that the combination of deflationary pressure and nominal wage stickiness increased labor costs.[11] Labor hoarding combined with stickiness of *real* wages would also lead to an increase in real unit labor costs. As documented in appendix A, however, there is convincing evidence that nominal wages do not fully respond to changes in prices. Thus, it seems reasonable to assume that at least part of the observed increase in real wage costs is due to the combination of deflationary pressure and sticky nominal wages.

The pattern displayed in figure 2 is not universally true in all economic downturns. In fact, when we repeat the exercise for the US, then we find that real wages increased relative to the pre-crisis trend, like they did in the Eurozone, but that real unit labor costs did not.

3 Model

The economy consists of a unit mass of households, a large mass of potential firms, and one government. The mass of active firms is denoted q_t, and all firms are identical. Households are ex-ante homogeneous, but differ ex-post in terms of their employment status (employed or unemployed) and their asset holdings.

Notation. Upper (lower) case variables denote nominal (real) variables. Variables with subscript i are household specific. Variables without a subscript i are either aggregate variables or variables that are identical across agents, such as prices.

[9] The nominal unit labor cost is defined as the cost of producing one unit of output, i.e., the nominal wage rate divided by labor productivity. The price index used as comparison is the price index used in defining labor productivity.

[10] The observation that real unit labor costs are not constant over the business cycle is interesting in itself. If the real wage rate is equal to the marginal product of labor and the marginal product is proportional to average labor productivity – properties that hold in several business cycle models – then real unit labor costs would be constant.

[11] Throughout this paper, we will use the term deflationary pressure broadly. In particular, we also use it – as is the case here – to indicate a slowdown in inflation relative to trend.

3.1 Households

Each household consists of one worker who is either employed, $e_{i,t} = 1$, or unemployed, $e_{i,t} = 0$. The period-t budget constraint of household i is given by

$$
\begin{aligned}
& P_t c_{i,t} + J_t \left(q_{i,t+1} - (1-\delta) q_{i,t} \right) + L_{i,t+1}, \\
& \qquad = (1-\tau_t) W_t e_{i,t} + \mu (1-\tau_t) W_t (1-e_{i,t}) + D_t q_{i,t} + R_{t-1} L_{i,t}, \quad (1)
\end{aligned}
$$

where $c_{i,t}$ denotes consumption of household i, P_t the price of the consumption good, $L_{i,t+1}$ the amount of the liquid asset bought in period t, R_t the gross nominal interest rate on this asset, W_t, the nominal wage rate, τ_t the tax rate on nominal income, and μ the replacement rate. The variable $q_{i,t}$ denotes the amount of equity held at the beginning of period t. One unit of equity pays out nominal dividends D_t. Firms are identical except that a fraction δ of all firms go out of business each period. We assume that households hold a diversified portfolio of equity, which means that each investor's portfolio also depreciates at rate δ. When the term $q_{i,t+1} - (1-\delta) q_{i,t}$ is positive, the worker is buying equity, and vice versa. The nominal value of this transaction is equal to $J_t \left(q_{i,t+1} - (1-\delta) q_{i,t} \right)$, where J_t denotes the nominal price of equity ex dividend.

Households are not allowed to take short positions in equity, that is

$$q_{i,t+1} \geq 0. \quad (2)$$

The household maximizes the objective function

$$\mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t \left(\frac{c_{i,t}^{1-\gamma} - 1}{1-\gamma} + \chi \frac{\left(\frac{L_{i,t+1}}{P_t} \right)^{1-\zeta} - 1}{1-\zeta} \right) \right],$$

subject to constraints (1), (2), and with $L_{i,0}$ and $q_{i,0}$ given.

The first-order conditions are given as

$$
\begin{aligned}
c_{i,t}^{-\gamma} &= \beta R_t \mathbb{E}_t \left[c_{i,t+1}^{-\gamma} \frac{P_t}{P_{t+1}} \right] + \chi \left(\frac{L_{i,t+1}}{P_t} \right)^{-\zeta}, & (3) \\
c_{i,t}^{-\gamma} &\geq \beta \mathbb{E}_t \left[c_{i,t+1}^{-\gamma} \left(\frac{D_{t+1} + (1-\delta) J_{t+1}}{J_t} \right) \frac{P_t}{P_{t+1}} \right], & (4) \\
0 &= q_{i,t+1} \left(c_{i,t}^{-\gamma} - \beta \mathbb{E}_t \left[c_{i,t+1}^{-\gamma} \left(\frac{D_{t+1} + (1-\delta) J_{t+1}}{J_t} \right) \frac{P_t}{P_{t+1}} \right] \right). & (5)
\end{aligned}
$$

Equation (3) represents the Euler equation with respect to the liquid asset; equation (4) the Euler equation with respect to equity; and equation (5) captures the complementary slackness condition associated with the short-selling constraint in equation (2).[12]

Characteristics of the liquid asset. The utility function captures the idea that the liquid asset facilitates transactions within the period or more generally provides other benefits than just earning a rate of return. Thus, one could think of the liquid asset as money. We want to allow for a broader interpretation and assume that the liquid asset does earn interest.[13] Important for our mechanism is that an increase in uncertainty about future consumption levels could lead to a precautionary increase in the demand for the liquid asset. Equation (3) shows that this frameworks allows for this insurance role of the liquid asset in a flexible way. Increased uncertainty about future consumption levels would increase $\mathbb{E}_t\left[c_{i,t+1}^{-\gamma} P_t/P_{t+1}\right]$, which would put upward pressure on $L_{i,t+1}/P_t$. The parameter ζ controls the strength of this effect.[14] Another salient feature of this setup is that the investment portfolio of the less wealthy will be skewed towards the liquid asset.[15] The utility aspect is also helpful in solving for the households' portfolio problems.[16] In this economy, agents can only invest in two assets and there is no financial intermediation. Thus, we think of the liquid asset representing a broader category than just money and this broader category could, for example, also include short-term government bonds.

The following characteristics of the liquid asset are important. First, as discussed above agents hold the liquid asset not only for transactions motives, but also to insure themselves against unemployment risk.[17] Second, it serves as the unit of account. In particular, wages are expressed in units of money. This means that real wages are affected if nominal wages do not respond one-for-one to changes in the price level. Third, equilibrium in the market for liquid assets implies that investors *as a whole* cannot shift into and out of this safer *but unproductive* asset unless the supply adjusts. The *desire* to do so when uncertainty about the future increases does play a key role in our model. It

[12]The utility specification implies that agents will always invest a strictly positive amount in the liquid asset. Short positions in the liquid asset would become possible if the argument of the utility function is equal to $(L_{i,t}+\Phi)/P_t$ with $\Phi > 0$ instead of $L_{i,t+1}/P_t$. At higher values of Φ, agents can take larger short positions in the liquid asset and are, thus, better insured against unemployment risk. Increases in χ – while keeping Φ equal to zero – have similar implications, since higher values of χ imply higher average levels of financial assets.

[13]Our mechanism would go through if the liquid asset does not earn any interest, that is, when $R_t = 1$ in each period. In fact, we reduce the quantitative importance of our mechanism by introducing realistic cyclical behavior for R_t.

[14]Monetary frameworks such as shopping time models and transaction costs models incorporate a specific transactions technology, but these can be expressed as models in which the amount of liquidity enters the utility function directly. See Feenstra (1986) and Den Haan (1990) for details. A cash-in-advance model is a special case of these frameworks, but is a lot more restrictive in terms of its implications for velocity defined here as the ratio of aggregate consumption over real money holdings. It is essential for our mechanism that the demand for liquidity is not largely pinned down by the current consumption level, but can respond to changes in uncertainty about the future through the impact of the latter on the expected marginal rate of substitution.

[15]The least wealthy will only hold the liquid assets. They would like to go short in equity, but are prevented from doing so because of the short-sale constraint.

[16]The transactions component "anchors" the portfolio and avoids large swings in the portfolio decision.

[17]Telyukova (2013) documents that households hold more liquid assets than they need for buying goods.

is important for our story that there is not an additional agent in the economy who is always willing to absorb risk and to channel any increase in aggregate demand for save liquid assets into productive but risky investments without asking a premium in return.

3.2 Active firms

An active firm produces z_t units of the output good in each period, where z_t is an exogenous stochastic variable that is identical across firms. The value of z_t follows a first-order Markov process with a low (recession) and a high (expansion) value.[18]

There is one worker attached to each active firm. Thus, the number of active firms, q_t, is equal to the economy-wide employment rate. The nominal wage rate, W_t, is the only cost to the firm. Consequently, nominal firm profits, D_t, are given by

$$D_t = P_t z_t - W_t. \tag{6}$$

Wage setting. The matching friction creates a surplus and one has to take a stand on how this surplus is divided between the worker and the owner of the firm. One possibility is Nash bargaining. Another popular approach is to assume that wages remain constant until the situation is such that either wage adjustment is required to prevent the worker or the firm owner from severing the relationship, and that the relationship is only severed when the surplus is negative." There are several other possibilities and the empirical literature provides only limited guidance. We want wage setting to be consistent with the following two properties. First, as discussed in appendix A, there is ample evidence that nominal wages do not fully adjust to changes in the price level. Second and consistent with the matching literature, wage setting rules should not lead to inefficient breakups, that is, to severance of the relationship while the surplus is positive. Incorporating (nominal) wage stickiness is problematic for the usual Nash bargaining setup, since it assumes that wages are renegotiated every period. Nash bargaining is also computationally challenging in our environment, since individual asset holdings would affect the worker's bargaining position and thus the wage. We also do not want to assume that wages are constant through time except in those instances when keeping the wage constant leads to inefficient severance, since there clearly is some adjustment of nominal wages to inflation. Instead we use the following flexible rule for the nominal wage:

$$W_t = \omega_0 \left(\frac{z_t}{\overline{z}}\right)^{\omega_z} \overline{z} \left(\frac{P_t}{\overline{P}}\right)^{\omega_P} \overline{P}, \tag{7}$$

[18] Although the model is solvable for richer processes, this simple specification for z_t helps in keeping the computational burden manageable.

where $\bar{z}$ is the average productivity level, P_t is the price level, and $\overline{P}$ is the average price level. The parameter ω_P controls how responsive wages are to changes in the price level. If ω_P is equal to one, for instance, then nominal wages adjust one-for-one to changes in P_t. By contrast, nominal wages are entirely unresponsive to changes in P_t if ω_P is equal to zero. The coefficient ω_z indicates the sensitivity of the wage rate to changes in productivity and – together with ω_P controls how wages vary with business cycle conditions. The coefficient ω_0 indicates the fraction of output that goes to the worker when z_t and P_t take on their average values, and pins down the steady state value of firm profits in real terms.

The specified wage is necessarily in the worker's bargaining set, since parameters are chosen such that it exceeds unemployment benefits, there is no home production nor any disutility from working, and the probability of remaining employed exceeds the probability of finding a job. The parameters are chosen such that the wage rate is also in the firm owner's bargaining set, that is, it is never so high that the firm would rather fire the worker than continue.

Wages of new and existing relationships. What matters in labor market matching models is the flexibility of wages of *newly* hired workers. Haefke, Sonntag, and van Rens (2013) argue that wages of new hires respond almost one-to-one to changes in labor productivity. Gertler, Huckfeldt, and Trigari (2016), however, argue that this result reflects changes in the composition of new hires and that – after correcting for such composition effects – the wages of new hires are not more cyclical than wages of existing employees. More importantly, however, what matters for our paper is whether nominal wages respond to changes in the price level, and this question is not addressed in either paper. Druant, Fabiani, Kezdi, Lamo, Martins, and Sabbatini (2009) find that many firms do not adjust wages to inflation. One would think that their results apply to new as well as old matches, since their survey evidence focuses on the firms' main occupational groups not on the wages of individual workers.

3.3 Firm creation and equity market

Agents that would like to increase their equity position in firm ownership, i.e., agents for whom $q_{i,t+1} - (1-\delta)\,q_{i,t} > 0$, can do so by buying equity at the price J_t from agents that would like to sell equity, i.e., from agents for whom $q_{i,t+1} - (1-\delta)\,q_{i,t} < 0$. Alternatively, agents who would like to obtain additional equity can also acquire new firms by creating them.

How many new firms are created by investing $v_{i,t}$ real units depends on the number of unemployed workers, u_t, and the *aggregate* amount invested, v_t. In particular, the aggregate number of new firms created is equal to

$$h_t \equiv q_t - (1-\delta)\,q_{t-1} = \psi v_t^{\eta} u_t^{1-\eta} \tag{8}$$

and an individual investment of $v_{i,t}$ results in $(h_t/v_t)v_{i,t}$ new firms with certainty. There is no risk in this transaction and new firms are identical to existing firms. Consequently, the cost of creating one new firm, v_t/h_t, has to be equal to the real market price, J_t/P_t.[19] Setting v_t/h_t equal to J_t/P_t and using equation (8) gives

$$v_t = \left(\psi \frac{J_t}{P_t}\right)^{1/(1-\eta)} u_t. \tag{9}$$

Thus, investment in new firms is increasing in J_t/P_t and increasing in the mass of workers looking for a job, u_t.

Equilibrium in the equity market requires that the supply of equity is equal to the demand for equity. That is,

$$h_t + \int_{i\in\mathscr{A}_-} \left(\left(1-\delta\right) q_i - q\left(e_i, q_i, L_i; s_t\right)\right) dF_t\left(e_i, q_i, L_i\right)$$
$$= \int_{i\in\mathscr{A}_+} \left(q\left(e_i, q_i, L_i; s_t\right) - \left(1-\delta\right) q_i\right) dF_t\left(e_i, q_i, L_i\right), \tag{10}$$

with

$$\mathscr{A}_- = \{i : q(e_i, q_i, L_i; s_t) - (1-\delta)q_i \leq 0\},$$
$$\mathscr{A}_+ = \{i : q(e_i, q_i, L_i; s_t) - (1-\delta)q_i \geq 0\},$$

where $F_t\left(e_i, q_i, L_i\right)$ denotes the cross-sectional cumulative distribution function in period t of the three individual state variables: the employment state, e_i, liquid asset holdings, L_i, and equity holdings, q_i. The variable s_t denotes the set of aggregate state variables and its elements are discussed in Section 3.7.

Combining the last three equations gives

$$\psi^{1/(1-\eta)} \left(\frac{J_t}{P_t}\right)^{\eta/(1-\eta)} u_t = \int_{i\in\mathscr{A}} \left(q\left(e_i, q_i, L_i; s_t\right) - \left(1-\delta\right) q_i\right) dF_t\left(e_i, q_i, L_i\right), \tag{11}$$

where $\mathscr{A}$ is the set of all households, that is, $\mathscr{A} = \{\mathscr{A}_+ \cup \mathscr{A}_-\}$.

Our representation of the "matching market" looks somewhat different than usual. As documented in appendix C, however, it is equivalent to the standard search-and-matching setup. Our way of "telling the story" has two advantages. First, the only investors are households. That is, we do not have entrepreneurs who fulfill a crucial arbitrage role in the standard setup, but attach no value to their existence or activities pursued. Second, all agents in our economy have access to the same

[19] An alternative interpretation of the matching friction is that an investment of one unit results in the creation of 1 firm *with probability* (h_t/v_t). Our approach implicitly assumes that this matching risk is diversified.

two assets; firm ownership and money. By contrast, households and entrepreneurs have different investment opportunities in the standard setup.[20]

3.4 Government budget constraint

The overall government budget constraint is given by

$$\tau_t q_t W_t + L_{t+1} - R_{t-1} L_t = (1 - q_t)\mu(1 - \tau_t) W_t. \tag{12}$$

An increase in q_t, i.e., an increase in employment, means that there is an increase in the tax base and a reduction in the number of unemployed. Both lead to a reduction in the tax rate. Unemployment insurance is the main component affecting the tax rate. The other component consists of net revenues of the central bank. The central bank supplies the liquid asset and sets the interest rate. Its net revenues are equal to $L_{t+1} - R_{t-1} L_t$.

3.5 Interest rate policy

In our environment, business cycles are amplified by an interaction of deflationary pressure due to precautionary savings and sticky nominal wages. The obvious monetary policy to fight against this mechanism consists of reducing price level variations. Therefore, we consider a monetary policy that allows for doing so. In particular, we assume that the interest rate rule is set by the central bank according to

$$R_t = \nu_0 \left(\frac{P_t}{\overline{P}} \right)^{\nu_P}, \tag{13}$$

where $\overline{P}$ is the average price level. The parameter ν_0 determines the average nominal interest rate and ν_P the intensity with which the central banks pursues price level stability. The central bank can reduce price and business cycle volatility by increasing ν_P.

[20] There is one other minor difference. In our formulation, there is no parameter for the cost of posting a vacancy and there is no variable representing the number of vacancies. Our version only contains the product, i.e., the total amount invested in creating new firms. In the standard setup, the vacancy posting cost parameter is not identified unless one has data on vacancies. The reason is that different combinations of this parameter and the scalings coefficient of the matching function can generate the exact same model outcomes as long as the number of vacancies are not taken into consideration.

3.6 Market for liquid assets

Equilibrium in the market for liquid assets requires that the aggregate demand by households equals the supply by the central bank. That is,

$$L_{t+1} = \int_{i \in \mathscr{A}} L(e_i, q_i, L_i; s_t)\, dF_t(e_i, q_i, L_i). \tag{14}$$

We assume that monetary policy mainly affects the economy by changing the interest rate not by changing the supply of the liquid asset.[21]

3.7 Equilibrium and model solution

In equilibrium, the following conditions hold: (i) asset demands are determined by the households' optimality conditions, (ii) the cost of creating a new firm equals the market price of an existing firm, (iii) the demand for equity from households that want to buy equity equals the creation of new firms plus the supply of equity from households that want to sell equity, (iv) the demand for the liquid assets from households equals the supply by the central bank, (v) the overall government's budget constraint is satisfied, and (vi) the interest rate is set according to the central bank's interest rate rule.

The state variables for agent i are individual asset holdings, employment status, and the aggregate state variables. The latter consist of the aggregate productivity level, z_t, and the cross-sectional joint distribution of employment status and asset holdings, F_t. We use an algorithm similar to the one used in Krusell and Smith (1998) to solve for the laws of motion of aggregate variables. The numerical procedure is discussed in appendix E.2.

3.8 Discounting firm profits correctly with heterogeneous ownership

With incomplete markets and heterogeneous firm ownership, the question arises how to discount future firm profits. There are two separate issues.

A long outstanding and unresolved debate in corporate finance deals with firm *decision making* when owners are heterogeneous and markets are incomplete.[22] This is not an issue here even though firms are owned by heterogeneous households. It obviously is not an issue for active firms, since they do not take any decisions. It is also not an issue for creating a new firm, since this is a static

[21] Specifically, we assume that the amount the government has to repay each period, $R_{t-1}L_t$ is fixed and equal to $\overline{L}$. This assumption ensures that R_{t-1} is not a state variable, which would be the case if, for example, L_t is held constant. This is an obvious computational benefit. Our approach does imply that there are some changes in the supply of the liquid asset. Relative to the alternative of a fixed L_t, these changes weaken our mechanism since supply L_{t+1} increases when R_t is low, that is, when there is deflationary pressure.

[22] See, for example, Grossman and Hart (1979).

decision that does not involve any risk. Consequently, arbitrage ensures that the cost of creating one firm, v_t/h_t, equals its market value, J_t/P_t.

Firm profits also show up in households' Euler equations. By contrast to the first issue, this does not lead to any *theoretical* challenges. As indicated in equations (3), (4) and (5), theory stipulates that future firm profits should be discounted with the household's own, *individual-specific*, MRS, just as future returns on the liquid asset are discounted with the household's own MRS. The fact that there is co-ownership does not make equity holdings different from any other asset. Although this does not raise any theoretical challenges, it does raise computational challenges, since all agents have their own individual-specific MRS. First, one has to solve a portfolio problem. This is nontrivial in environments like ours in which (idiosyncratic) uncertainty plays a key role in portfolio composition. Second, this has to be done in general equilibrium. That is, one has to construct an algorithm that finds the MRS and the demand for both assets for *all* individual households as well as equilibrium prices that solve the simultaneous system of equations consisting of Euler equations and equilibrium conditions.

In the literature on precautionary savings and idiosyncratic risk, one can find two approaches to avoid this computational challenge.[23] The first approach assumes some form of communal ownership of the productive asset, with fixed ownership shares that can never be sold no matter how keen an agent would be to do so.[24] Investment decisions in the productive asset are then reduced to one aggregate investment decision, that is, it is determined by only one "Euler equation" using an MRS based either on aggregate consumption; on an average of the marginal rate of substitution of all agents; or on risk neutral geometric discounting. The second approach assumes that there exist two distinct types of agents: One type of agent faces idiosyncratic risk but cannot invest in the productive asset; the other who can invest in the productive asset, but is not affected by any type of idiosyncratic risk. Since there is no ex-post heterogeneity within the group of the latter type, their analysis lends itself to a representative agent, which then dictates the aggregate investment decisions in the economy.[25]

Both approaches simplify the analysis considerably, but both limit our understanding of the effect of idiosyncratic risk on business cycles through precautionary savings. The reason is the following. Productive assets, such as firms in our model, generate a flow of profits and a reduction

[23] An exception is Krusell, Mukoyama, and Sahin (2010). They describe a procedure to discount firm profits (almost) correctly. They assume that the number of assets is equal to the number of realizations of the aggregate shock. Firm profits can then be discounted with the prices of the two corresponding contingent claims and this would be exactly correct if borrowing or short-sell constraints are not binding for any investor. Our procedure allows investors to be constrained and the number of realizations of the aggregate shock can exceed the number of assets.

[24] Examples are Shao and Silos (2007), Nakajima (2010), Gorneman, Kuester, and Nakajima (2012), Favilukis, Ludvigson, and Van Nieuwerburgh (2013), Jung and Kuester (2015), and Ravn and Sterk (2015).

[25] Examples are Rudanko (2009), Bils, Chang, and Kim (2011), McKay and Reis (2016), Challe, Matheron, Ragot, and Rubio-Ramirez (2014), and Challe and Ragot (2014).

in real interest rates (or discount rates more generally) put upward pressure on the value of such productive assets, which would stimulate investment in this asset. When an increase in precautionary savings lowers discount rates rates, then this would stimulate investment in the productive asset, not depress it. Increased investment in the productive asset typically leads to an increased demand for labor, which in turn would reduce unemployment and idiosyncratic uncertainty. This effect is very direct in labor market matching models in which investment in the productive asset is equivalent to job creation.[26]

We do not make such simplifying assumption. Consequently, we can analyze the question whether an increase in precautionary savings induced by an increase in idiosyncratic uncertainty could lead to an increased demand for equity as well as an increase in the demand for the liquid asset. As discussed below, key for the answer to this question is the difference in risk characteristics of the two assets.

4 Calibration

We start with a discussion of model parameters for which we can directly choose the appropriate value. Next we discuss the remaining parameters for which the values are chosen to ensure that the model aligns well with a set of empirical observations. Finally, we discuss parameters for the representative-agent model. The model period is one quarter. The calibration targets are constructed using Eurozone data.[27]

4.1 Directly chosen parameter values.

Unemployment insurance regimes vary a lot across Eurozone countries. Esser, Ferrarini, Nelson, Palme, and Sjöberg (2013) report that net replacement rates for insured workers vary from 20% in Malta to just above 90% in Portugal. Most countries have net replacement rates between 50% and 70% with an average duration of around one year. Coverage ratios vary from about 50% in Italy to 100% in Finland, Ireland, and Greece. Net replacement rates for workers that are not covered by an unemployment insurance scheme are much lower. In most countries, replacement rates of workers only receiving unemployment/social assistance are less than 40%. In the model, unemployment benefits are set equal to 50% and – for computational convenience – are assumed to last for the entire duration of the unemployment spell. A replacement rate of 50% is possibly a bit less than the average observed, but this is compensated for by the longer duration of unemployment benefits in the model and the universal coverage.

[26] But an increase in capital investment would also lead to an increase in the demand for labor if it increases the marginal product of labor.

[27] We use data from 1980 to 2012, whenever possible. Details are given in appendix B.

The curvature parameter in the utility component for liquidity services, ζ, plays an important role, because it directly affects the impact of changes in future job security on the demand for the liquid asset. With more curvature, the demand for the liquid asset is less sensitive to changes in the expected marginal rate of substitution and increased concerns about future job prospects would generate less deflationary pressure. We follow Lucas (2000), and target a demand elasticity equal to -0.5. The resulting value of ζ is equal to 2.[28] The other key parameter in money demand functions is the elasticity with respect to a transactions volume measure. Our transactions variable is consumption and the elasticity of demand for the liquid asset with respect to consumption is equal to γ/ζ, where γ is the coefficient of relative risk aversion. By setting $\gamma = 2$, this elasticity takes on the standard unit value and we are conservative in terms of agents' risk aversion.[29,30]

A key aspect of the mechanism emphasized in this paper is that nominal wages do not fully adjust to changes in the price level, that is, we need $\omega_P < 1$. Direct estimates of ω_P are not available. We want to make a conservative choice, since this is such a key parameter. Our benchmark value for ω_P is equal to 0.7, which means that a 1% increase in the price level leads to an 0.7% increase in nominal wages. This seems conservative given that Druant, Fabiani, Kezdi, Lamo, Martins, and Sabbatini (2009) report that only 6% of European firms adjust wages (of their main occupational groups) more than once a year to inflation and only 50% do so once a year.[31]

Based on the empirical estimates in Petrongolo and Pissarides (2001), the elasticity of the job finding rate with respect to tightness, η, is set equal to 0.5. In our model, the presence of idiosyncratic risk lowers average real rates of return. This motivates us to set the discount factor, β, to 0.98, which is below its usual value of 0.99.[32]

The two values for z_t are 0.978 and 1.023 and the probability of switching is equal to 0.025. With

[28] The demand elasticity of $L_{i,t+1}$ with respect to the expected marginal rate of substitution is equal to the demand elasticity with respect to the interest rate, $\widetilde{R}_t$, of an asset with a risk-free nominal payoff and *no* liquidity benefits. The Euler equation of this (hypothetical) asset is given by

$$1 = \beta \widetilde{R}_t \mathbb{E}_t \left[\left(\frac{c_{i,t+1}}{c_{i,t}} \right)^{-\gamma} P_t / P_{t+1} \right].$$

Using $R_t / \widetilde{R}_t \approx 1 + R_t - \widetilde{R}_t$ and equation (3), we get

$$\ln(L_{i,t+1}/P_t) \approx -\zeta^{-1} \ln\left(\widetilde{R}_t - R_t\right) + \zeta^{-1} \left(\ln\chi + \gamma \ln c_{i,t}\right).$$

[29] For example, Lucas (2000) imposes a unit elasticity.

[30] This elasticity is also equal to 1 in standard cash-in-advance models. Our framework is more flexible than a cash-in-advance model, because we can vary ζ to ensure the right sensitivity of demand for the liquid asset to the expected marginal rate of substitution.

[31] Moreover, even if firms adjust wages for inflation they typically do so using backward looking measures of inflation, which reduces the responsiveness to changes in inflationary pressure.

[32] At this relatively high 8% annual discount rate, the average real rate of return is already quite low, namely 3.2% on an annual basis in the economy with aggregate uncertainty.

these values we match the key characteristics of the typical process for exogenous productivity.[33] Although we rely on regular magnitudes for changes in z_t, a sustained drop in z_t generates a drop in aggregate output that resembles the observed drop in Eurozone output during the great recession. That is, the deflationary mechanism magnifies shocks considerably.

The value of ν_0 is chosen such the steady state return on the liquid asset is equal to 50 basis points.[34] Finally, average supply of the liquid asset, $\overline{L}$, is chosen such that the average price level, $\overline{P}$, is equal to 1.

4.2 Calibration targets and calibrated parameters

For the quantitative importance of our mechanism to be credible, we want to ensure that our choice of parameter values does not exaggerate the importance of unemployment risk. Given the emphasis on deflationary pressure, we want our model to have reasonable predictions for prices as well.

Regarding the importance of idiosyncratic risk, we want our model to be consistent with five empirical properties. First, the unemployment rate should not increase to unrealistically high levels during recessions. If that would be the case, then we would exaggerate the importance of changes in idiosyncratic risk over the business cycle. Consequently, it is important that our model generates a reasonable amount of volatility in the cyclical employment rate relative to the volatility of the cyclical output component. For the same reason, we want the average unemployment rate and the average length of an unemployment spell to be close to their empirical counterparts. In order to not overstate the importance of idiosyncratic risk, it is also important that the decline in consumption during unemployment is not too large. Finally, we ensure that agents are not unrealistically poor.[35]

The last target is related to the behavior of prices. As discussed in section 2, the Eurozone economy was characterized by deflationary pressure during the great recession. Consequently, we want the model to generate a nontrivial drop in the price level relative to its trend value when economic activity deteriorates.

There are six parameters that are not yet determined and these are used to ensure that the model is consistent with aforementioned targets. Those parameters are the job destruction rate, δ, the parameter characterizing the efficiency in the matching market, ψ, the parameter that controls the share of firm revenues going to workers, ω_0, the slope coefficients in the wage setting rule

[33] That is, $\mathbb{E}[\ln z_t] = 0$, $\mathbb{E}_t[\ln z_{t+1}] = 0.95 \ln z_t$, and $\mathbb{E}_t[(\ln z_{t+1} - \mathbb{E}_t[\ln z_{t+1}])^2] = 0.007^2$.

[34] The average interest rate level is very similar to the steady-state level. The actual level is not that important for the results. Eurozone inflation, calculated using the GDP deflator from 1999 to 2007 was equal to 0.87% on an annual basis. The ECB deposit rate for overnight deposits fluctuated between 1% and 3.75%. In real terms, agents in our model receive slightly more for their quarterly holdings of the liquid asset. Higher real interest rates on the relatively safe asset helps agents ensure against idiosyncratic risk and weakens our mechanism.

[35] By contrast, agents in the model of Ravn and Sterk (2015) have zero wealth and cannot smooth consumption at all. McKay, Nakamura, and Steinsson (2016) and Auclert (2016) impose a zero aggregate wealth to income ratio.

Table 1: Parameters and calibration targets

calibration targets	empirical values	model outcomes
average unemployment duration	[3.54 3.71] quarters	3.58 quarters
average unemployment rate	10.7%	10.7%
median wealth to income ratio	[0.213,0.312]	0.255
$\sigma_{q^{HP}} / \sigma_{y^{HP}}$	[0.39,0.67]	0.46
Δc_i first year of unemployment	[-15.8%,-26.3%]	-24.5%
$\Delta\left(\frac{P}{P^{\text{trend}}}\right)$ during prolonged recession	[-1.26%,-3.25%]	-1.73%

parameters used to match calibration targets

$\omega_0 = 0.965, \omega_z = 0.3, \chi = 1.1 \cdot 10^{-4}, \delta = 0.0336, \psi = 0.5908, \nu_P = 0.05$

other parameter values

$\mu = 0.5, \beta = 0.98, \overline{L} = 0.199, \nu_0 = 1.005, \gamma = 2, \zeta = 2, \eta = 0.5, \omega_P = 0.7$,
$z \in \{0.978, 1.023\}$,probability$\{z_{t+1} = z_t\} = 0.975$

characterizing the sensitivity to changes in z_t, ω_z, the scale parameter which characterizes the liquidity benefits of money, χ, and the parameter in the monetary policy rule that affects the sensitivity of the interest rate to inflationary pressure, ν_P.

Table 1 reports the chosen parameter values as well as the calibration targets and the model counterparts. In the remainder of this section, we present a detailed discussion of the empirical targets and the choice of parameter values.[36]

Targets for individual wealth levels and unemployment-related consumption drops. There is not a lot of empirical guidance on what the empirical counterparts are for wealth levels at the start of unemployment spells nor on typical consumption drops during unemployment spells for European workers. But there is some and we have constructed some evidence ourselves using data from the Eurosystem Household Finance Consumer Survey (HFCS).[37]

The HFCS provides household and individual level data collected from more than 62,000 households in a harmonized way for 15 Eurozone countries in 2010. In our model, workers only hold two financial assets, the liquid asset and equity. In reality individuals also hold other assets, the most important one being real estate. We exclude this wealth component as it is likely to be too illiquid to be a useful source of insurance against income drops during a typical unemployment spell. Similarly, we ignore mortgage debt and other collateralized debt when constructing our measure

[36] In appendix B, we provide additional details on the data used to construct the empirical targets.
[37] See appendix B.3 for details on how we constructed the statistics reported here.

Table 2: Median financial wealth to labor income ratios.

	data	model	
		expansion	recession
$\frac{\text{financial assets}}{\text{annual income}}$	0.312	0.342	0.255
$\frac{\text{net financial assets}}{\text{annual income}}$	0.213	0.342	0.255

Notes. The table shows the ratio of the indicated financial wealth variable to annual labor income. Details are given in appendix B.3.

of *net* financial wealth under the assumption that collateralized debt is not under pressure to be redeemed during unemployment spells. The financial assets we include are bank deposits, both sight accounts and savings accounts, and an extended set of financial assets that one could in principle use for consumption smoothing because they can be relatively easily sold.

The HFCS only reports income before taxes. Workers pay taxes in our model, but these are very low, since taxes are only used to finance unemployment benefits and interest payments. To make sure that the observed data are comparable to the model data, we use after tax income for both and we use a tax rate of 29.5% for the HFCS income data.[38]

Table 2 provides information on the median value for the financial wealth to income ratio. [39] The table indicates that the median agent's level of financial assets are sufficient to cover the income loss during an unemployment spell lasting 2.5 quarters.[40] As indicated in table 1, this is at least one quarter less than the average unemployment spell for European workers. Using net financial assets, the median worker only has enough funds to cover an unemployment spell lasting 1.8 quarters. Thus, the data indicate that the median household does not have a lot of financial wealth to insure against unemployment spells.[41]

The HFCS data are for 2010. Since the data are from a recession year, it would make most sense to focus on the model outcomes for a recession as well. In our model, agents cannot borrow, so net

[38] This rate is an average of the average income tax rate for a set of 18 Eurozone countries using 2015 data from the OECD.

[39] We focus on households with either one or two individuals employed and nobody unemployed. In our model, all workers have the same labor income. That is, of course, not true in the data. If we look at the median value for the wealth to income ratio for the whole sample, then one would find that both some rich and some poor agents have wealth to income ratios above the median. The rich for obvious reasons and the poor because some households in the data have quite low labor income, but still some bank deposits. To make sure that this is not an issue we divided the data into ten income deciles according to their labor income and calculated the median for each decile. The average across deciles is equal to 0.216 for net financial assets and 0.306 for financial assets. These numbers are very similar to the ones reported here. Appendix B.3 provides additional details on the data used.

[40] Using a net replacement rate of 50%.

[41] Using US data, Gruber (2001) finds that the median agent holds enough gross financial assets to cover 73% of the average net-income loss during an unemployment spell. In terms of net financial assets, the median agents does not even have enough to cover 10% of the average net-income loss.

financial assets are equal to total financial assets. Whether we should compare the model outcome with *gross* financial assets or financial assets *net* of liabilities depends on whether one thinks that these liabilities could be easily rolled over during unemployment spells. Kolsrud, Landais, Nilsson, and Spinnewijn (2015) report that the amount of consumption that is financed out of an increase in debt actually *decreases* following a displacement. Our strategy is to choose parameter values such that the average level of the ratio of financial assets over income for employed workers is in between the empirical counterparts using net and gross financial assets.

We are not aware of any studies documenting representative information on the magnitude of consumption drops during unemployment spells for the Eurozone as a whole. However, Kolsrud, Landais, Nilsson, and Spinnewijn (2015) study consumption behavior of Swedish unemployment workers and find that individual consumption has dropped by on average 26.3% after one year of unemployment. Using household consumption levels, this drop is equal to 15.8%.[42] It is not clear which of the two observed statistics is most relevant for comparison, since there is no difference between individual and household consumption in our model. Our strategy is to choose parameter values such that the model outcome is in between these two empirical estimates.

Other calibration targets related to idiosyncratic risk. Observed volatility of cyclical employment relative to observed volatility of cyclical output varies between 0.39 and 0.67 for the set of Eurozone countries for which quarterly data for a sufficiently long period are available.[43] The observed average Eurozone unemployment rate is equal to 10.7%.

The last target related to idiosyncratic risk is the average duration of unemployment spells. Most data sources divide the unemployed workers into different groups, for example, those that are unemployed for less than one month or more than one year. Direct information is provided in Pellizzari (2006) and Tatsiramos (2009) who use individual data from different waves of the European Community Household Panel. Pellizzari (2006) reports estimates for average unemployment duration for European workers ranging from 3.54 to 3.71 quarters.[44]

Calibration target for deflationary pressure. Figure 2 documents that the observed Eurozone price level dropped considerably relative to its trend value during the great recession. In the beginning of 2010, the gap is 1.26%. At the end of the sample the gap has increased to 3.25%. We choose parameters such that the price drop is in between these numbers during a sustained

[42] This is the average consumption level during the first year of an unemployment spell relative to the average consumption level during the first two years before the start of the unemployment spell for workers which were employed in all eight quarters before the unemployment spell.

[43] See appendix B for details.

[44] Tatsiramos (2009) reports estimates for a few individual Eurozone countries ranging from 2.83 to 4.80 quarters.

recession.[45]

Values of calibrated parameter values and model outcomes. It should be emphasized already at this point that each parameter of the model is not directly related to one moment of the data, but rather to several. As such, our calibration strategy involves choosing an array of parameters such that the model aligns well with an array of moments. The mapping between parameter values and model properties is complex and we need a costly computer algorithm to figure out what the model predictions are for a given set of parameter values.[46]

Key parameters affecting the volatility of employment are ω_0 and ω_z. Decreasing ω_z and/or increasing ω_0 increase employment volatility by making profits more volatile. If we choose a high value of ω_z, then we would need a higher value of ω_0 to get enough employment volatility. But a high value of ω_0 means a low profit share and a low value of equity holdings, a key household wealth component. For our results to be credible, it is important that agents are not too poor, which prevents us from setting ω_0 too high, which in turn prevents us from setting ω_z too high. We set ω_0 and ω_z equal to 0.965 and 0.3, respectively.

The parameter ω_0 and the parameter characterizing the liquidity benefits of the liquid asset, χ, are important for the wealth of individual agents. At the chosen parameter values, the model generates values for the median wealth level and the consumption drop during unemployment spells that are in the target ranges for these statistics. Specifically, the median agent in our model is not unrealistically poor. Agents in our model are a bit richer than their empirical counterparts when we consider net financial assets. The two financial wealth ratios are 0.25 (model) and 0.22 (data). When we consider gross financial assets , then the opposite is true and the two statistics are 0.25 (model) and 0.31 (data).

Our calibration strategy is conservative by focusing on the median agent, since there are quite a few workers in the data that have a lot less assets than the median agent, which is much less true in the model. For example, the observed 5$^{\text{th}}$ and 10$^{\text{th}}$ percentile values for gross financial assets over labor income are equal to 0 and 0.012, respectively, whereas, they are equal to 0.078 and 0.122 in the model.

In our model, the consumption drop during the first year of an unemployment spell is equal to 24.5%, which is more than the observed number for Swedish households but less than the observed number for Swedish individuals. Even if the right comparison would be with the observed drop in *household* consumption, we may very well not overpredict consumption drops during unemployment spells. The reason is that the observed consumption drop is for a group of Swedish

[45] What really matters is the price drop relative to the drop in GDP. Our model does generate a drop in GDP that is comparable to the one observed in the great recession for the Eurozone area.

[46] Given the complexity of the numerical algorithm, we cannot simply use a minimization routine that will find the best parameter values given a set of desired model properties.

workers with an average replacement rate of 72%, which exceeds the average level for the Eurozone and the 50% replacement rate in the model.

The average unemployment rate in the model matches its empirical counterpart exactly. The model equivalent for the average duration is equal to 3.58 quarters, which is in the lower region of the target range.

The model predicts a sharp drop in the price level followed by a quick partial recovery if the model economy starts out in an expansion and then faces the low productivity outcome for a sustained period. After roughly 10 quarters the price level has (almost) stabilized at a level that is 1.73% below its starting value. Although the sharp initial drop generated by the model is not observed in the data, we are conservative in terms of the longer-term deflationary pressure that we consider. Recall that the observed drop in the price level increased to 3.25% which significantly exceeds the value predicted by the model. Several parameter values are important for the behavior of prices in the model. For prices to respond *negatively* to a negative productivity shock, we need the parameters related to precautionary saving and demand for the liquid asset to be such that our mechanism is sufficiently strong. For the price drop to be sufficiently pronounced, it is also important that monetary policy does not fully undo changes in prices. This is a reasonable property to impose on the model, since the ECB was not capable of avoiding some deflationary pressure in the Eurozone. Our choice of ν_P ensures that monetary policy reduces the drop in the price level during a prolonged recession by 43%. In that sense, monetary policy has been quite active.

Parameter values in the representative-agent model. We will compare the results of our model with those generated by the corresponding representative-agent economy. Parameter values in the representative-agent model are identical to those in the heterogeneous-agent model, except for β. We choose the value of β for the representative-agent model such that the MRS in the representative-agent model is equal to the MRS for the agents holding equity in the heterogeneous-agent model.[47] Without this adjustment, the agent in the representative-agent economy would have a more shortsighted investment horizon and average employment would be lower.

5 Agents' consumption, investment and portfolio decisions

In section 5.1, we describe key aspects of the behavior of individual consumption, and in particular its behavior during an unemployment spell. In section 5.2, we focus on the individuals' investment portfolio decisions. Appendix D provides more detailed information on both topics.

[47] Here we use the models without aggregate uncertainty. Notice that the expected intertemporal marginal rate of substitution, $\beta \mathbb{E}_t \left[(c_{i,t+1}/c_{i,t})^{-\gamma} \right]$, is constant and the same for all agents holding equity in the model without aggregate shocks. The value of β in the representative-agent model is equal to 0.99.

5.1 Post-displacement consumption

Consumption during the first year of an unemployment spell is on average 24.5% below pre-displacement levels, which is consistent with empirical observations. There are several reasons why the fall in consumption is of such a nontrivial magnitude. One reason is, of course, that unemployment benefits are only half as big as labor income. But a key factor affecting the magnitude of the drop is the average level of wealth at the beginning of an unemployment spell. We calibrated our parameters such that median holdings of financial assets relative to income are in line with their empirical counterparts. However, in the data and in the model, workers are not well insured against unemployment. In our model, the median agent's asset holdings are equal to 62% of the average net-income loss during unemployment spells.[48]

The question arises why infinitely-lived agents do not build a wealth buffer that insulates them better against this consumption volatility, as is the case in the model of Krusell and Smith (1998).[49] By choosing a low value for the scaling coefficient affecting the utility of liquid asset, χ, we directly limit the magnitude of one of the two wealth components. The other wealth component is the value of equity holdings, $J_t q_{i,t}$. Elevated uncertainty about future individual consumption increases the expected value of an agent's MRS, which would increase the price of equity, J_t. As a consequence, the number of new firms as well as the total number of shares outstanding would therefore rise. However, there are several reasons why this component of wealth is not very large in our model. First, the equity price, J_t, cannot increase by too much, because the presence of a liquid asset with a positive transactions benefit puts a lower bound on the average real return on equity. Moreover, the nonlinearity of the matching function dampens the impact of an increase in equity prices on the creation of new firms. Lastly, the equity price depends positively on the average share of output going to firm owners, $1-\omega_0$. To generate sufficient volatility in employment we chose a relatively high value for ω_0, which reduces the value of J_t. For all these reasons, agents in our model do not build up large buffers of real money balances or equity to insure themselves against the large declines in consumption upon and during unemployment.

Another aspect affecting consumption during unemployment is the ability to borrow. In our model, agents cannot go short in any asset, and they would presumably hold less financial assets if they had the option to borrow. Kolsrud, Landais, Nilsson, and Spinnewijn (2015) report, however, that the amount of consumption that is financed out of an increase in debt actually *decreases* following a displacement.

[48] Whereas the calibration focused on wealth levels during recessions, this is the unconditional average and, thus, includes both recessions and expansions.

[49] For the model of Krusell and Smith (1998), solved in Den Haan and Rendahl (2010) using a 15% unemployment replacement rate, the average post-displacement consumption level has dropped by only 5% after one year of being unemployed.

State dependence of consumption drop. Figure 3 presents a scatter plot of the reduction in consumption (y-axis) and beginning-of-period cash on hand (x-axis), where both are measured in the period when the agent becomes unemployed.[50] There are two distinct patterns, one for expansions and one for recessions.[51]

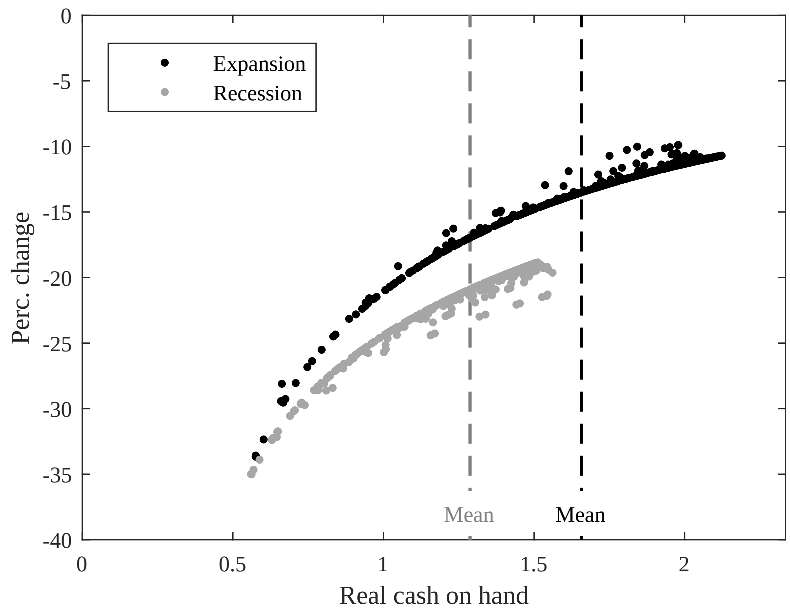

Figure 3: Consumption drop upon becoming unemployed.

Figure 3 documents that the drop in consumption is, on average, *much* more severe if the unemployment spell initiates in a recession. The figure also underscores the non-trivial role played by the agents' wealth levels. In particular, during recessions the decline in consumption varies from 18.8% for the richest agent to 35.5% for the poorest. This range increases during an expansion: The richest agent faces a modest drop of 9.4%, whereas the poorest agent can expect to see consumption fall by 35.1%. The latter is only slightly below the equivalent number in a recession.

There are several reasons why consumption falls by more during recessions. First, job finding rates are lower in recessions than in expansions. As a consequence, agents anticipate longer unemployment spells and will, for a given amount of cash on hand, therefore reduce consumption more sharply. A second factor that affects agents' reduced consumption is the amount of cash on hand they hold. Because the price of equity declines in recessions, so does the agents' cash on hand.

[50] Cash on hand is equal to the sum of non-asset income (here unemployment benefits), money balances, dividends, and the value of equity holdings.

[51] The level of employment is also important for the observed decline in consumption, which explains the scatter of observations. In particular, the fall in the level of consumption is smaller at the beginning of an expansion and larger at the beginning of a recession. The reason is that expected investment returns are higher (lower) at the beginning of the expansion (recession), which would put upward (downward) pressure on consumption when the income effect dominates the substitution effect.

Indeed, the average value of cash on hand held by a newly unemployed agent is equal to 1.29 in a recession compared to 1.65 in an expansion.

In reality, a typical worker may not face such a large decline in the value of their equity position when the economy enters a recession. After all, quite a few workers do not own equity at all. We think, however, that the cyclicality of post-displacement consumption behavior that is driven by the cyclicality of equity prices, captures real world phenomena. First, although not all workers hold equity, many hold assets such as housing that also have volatile and cyclical prices.[52] Second, unemployed workers may receive loans, and or handouts, from financial intermediaries, affluent family members, or friends whose ability and willingness may be affected by the value of their assets, which is likely to be cyclical.

5.2 Investment decisions

In our heterogeneous-agent model, the demand for the liquid asset increases during recessions, whereas it decreases in the representative-agent version. In this section, we shed light on this difference.

Cash on hand and demand for the liquid asset. A key result of this paper is that the interaction between sticky nominal wages and the inability to insure against unemployment risk deepens recessions. An integral part of the mechanism underlying this result is the upward pressure on demand for the liquid asset that emerges during recessions when job prospects worsen. Consumption smoothing motives *reduce* demand for all assets, including the liquid asset, during recessions. With incomplete markets, however, there are two additional mechanisms. These lead to an *increase* in the aggregate demand for the liquid asset and are strong enough to more than offset the reduction induced by the standard consumption smoothing motive. First, as documented in figure 4, for given cash-on-hand levels, all agents demand more of the liquid asset during recessions. This is consistent with the observed shift towards more liquid assets during the great recession.[53] Second, for equal cash-on-hand levels unemployed agents demand more of the liquid asset than employed agents, and there are more unemployed agents in the economy during recessions. Countercyclical demand for the liquid asset stands in sharp contrast with the representative-agent version of our economy, in which aggregate demand for the liquid asset unambiguously *decreases* during recessions.

[52] In addition to countercyclical prices, transaction costs also make home ownership a bad asset to buffer against employment risk.

[53] See Bayer, Luetticke, Pham-Dao, and Tjaden (2014).

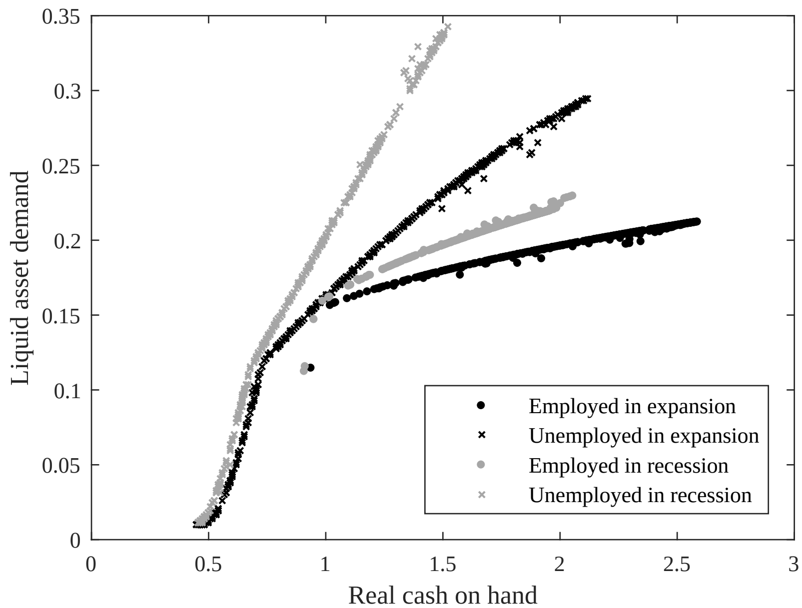

Figure 4: Demand for liquid asset (real).

Notes. This figure displays the amount invested in the liquid asset as a function of beginning-of-period cash on hand for workers of the indicated employment status and for both outcomes of aggregate productivity

To see that this is a remarkable result, consider the economy without aggregate uncertainty. The price level, wages, and the equity price are all constant in this economy. The first-order condition for equity, equation (4), then implies that the expected marginal rate of substitution does not depend on the employment status for any of the agents that are not at the short-sale constraint.[54] The first-order condition for the liquid asset, equation (3), then specifies that the real value of the liquid asset and consumption must move in the same direction. Since unemployed agents consume less than employed agents with the same level of cash on hand, they should hold less of the liquid asset. Although this simple reasoning abstracts from the presence of the short-sale constraint, the implication is that absent aggregate uncertainty unemployed agents would hold less of the liquid asset than employed agents with the same amount of cash on hand.[55] By contrast, as indicated in

[54] In this case, equation (4) can be rearranged as

$$J = \beta\,(D + (1-\delta)J)\,\mathbb{E}_t\left[\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{-\gamma}\right],$$

which implies that the individual MRS, $\beta\mathbb{E}_t\left[\left(c_{i,t+1}/c_{i,t}\right)^{-\gamma}\right]$, is pinned down by aggregate prices only, and is therefore not affected by employment status.

[55] A similar reasoning can be used to make clear that it is also remarkable that employed as well as unemployed agents hold more liquid asset when aggregate economic conditions deteriorate. Envisage a partial equilibrium version of our model with aggregate uncertainty in which all prices are constant, and there is no short-sale constraint. Markets are still incomplete because the agents cannot insure fully against unemployment risk. As discussed in the text, consumption and demand for the liquid asset move in the same direction under these conditions. But the reduction in the job finding rate lowers consumption. Thus, in real terms the demand for the liquid asset must decrease as well.

figure 4, the opposite is true in the economy with aggregate uncertainty.

Liquid asset holdings during unemployment spells. The analysis above focused on demand for the liquid asset taking cash-on-hand levels as given. Here we discuss the demand for liquid assets during an unemployment spell taking into account the fall in cash on hand. Consumers cushion the drop in consumption following displacement by selling assets. Although the total amount of financial assets, and the amount invested in equity, sharply decrease, the amount held in the liquid asset actually *increases* during the first two quarters of an unemployment spell. The loss of labor income means that workers' cash-on-hand levels drop when they become unemployed. This reduces the demand for the liquid assets in real terms. However, and as discussed above, the unemployed actually hold more liquid assets for a given level of cash on hand. The last effect dominates in the beginning of an unemployment spell.

6 Economic aggregates over the business cycle

In the previous section, we showed that the inability of agents to insure against unemployment risk means that workers face a sharp drop in consumption when they become unemployed. We also discussed how imperfect insurance affects demand for the safer liquid asset in ways that are not present in an economy with complete markets. In this section, we discuss what this implies for aggregate activity. In particular, we document and explain why the interactions between sticky nominal wages, gloomy outlooks regarding future employment prospects, and the inability to insure against unemployment risk can deepen recessions. We compare the business cycle properties of the economy with imperfect risk sharing to those of an economy with full risk sharing. We first do this when nominal wages are sticky, i.e., when $\omega_P < 1$. Subsequently, we discuss the same comparison when nominal wages are not sticky, i.e., $\omega_P = 1$.

6.1 The role of imperfect insurance when nominal wages are sticky

Figure 5 shows the impulse response functions (IRFs) of key aggregate variables to a negative productivity shock for our benchmark economy and for the corresponding representative-agent economy.[56] The responses for output and employment document that the economy with incomplete risk sharing faces a much deeper recession than the economy with complete risk sharing. In

[56] In our benchmark calibration, productivity takes on only two values. The IRFs are calculated as follows. The starting point is period s, when productivity takes on its "expansion" value and employment is equal to its limiting value, that is, its value when the economy has been in an expansion for a long time. We then calculate the following two time paths for each variable. The "no-shock" time path is the *expected* time path from this point onward. The "shock" time path is the *expected* time path when the productivity switches to the low value in period $s+1$. The IRF is the difference between these two time paths.

particular, in response to a 4.3% drop in productivity, output falls by 6.1% in the heterogeneous-agent economy and by only 5.0% in the representative-agent economy.

The key aspect in understanding this large difference is the behavior of the price level. In the representative-agent economy, the reduction in real activity decreases the demand for the liquid asset and *increases* the price level. In our benchmark calibration wages are sticky ($\omega_P = 0.7$), and a 1% increase in the price level leads to a 0.7% increase in nominal wages and therefore a 0.3% *decrease* in real wages. Figure 5 documents that the real wage drops by 2.2% in the representative-agent economy, which is driven by the direct effect of the reduction in z_t, since $\omega_z > 0$, and the indirect effect through P_t, since $\omega_P < 1$. Thus, the direct effect of the reduction of productivity, z_t, on profits is counteracted, because nominal wages do not fully respond to the increase in the price level. That is, our starting point is an economy in which the sluggish response of nominal wages to changes in prices actually *dampens* the economic downturn.

By contrast, the price level falls in the heterogeneous-agent economy. This fall is caused by an *increase* in the aggregate demand for the safer asset. To understand this different outcome, consider again figure 4, which illustrates the relationship between the demand for money as a function of beginning-of-period cash-on-hand levels during expansions and recessions, for both employed and unemployed agents. The reduction in real activity lowers cash-on-hand levels which reduces the demand for the liquid asset by both employed and unemployed agents. The drop in cash-on-hand levels is substantial because the value of equity declines sharply. Nevertheless, aggregate demand for the liquid asset *increases*. As previously discussed, both employed and unemployed agents hold more liquid funds during recessions for the same cash-on-hand level. In addition, there are more unemployed agents during recessions, and unemployed agents have larger holdings of the liquid asset than employed at the same level of cash on hand.

As documented in figure 5, the heterogeneous-agent model predicts a much smaller decrease in the real wage rate. In fact, initially the real wage rate *increases* because the indirect effect through deflationary pressure is so strong that it dominates the direct effect of the reduction in z_t. Overall, real wages are procyclical. The correlation between real wages and output is equal to 0.73. After HP-filtering the correlation drops to 0.04.[57] Similarly, real unit labor costs increase by more when markets are incomplete because deflationary pressure induced by increased idiosyncratic risk increases real wage costs when $\omega_P < 1$.[58] Real unit labor costs are countercyclical, also after HP-filtering.[59]

[57]The reason the correlation declines by so much after HP-filtering is that the short-lived initial increase in the real wage rate is part of the cyclical component while the subsequent sustained decline is largely picked up by the trend component.

[58]Real unit labor costs increase because $\omega_z < 1$ and because $\omega_P < 1$.

[59]Real unit labor costs are calculated as total wages over total output. If we include hiring costs, then real unit labor costs are slightly less countercyclical. Although hiring workers is cheaper when there are more unemployed workers these costs are too small relative to the wage bill to have a big impact.

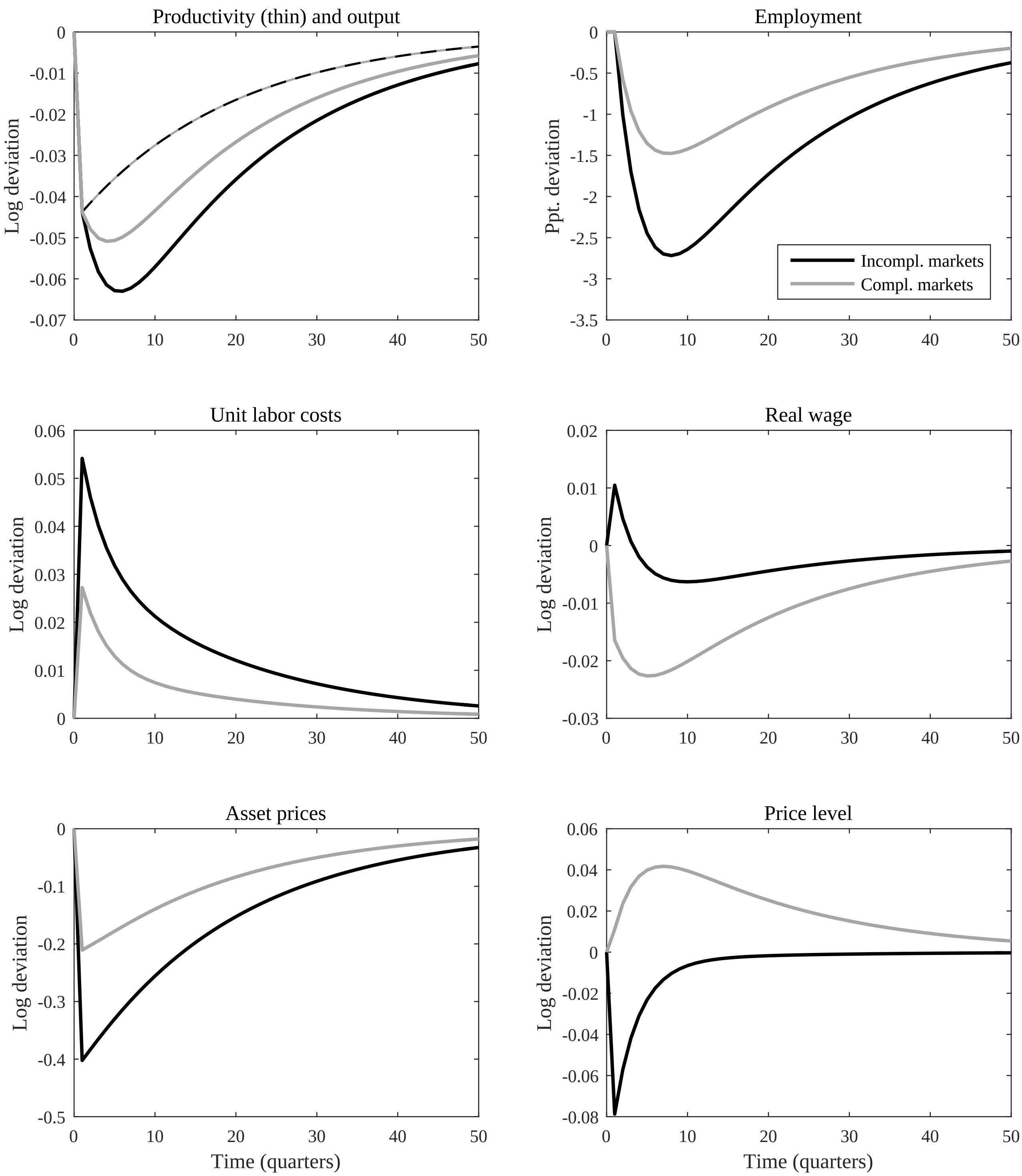

Figure 5: Impulse responses with sticky nominal wages

Notes. These graphs illustrate the difference between the expected time path when the economy is in an expansion in period 0 and the expected time path conditional on being in a recession in period 1. $\omega_P = 0.7$, i.e., nominal wages increases with 0.7% when prices increase with 1%.

Whereas sticky nominal wages reduce the depth of recessions in the representative-agent economy, they worsen recessions in the heterogeneous-agent economy. This is a quantitatively important effect, because a reduction in the price level (for any reason) starts a self-reinforcing process that deepens recessions. In particular, the reduction in the price level puts upward pressure on real wages, which reduces profits. The fall in profits reduces investment in new jobs, which in turn reduces employment. Since this reduction in employment is persistent, employment prospects worsen. With elevated risk there is a further increase in the demand for the liquid asset, which in turn puts additional upward pressure on the price level, and so on. The impulse responses show that this mechanism is powerful enough to completely overturn the dampening effect that sticky nominal wages have in an economy with complete risk sharing.

Although this is a powerful mechanism, there is a counterforce. In particular, a higher unemployment rate increases the number of jobs that can be created at a given level of investment. For the results reported here, this counterforce is strong enough to ensure stability. For some parameter values, the fluctuations could very well become so large that no non-explosive solution exists.[60]

6.2 Role of imperfect insurance when nominal wages are not sticky

In this section, we discuss business cycle properties when changes in the price level leave *real* wages unaffected, that is, $\omega_P = 1$. Real wages are then necessarily procyclical, since $\omega_z > 0$. Figure 6 plots the IRFs for the heterogeneous-agent economy and the IRFs for the corresponding representative-agent economy. There are several similarities with our benchmark results, but also one essential difference. We start with the similarities.

A negative productivity shock still has a direct negative effect on profits, which leads to a reduced demand for equity (firm ownership), which in turn means that fewer jobs are created. Also, increased concerns about employment prospects still induce agents in the heterogeneous-agents economy to increase their demand for the liquid asset, which again is strong enough to push the price level down, while it increases in the representative-agent economy.[61]

[60] In particular, changes in parameter values that substantially enhance the deflationary mechanism make it computationally challenging, or even impossible, to find an accurate solution. This does not prove that a stationary solution does not exist, but it would be consistent with this hypothesis. If such a solution would exist, however, it is likely to have complex nonlinear features. This result is in contrast to standard perturbation methods which impose that aggregate shocks of any size will not destabilize the economy as long as arbitrarily small shocks do not. For example, the technique developed in Reiter (2009) to solve models with heterogeneous agents relies on a perturbation solution for changes in the aggregate shock, which implies that the solution is imposed to be stable – for shocks of any size – as long as the Blanchard-Kahn conditions are satisfied, that is, when the solution is stable for small shocks. Our experience suggests that this may impose stability where there is none.

[61] In the representative-agent economy, there is a small decrease in the price level in the first period. The reason is that the largest drops in consumption and output occur with quite a delay, for consumption in the 5th quarter. Consequently, the demand for money increases for consumption smoothing motives at the outset of the recession.

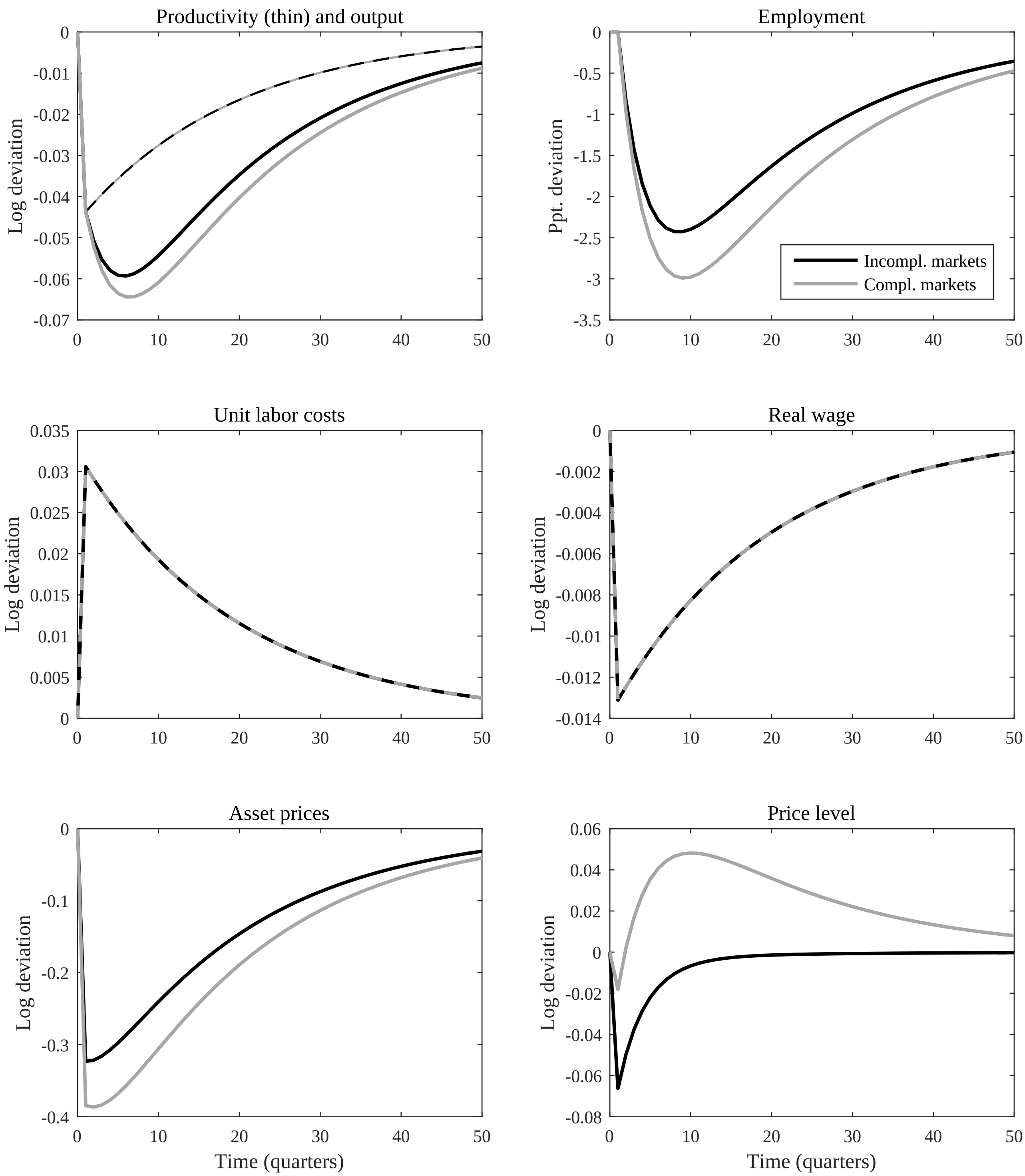

Figure 6: Impulse responses with flexible nominal wages

Notes. These graphs illustrate the difference between the expected time path when the economy is in an expansion in period 0 and the expected time path conditional on being in a recession in period 1. $\omega_P = 1$, that is, nominal wages respond 1-for-1 to price changes.

There is also a striking difference. In the economy with flexible nominal wages, recessions are *less* severe when agents cannot insure themselves against unemployment risk. The reason is the following. Increased uncertainty, alongside with an expected reduction in individual consumption, increase the expected value of the marginal rate of substitution. This affects the first-order condition of the liquid asset *as well as* the first-order condition of the productive investment, because each agent's future revenues of *both* assets are (correctly) discounted by the agent's own individual MRS. Since wages are flexible, the associated rise in the price level bears no consequence on the return on equity, and the chain of events underlying the deflationary spiral breaks down.

Thus, if the rise in precautionary savings is partially used as productive investments, then this would *dampen* the reduction in the demand for equity induced by the direct negative effect of the productivity shock on profits. The IRFs document that this is indeed the case when nominal wages respond one-for-one to changes in the price level. The magnitude of the dampening effect is nontrivial. Whereas the biggest drop in employment is 3.14ppt in the representative-agent economy, it is equal to 2.43ppt in the heterogeneous-agent economy. These results make clear that a researcher would bias the model predictions if this dampening aspect of precautionary savings is not allowed to operate, for example, because there is communal firm ownership.[62]

In our benchmark economy, we allow this channel to operate, but the effect is dominated by the *interaction* between sticky nominal wages and uninsurable unemployment risk. Increased uncertainty may increase the demand for equity, but it will also increase the demand for the liquid asset. The latter depresses the price level, which, provided that nominal wages are somewhat sticky, increases real wages. The rise in real wages reduces profits, which in turn lowers the demand for equity. This channel dominates any positive effect that precautionary savings may have on the demand for equity.

Robustness of the dampening effect. In all cases considered, we find that recessions are less severe in the heterogeneous-agent economy than in the representative-agent economy *if* nominal wages respond one-for-one to change in the price level. That is, this dampening effect is very robust. During the nineties, several papers argued that an increase in idiosyncratic risk could lead to a *reduction* in the demand for a risky asset when investors can save through both a risky and a risk-free asset even though it would increase total savings. This effect is referred to as *temperance*.[63] We find that this result is quite fragile for several reasons.

The first is that it is a partial equilibrium result. In general equilibrium prices adjust. This is important. Suppose that the economy *as a whole* can increase savings through the risky investment, but not through the risk-free investment. Then the relative price of the risk-free asset would increase

[62] See footnote 3 for a list of papers following this approach.

[63] See Kimball (1990), Kimball (1992), Gollier and Pratt (1996), and Elmendorf and Kimball (2000).

making the riskier asset more attractive. This plays a role in our economy, because the only way the economy as a whole can do something now to have more goods in the future is by investing more in the productive asset, that is, in the risky asset. There are several other features, typically present in macroeconomic models, that make temperance less likely. One is that the temperance result relies on idiosyncratic risk to be sufficiently independent of investment risk. In macroeconomic models, that is not the case. The amount of idiosyncratic risk depends on the level of the wage rate.[64] But the level of the wage rate is often correlated with the return of the risky asset, since both are affected by the same shocks.[65] Another feature that works against the temperance result is the short-sale constraint on equity, which directly prevents a reduction in the demand for equity, at least for some agents. In our model, diminishing returns on the transactions aspect of money also work against temperance. This makes increased investment in the risk-free asset less attractive relative to a framework in which the return remains fixed.

It may be the case that temperance can be generated in models with different utility functions, for example, if the utility function is such that the price of risk increases during recessions.[66] We leave this for future research.

7 Prolonged recessions

In the previous section, we discussed the expected behavior of macroeconomic aggregates when productivity switches from its high to its low value. When presenting this behavior we took into account the possibility that productivity would return to the high value as indicated by our driving process. Here we discuss the results when productivity switches to the low value and stays low for a sustained period.

Figure 7 reports the results. The responses for output and employment simply become more persistent when the responses are conditioned on there being no recovery. Most of the decline in aggregate activity has taken place within 10 quarters. Relative to the observed drops discussed in section 2, this is somewhat too slow for output and somewhat too fast for employment. Even though we use a typical TFP process and the drop in productivity is moderate, the model generates a drop in output relative to trend that is just slightly below its empirical counterpart; the limiting value of the drop is 8.5% in the model, whereas observed GDP is 10.2% below its trend value at the end of 2013. The model also does a good job in matching the increase in the unemployment rate. From the first quarter of 2008 to the end of our sample, the Eurozone unemployment rate increases with

[64] The consequences of idiosyncractic risk are reduced when the wage rate falls. In the extreme case when the wage rate is zero, there is no unemployment risk.

[65] In the model considered here, they are both directly affected by z_t.

[66] We considered models with different degrees of risk aversion, but this does not seem to matter for this particular issue.

4.8ppt. In the model the unemployment rate in the model increases with 3.9ppt.

Similar to the data, asset prices display a large drop at the outset of the crisis.[67] The price level in our model displays a large initial drop followed by a partial recovery. By contrast, the observed fall in the price level (relative to its trend level) is more gradual. Nevertheless, we do not think that we exaggerate the extent of the deflationary pressure because the gap between trend and actual value reaches 3% at the end of the sample, whereas this is only 1.73% in the model.[68]

Real wage rates increase in the beginning of the recession, but then start to decline. After ten periods they are 0.7% below the pre-crisis value. By contrast, average Eurozone wages have increased relative to their trend values throughout the economic slowdown. The response of real unit labor costs resembles its empirical counterpart more closely. Both display a sharp initial increase followed by a partial recovery.

[67] In contrast to the data, the generated time path for asset prices does not display a partial recovery.

[68] The model would predict a more gradual drop in the price level if the economy faced a sequence of smaller negative reductions in z_t as opposed to one large immediate decline.

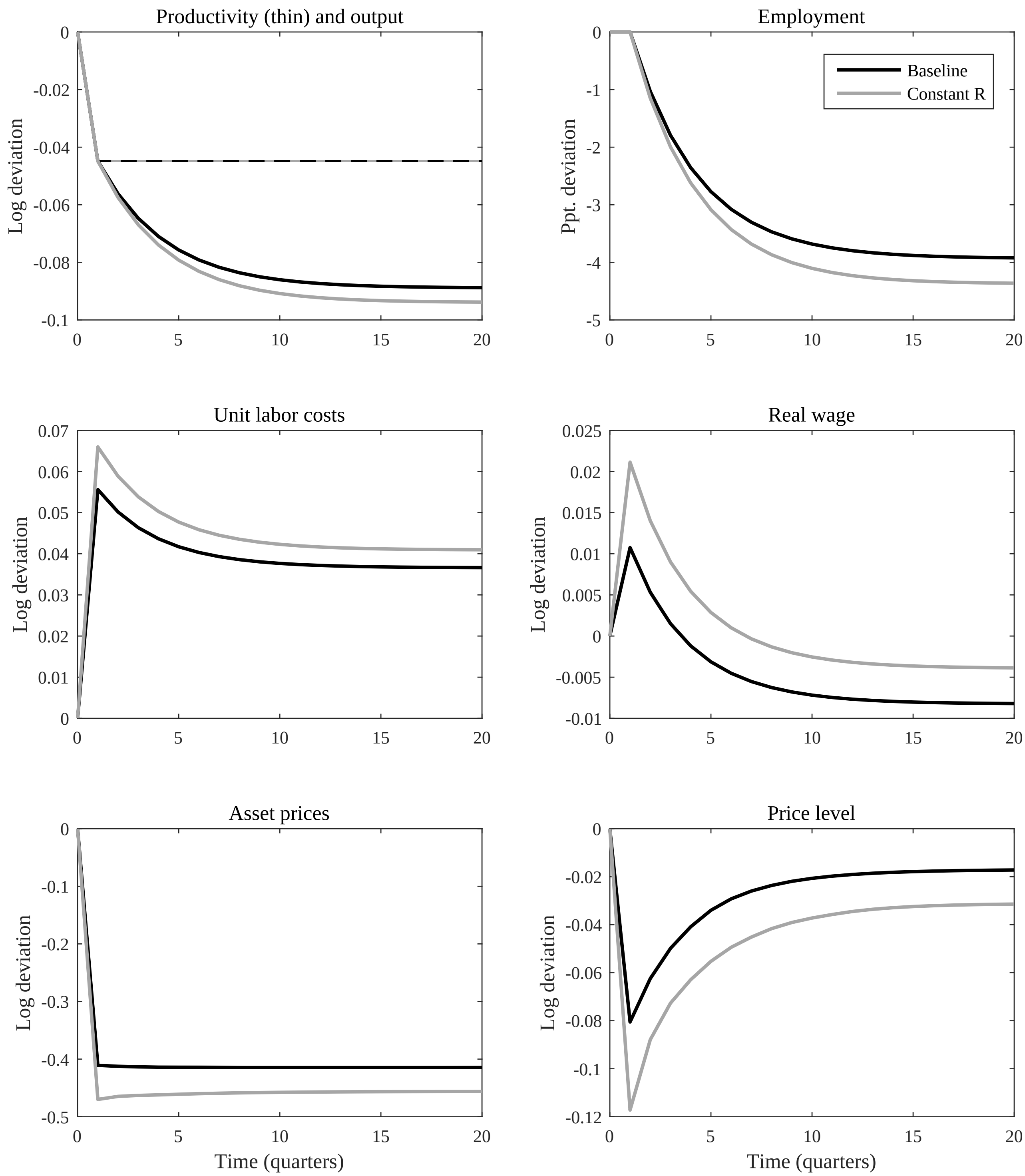

Figure 7: Role of monetary policy during a prolonged recession

Notes. These graphs illustrate the behavior of the indicated variables when the productivity z_t switches to the low value and stays low. Under the baseline scenario, the interest rate adjusts.

To summarize, the model does a good job in capturing several qualitative and quantitative aspects of economic aggregates during the great recession. The main failure is that the model does not generate a sustained increase in real wages, although it does generate a nontrivial increase during the first year of the economic slowdown. As mentioned above, the model is also modest in terms of its predictions for long-term deflationary pressure. If the model would generate stronger deflationary pressure, then real wages would have increased by more. There are several ways the model can generate stronger deflationary pressure. One possibility is to modify the utility function to enhance precautionary savings. Another possibility is a less powerful monetary policy response. In our model, the nominal interest rate is equal to 2.0% on average and its lowest value – attained in a sustained recession – is equal to 0.56%. Thus, our average nominal interest rate is high enough to avoid the zero lower bound. The average level of the nominal interest rate is not very important for the results as long as the zero lower bound constraint does not bind. To show the importance of constraints on monetary policy, figure 7 plots the responses when the nominal interest rate remains constant. When the interest rate cannot adjust, then deflationary pressure is stronger and the recession is deeper. Moreover, the behavior of real wages is also closer to its empirical counterpart. It is still the case that the real wage response eventually turns negative. But it takes longer before it turns negative and the limiting negative response is only -0.4% compared to an initial positive response of 2.1%.

The result that the recession is deeper when interest rates do not decline raises the question whether the dynamics explored in this paper resemble, or even mimic, those emphasized in the zero-lower-bound literature.[69] It does not. To understand why, it is important to notice that the dynamics underlying the zero-lower-bound literature hinges on the idea that a negative demand shock – which is similar to the precautionary amplification mechanism in this paper – gives rise to a *decline* in expected inflation and quite often even deflation. With nominal interest rates at zero (or at some constant, unchanged, level), this decline in expected inflation *raises* real interest rates, which further propagates the initial shock to demand, and the process reinforces itself. This mechanism contrasts markedly to the one explored in this paper, in which a negative effect on demand – through the precautionary savings in liquid assets – gives rise to a persistent, but mean reverting, decline in the price level, which leads to a substantial *rise* in expected inflation. The rise in expected inflation *lowers* the real interest rate, which therefore alleviates some of the adverse consequences of the initial shock. In fact, the real interest rate falls to levels that are substantially below the nominal interest rate, whereas the opposite is true in the zero-lower-bound literature.

Interestingly, a more reactive interest rate policy, that is, a higher value of v_p does not necessarily lead to a larger reduction in the real interest rate during recessions. The reason is the following. A more aggressive monetary policy response dampens the recession which reduces the increase in the

[69] See, for example, Eggertsson and Woodford (2003), Christiano, Eichenbaum, and Rebelo (2011), and Eggertsson and Krugman (2012).

demand for the liquid asset, which in turn reduces deflationary pressure and, thus, the increase in the expected inflation rate and the reduction in the real rate. Specifically, in the experiment discussed in this section the real interest rate decreases with up to 2.62ppt when monetary policy responds according to equation 13 and ν_P is set to its calibrated value and decreases with up to 2.91ppt when the nominal interest rate is kept fixed.

8 The role of unemployment insurance for business cycles

In this section, we analyze the impact of alternative unemployment-insurance policies. In our model, changes in such policies affect the economy quite differently than in many other models. Our results do not only differ from those of the standard labor search business cycle model with a representative agent, but also from those with heterogeneous agents, such as the models of Krusell, Mukoyama, and Sahin (2010) and McKay and Reis (2016).

The experiment we consider is straightforward. Specifically, we solve the model for a range of values of the replacement rate, μ, and we report the resulting effect on the *average* employment rate conditional on the economy being in an expansion and in a recession, as well as its unconditional average. Here we keep the wage setting rule fixed.[70] In Den Haan, Rendahl, and Riegler (2015), we show that the same mechanisms apply and that the presence of aggregate uncertainty still leads to qualitatively different outcomes when wages do depend on the level of unemployment benefits.[71] Figure 8 illustrates the impact of changes in the replacement rate on employment levels. The value of the replacement rate, μ, is provided on the x-axis, and the resulting employment rate on the y-axis.

First, consider the case without aggregate uncertainty. An increase in the replacement rate means that agents are better insured against idiosyncratic risk, which lowers the expected value of their MRS. The latter triggers a decrease in precautionary savings, which decreases investment and employment.[72]

[70] It is not unreasonable to assume that the wage-setting rule remains unchanged when unemployment insurance changed since several empirical papers find that UI benefits do not have a significant effect on wages. Examples are Card, Chetty, and Weber (2007), Lalive (2007), van Ours and Vodopivec (2008), and Le Barbanchon (2012). However, not all papers reach this conclusion. Schmieder, von Wachter, and Bender (2014) find that more generous UI benefits have a significant *negative* effect on wages and Nekoei and Weber (2015) find that UI benefits have a positive effect on re-employment wages.

[71] In particular, we adjust ω_0 such that the average implied Nash bargaining weight of the worker remains the same when unemployment benefits change.

[72] At low values of μ, however, changes in the replacement rate have virtually no effect on the employment level. The reason is that the presence of money puts a lower bound on the expected return on equity, and therefore an upper bound on the expected MRS. As a consequence, equity prices are bounded from above, which – through the free-entry condition – implies that employment is as well. In the model without aggregate uncertainty, the presence of money implies that the real return on firm ownership cannot be less than minus the (constant) inflation rate.

For the case with aggregate uncertainty, we report the average "expansion" and "recession" employment levels. For values of μ above 0.6, they form a band around the no-aggregate-uncertainty employment level with a roughly constant width. As the replacement rate increases beyond 0.6, all three employment levels decrease. Thus, for these values of μ the model with aggregate uncertainty and the model without aggregate uncertainty have similar predictions on the impact of changes in unemployment insurance on average employment levels.

At values of μ below 0.6, our deflationary mechanism kicks in and an increase in the replacement rate leads to a *decrease* in aggregate volatility, that is, the band narrows. The reduction in aggregate volatility is especially strong when μ is in between 0.45 and 0.55.

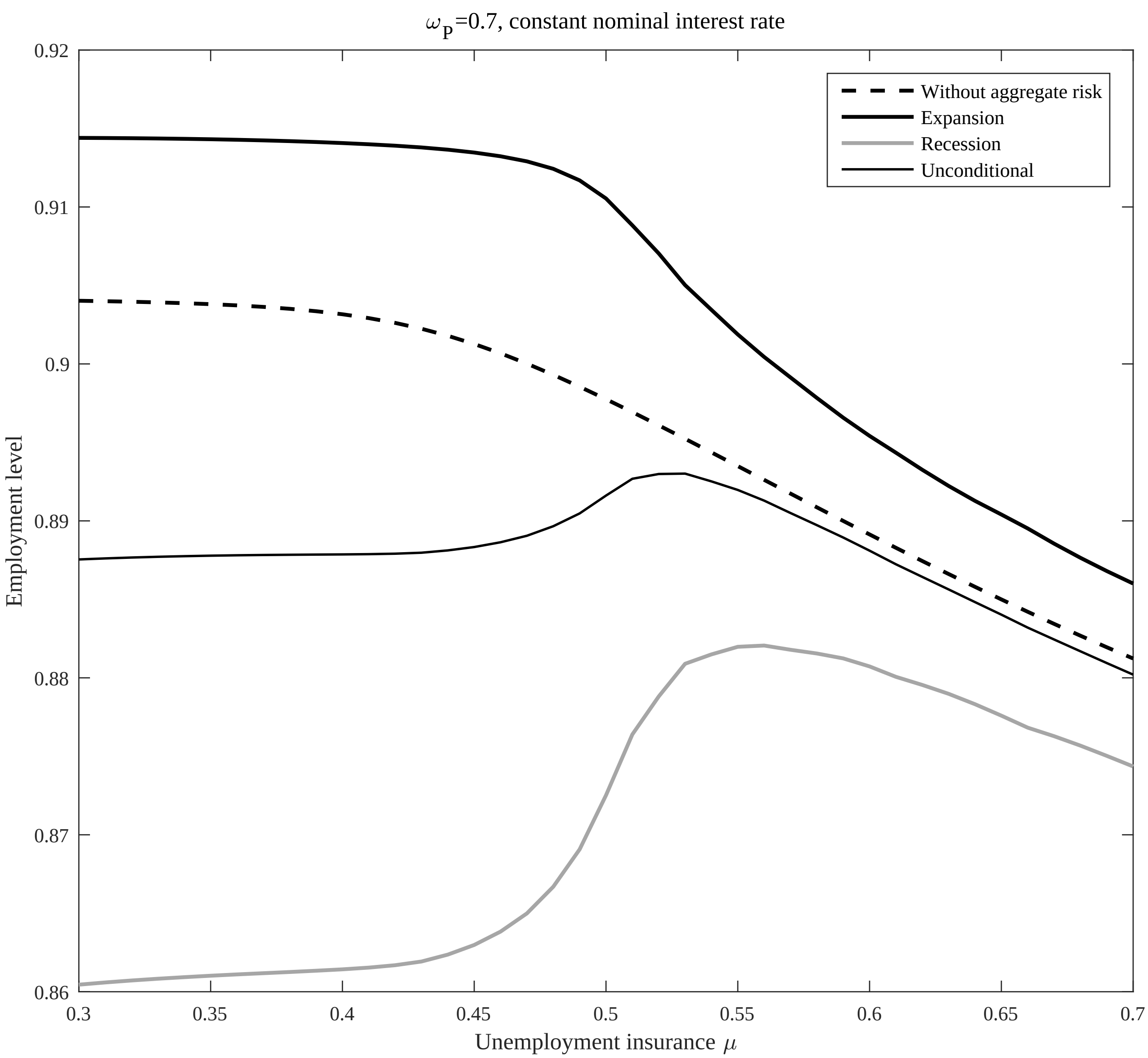

Figure 8: Average employment and replacement rates.

Notes. The left column displays the results when wage setting is not affected by changes in the replacement rate, μ. The right column displays the results when wages setting is such that the implied average Nash-bargaining weights are kept constant when μ changes. The top row presents the results when nominal wages do not fully respond to changes in the price level and the bottom row presents results when they do.

The figure also documents that the increase in μ not only decreases aggregate volatility, it can also increase the average employment rate. By contrast, in the version of our model without aggregate uncertainty an increase in the replacement rate always leads to a *decrease* in average employment. Such comparative statics typically result in similar answers for economies with and without aggregate uncertainty, because aggregate uncertainty is relatively small. Volatility of the only aggregate exogenous random variable, productivity, is indeed modest in our model. Nevertheless, the economy with aggregate uncertainty responds to a change in the replacement rate quite differently than the economy without aggregate uncertainty.

In this section, we abstract from disincentive effects of UI on search behavior. Carlstrom and Fuerst (2006) and Johnston and Mas (2016) argue that these can be quite large. Taking these into account is, therefore, likely to be important to assess the total impact of changes in unemployment insurance on average employment levels. The main point made in this section is that the answer to this question can depend strongly on whether one considers a model with or a model without aggregate uncertainty. The reasons for this difference are likely to be present in a model with endogenous search behavior as well.

9 Concluding comments

The properties of our model depend crucially on whether the deflationary mechanism is sufficiently powerful. If it is not powerful enough, then the model properties are close to the outcomes of a representative-agent version of the model. In particular, the presence of nominal sticky wages would then *dampen* the effects of productivity shocks, and an increase in the replacement rate would *decrease* the average employment rate. If the deflationary mechanism is strong enough, however, then our model predicts the opposite. In so far as the conditions that affect the strength of the deflationary mechanism vary across time and place, one can also expect business cycle properties to vary across time and place. The same is true for the effects of changes in unemployment insurance. Whether the deflationary mechanism is operative or not may depend on relatively small changes. For example, the mechanism is quantitatively very important when the replacement rate is equal to its benchmark value of 50%, but not when the replacement rate exceeds 60%. The message is that even if one is confident that a particular model describes the data well, it may still be difficult to predict business cycle behavior and the consequences of policy changes.

A Further empirical motivation

In this appendix, we provide more empirical motivation for our model and the underlying assumptions. First, we review some evidence in support of our assumption that nominal wages do not respond one-for-one to price changes. Second, we discuss the inability of individuals to insure themselves against unemployment spells. Lastly, we discuss whether savings respond to an increase in idiosyncratic uncertainty.

Nominal wage stickiness and inflation. There are many papers that document that nominal wages are sticky.[73] However, what is important for our paper is the question of to which extent nominal wages adjust to aggregate shocks and, in particular, to changes in the aggregate price level. Druant, Fabiani, Kezdi, Lamo, Martins, and Sabbatini (2009) provide survey evidence for a sample of European firms with a focus on the wages of the firms' main occupational groups; these would not change for reasons such as promotion. Another attractive feature of this study is that it explicitly investigates whether nominal wages adjust to inflation or not. In their survey, only 29.7% of Eurozone firms indicate that they have an internal policy of taking inflation into account when setting wages, and only half of these firms do so by using automatic indexation. Moreover, most firms that take inflation into account are backward looking. Both findings imply that real wages increase (or decrease by less) when inflation rates fall.

Papers that document nominal wage rigidity typically highlight the importance of *downward* nominal wage rigidity. Suppose there is downward, but no upward nominal wage rigidity. Does this imply that all nominal wages respond fully to changes in aggregate prices as long as aggregate prices increase? The answer is no. The reason is that firms are heterogeneous and a fraction of firms can still be constrained by the inability to adjust nominal wages downward. In fact, downward nominal wage rigidity is supported by the empirical finding that the distribution of firms' nominal wage changes has a large mass-point at zero.[74] The fraction of firms that is affected by this constraint would increase if the aggregate price level increases by less. In fact, Daly, Hobijn, and Lucking (2012) document that the fraction of US workers with a constant nominal wage increased from 11.2% in 2007 to 16% in 2011, whereas the fraction of workers facing a reduction in nominal wages was roughly unchanged.[75] This indicates that there is upward pressure on real wages when the inflation rate falls, even if it remains positive and nominal wages are only rigid downward.

Inability to insure against unemployment risk An important feature of our model is that workers are poorly insured against unemployment risk. That is, that consumption decreases considerably following a displacement. Using Swedish data, Kolsrud, Landais, Nilsson, and Spinnewijn (2015) document that

[73] See, for example, Dickens, Goette, Groshen, Holden, Messina, Schweitzer, Turunen, and Ward (2007), Druant, Fabiani, Kezdi, Lamo, Martins, and Sabbatini (2009), Barattieri, Basu, and Gottschalk (2010), Daly, Hobijn, and Lucking (2012), and Daly and Hobijn (2013).

[74] See Barattieri, Basu, and Gottschalk (2010), Dickens, Goette, Groshen, Holden, Messina, Schweitzer, Turunen, and Ward (2007), Daly, Hobijn, and Lucking (2012), and Daly and Hobijn (2013).

[75] Similarly, at `http://nadaesgratis.es/?p=39350`, Marcel Jansen documents that from 2008 to 2013 there was a massive increase in the fraction of Spanish workers with no change in the nominal wage. There is some increase in the fraction of workers with a decrease in the nominal wage, but this increase is small relative to the increase in the spike of the histogram at constant nominal wages.

expenditures on consumption goods drop sharply during the first year of an unemployment spell, after which they settle down at 34% below the pre-displacement level. This sharp fall is remarkable given that Sweden has a quite generous unemployment benefits program. As is discussed in section 4, one reason is that the amount of assets workers hold at the start of an unemployment spell is low. Another reason is that average borrowing actually *decreases* during observed unemployment spells.

Using US data Stephens Jr. (2004), Saporta-Eksten (2014), Aguiar and Hurst (2005), Chodorow-Reich and Karabarbounis (2015) provide empirical support for substantial drops in consumption follow job loss, even when expenditures on durables are not included.[76] Using Canadian survey data, Browning and Crossley (2001) find that workers that have been unemployed for six months report that their total consumption expenditures level during the last month is 14% below consumption in the month before unemployment.

Savings and idiosyncratic uncertainty The idea that idiosyncratic uncertainty plays an important role in the savings decisions of individuals has a rich history in the economics literature. From a theoretical point of view Kimball (1992) shows that idiosyncratic uncertainty increases savings when the third-order derivative of the utility function with respect to consumption is positive and/or the agent faces borrowing constraints. Moreover, idiosyncratic uncertainty regarding unemployment is more important in recessions which are characterized by a prolonged downturn and an increase in the average duration of unemployment spells. Krueger, Cramer, and Cho (2014) document that during the recent recession the number of long-term unemployed increased in Canada, France, Italy, Sweden, the UK, and the US. The only case in which they found a decrease is Germany. The results are particularly striking for the US. During the recent recession, the amount of workers who were out of work for more than half a year relative to all unemployed workers reached a peak of 45%, whereas the highest peak observed in previous recessions was about 25%.

Several papers have provided empirical support for the hypothesis that increases in idiosyncratic uncertainty increases savings. Using 1992-98 data from the British Household Panel Survey (BHPS), Benito (2004) finds that an individual whose level of idiosyncratic uncertainty would move from the bottom to the top of the cross-sectional distribution reduces consumption by 11%. An interesting aspect of this study is that the result holds both for a measure of idiosyncratic uncertainty based on an individuals' own perceptions as well as on an econometric specification.[77] Further empirical evidence for this relationship during the recent downturn can be found in Alan, Crossley, and Low (2012). They argue that the observed sharp rise in the

[76]Using the four 1992-1996 waves of the Health and Retirement Study (HRS), Stephens Jr. (2004) finds that annual food consumption is 16% lower when a worker reports that he/she is no longer working for the employer of the previous wave either because of a layoff, business closure, or business relocation, that is, the worker was displaced between two waves. Similar results are found using the Panel Study of Income Dynamics (PSID). Using the 1999-2009 biannual waves of the PSID, Saporta-Eksten (2014) finds that job loss leads to a drop in total consumption of 17%. About half of this loss occurs before job loss and the other half around job loss. The drop before job loss suggests that either the worker anticipated the layoff or labor income was already under pressure. Moreover, this drop in consumption is very persistent and is only slightly less than 17% six years after displacement. Using data for food and services, Chodorow-Reich and Karabarbounis (2015) find that the consumption level of workers that are unemployed for a full year is 21% below the consumption level of employed workers. Using scanner data for food consumption, Aguiar and Hurst (2005) report a drop of 19%.

[77]Although the sign is correct, the results based on individuals' own perceptions are not significant.

savings ratio of the UK private sector is driven by increases in uncertainty, rather than other explanations such as tightening of credit standards. In line with the mechanism emphasized in this paper, Carroll (1992) argues that employment uncertainty is especially important because unemployment spells are the reason for the most drastic fluctuations in household income. In addition, Carroll (1992) provides empirical evidence to support the view that the fear of unemployment leads to an increased desire to save even when controlling for expected income growth.

B Data Sources

B.1 Data used for figures 1 and 2

- Eurozone GDP implicit price deflators are from the Federal Reserve Economic Data (FRED). Data are seasonally adjusted. Here the Eurozone consists of the 18 countries that were members in 2014.
- Eurozone harmonized unemployment rate, total, all persons from the Federal Reserve Economic Data (FRED). Data are seasonally adjusted.
- Eurozone total share price index for all shares from the Federal Reserve Economic Data (FRED), originally from the OECD main economic indicators. Data are not seasonally adjusted.
- Eurozone private sector hourly earnings are from OECD.STATExtracts (MEI). The target series for hourly earnings correspond to seasonally adjusted average total earnings paid per employed person per hour, including overtime pay and regularly recurring cash supplements. Data are seasonally adjusted.
- Unit labor costs are from OECD.Stat. Data are for the total economy. Unit labour costs are calculated as the ratio of total labour costs to real output. Data are seasonally adjusted.
- GDP
- Unemployment rate

B.2 Data used for calibration

- Average unemployment rate: Average unemployment rate for the four large Eurozone economies, France, Germany, Italy, and Spain for 1980Q1 to 2012Q4. Data is from OECD.Stat.
- Average unemployment duration: Average unemployment duration in Europe in the period from 1980Q1 to 2012Q4. Data is from OECD.Stat. This is annual data. The data series for Europe is used because no data for the Eurozone is available, nor data for the big Eurozone countries. Starting in 1992, separate data is given for Europe, the European Union with 21 countries, and the European Union with 28 countries, and the series are quite similar over this sample period.

- Employment rate and GDP. Data are from OECD.Stat. Quarterly employment rate series for Eurozone countries are only available for relatively short samples. The longest series are available for France (from 1990Q1), for Germany (from 1991Q1), and for Italy (from 1995Q1). When we use samples up to 2012Q4, then we get for the ratio of the standard deviation of HP-filtered employment over HP-filtered output 0.672 for France, 0.391 for Germany, and 0.505 for Italy.
- HFCS data is discussed in the next subsection.

B.3 HFCS data: Details and additional results

Excluded households. To ensure that the data are used resemble the households of our model, we exclude types on agents that are not present in our model. In particular, we apply the following filters:

(i) Always exclude the *entire* household if *any* household member is (according to PE0100a)

  (a) #2 (sick/maternity leave),
  (b) #5 retiree or early retiree,
  (c) #6 permanently disabled,
  (d) #7 compulsary military service, and
  (e) #9 other not working for pay.

(ii) Always exclude the entire household if *nobody* in the household is

  (a) either #1 (employed) or #3 (unemployed).

(iii) Exclude the entire household if there are more than 2 people either employed or unemployed.

(iv) Exclude the entire household if *any* in the household is aged 65 or higher.

(v) Exclude the entire household if *nobody* is aged 20 or older.

(vi) Exclude individuals without reported labour force status.

Employed and unemployed households. In the main paper, we report results for two groups. The ”employed” households are households in which nobody is unemployed and either 1 or 2 household members are working. The ”unemployed” households are households in which nobody is working and either 1 or 2 household members are unemployed. We also looked at subgroups, such as, households with 1 household member working. The results for these subgroups are very similar to the ones for the broader group.

Weighting and imputation. If an answer to a particular question is missing, then HFCS imputes the answer. An imputed answer consists of five different answers. We calculate statistics using all the data including imputed responses. We average the imputed observations to get one observation per individual or household.[78] HFCS provides weights with each observation. The weights are provided to make the sample representative. We calculate statistics using the provided weights.

Definitions of variables. The variables used are defined as follows:

(i) *Labor income*: Income for employed households is defined as the sum of gross cash employee income (PG0110) across household plus the sum of gross self employment income (PG0210) across household members.

(ii) *Unemployment benefits*: Income for unemployed households is defined as the sum of regular social transfers across housholds. These include unemployment benefits (PG0510) and gross income from regular social transfers (HG0110). We do not include pension benefits, since we focus on working age population.

(iii) *Liquid assets*: The sum of sight accounts (HD110) plus savings accounts (HD1210).

(iv) *Financial assets*: The sum of sight accounts (HD110), savings accounts (HD1210), mutual funds (HD1320a-f), bonds (HD1420), publicly traded shares (HD1510), and managed accounts (HD1620).[79]

C Equivalence with standard matching framework.

In the standard matching framework, new firms are created by "entrepreneurs" who post vacancies, $\widetilde{v}_t$, at a cost equal to κ per vacancy. The number of vacancies is pinned down by a free-entry condition. In the description of the model above, such additional agents are not introduced. Instead, creation of new firms is carried out by investors wanting to increase their equity holdings.

Although, the "story" we tell is somewhat different, our equations can be shown to be identical to those of the standard matching model. The free-entry condition in the standard matching model is given by

$$\kappa = \frac{\widetilde{h}_t}{\widetilde{v}_t}\frac{J_t}{P_t}, \tag{15}$$

where

$$\widetilde{h}_t = \widetilde{\psi}\widetilde{v}_t^{\eta} u_t^{1-\eta}. \tag{16}$$

Each vacancy leads to the creation of $\widetilde{h}_t/\widetilde{v}_t$ new firms, which can be sold to households at price J_t.

[78] An issue in the data is that occasionally flags indicates that there is no imputation, but there are still five different numbers given. We treat those cases like imputations.

[79] ECB (2013) refer to this group of assets plus non-selfemployment private business wealth as liquid assets. The latter asset is not very large. We exclude it, because it seems unlikely this type of asset could be easily sold. Note that in our framework "liquid" refers the ability of assets to facilitate transactions during the period.

Equilibrium in the equity market requires that the *net* demand for equity by households is equal to the supply of *new* equity by entrepreneurs, that is

$$\begin{aligned} & \int_i \left(q\left(e_i, q_i, L_i; s_t\right) - (1-\delta)\, q_i\right) dF_t\left(e_i, q_i, L_i\right) \\ = \; & \widetilde{\psi} \widetilde{v}_t^{\eta} u_t^{1-\eta}. \end{aligned} \tag{17}$$

Using equations (15) and (16), this equation can be rewritten as

$$\begin{aligned} & \int_i \left(q\left(e_i, q_i, L_i; s_t\right) - (1-\delta)\, q_i\right) dF_t\left(e_i, q_i, L_i\right) \\ = \; & \widetilde{\psi}^{1/(1-\eta)} \left(\frac{J_t}{\kappa}\right)^{\eta/(1-\eta)} u_t. \end{aligned} \tag{18}$$

This is equivalent to equation (11) if

$$\widetilde{\psi} = \psi \kappa^{\eta}. \tag{19}$$

It only remains to establish that the number of new jobs created is the same in the two setups, that is,

$$h_t = \widetilde{h}_t \tag{20}$$

or

$$\psi v_t^{\eta} u_t^{1-\eta} = \widetilde{\psi} \widetilde{v}_t^{\eta} u_t^{1-\eta}. \tag{21}$$

From equations (15) and (16), we get that

$$\widetilde{v}_t = \left(\frac{\widetilde{\psi} J_t}{\kappa P_t}\right)^{1/(1-\eta)} u_t. \tag{22}$$

Substituting this expression for $\widetilde{v}_t$ and the expression from equation (9) for v_t into equation (21) gives indeed that $h_t = \widetilde{h}_t$. Moreover, the total amount spent on creating new firms in our representation, v_t, is equal to the number of vacancies times the posting cost in the traditional representation, $\kappa \widetilde{v}_t$.

The focus of this paper is on the effect of negative shocks on the savings and investment behavior of agents in the economy when markets are incomplete. We think that our way of telling the story behind the equations has the following two advantages. First, there is only one type of investor, namely, the household and there are no additional investors such as zombie entrepreneurs (poor souls who get no positive benefits out of fulfilling a crucial role in the economy).[80] Second, all agents have access to investment in the same two assets, namely equity and the liquid asset, whereas in the standard labor market model there are households and entrepreneurs and they have different investment opportunities.

[80]One could argue that entrepreneurs are part of the household, but with heterogeneous households the question arises which households they belong to.

D Consumption and portfolio decisions: Additional results

In this appendix, we provide some more detailed information regarding the agents' consumption, investment, and portfolio decisions. Figure 9 displays the average post-displacement change in consumption. As discussed in the main text, the model captures the drop in consumption during the first year following a displacement, but misses that consumption stops falling after the first year. Figure 10, however, documents that most unemployment spells do not exceed one year.

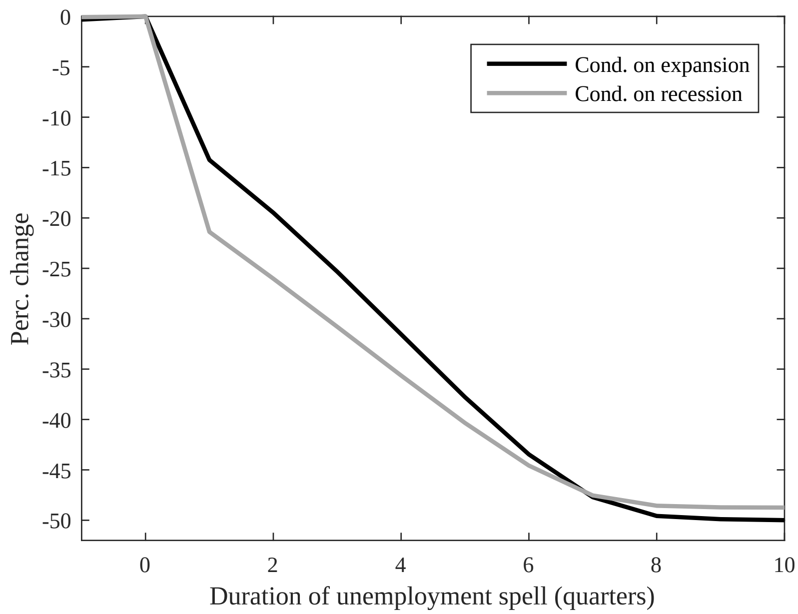

Figure 9: Evolution of consumption drop over the unemployment spell.

Notes. The black line illustrates the average path of consumption of an individual that becomes unemployed in period 1, conditional on being in an expansion at the time of displacement. The grey line illustrates the equivalent path conditional on being in a recession.

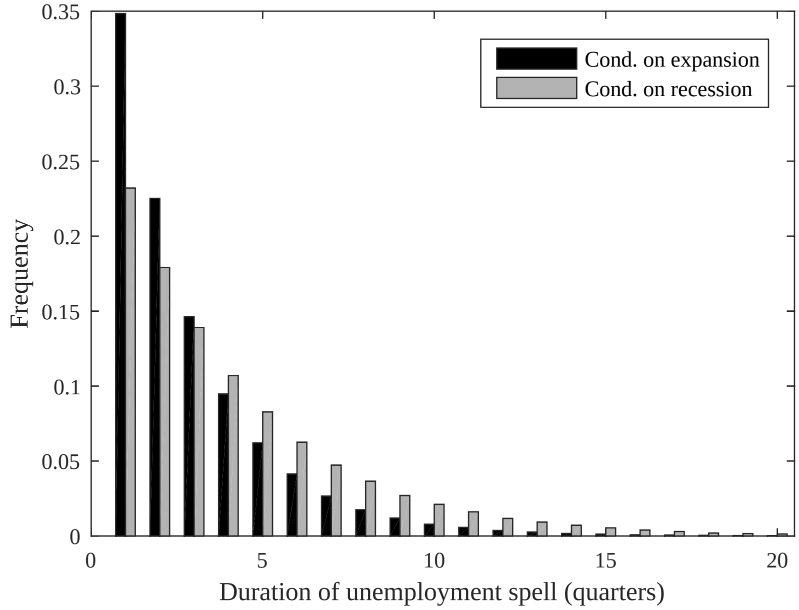

Figure 10: Distribution of the unemployed.

Notes. The black bars measure the fraction of unemployed at various durations conditional on being in an expansion at the time of displacement. The grey bars provide the corresponding measure conditional on being in a recession.

Figure 11 displays the complete cumulative distribution function of the value of assets at the beginning of an unemployment spell relative to the average net-income loss. As discussed in the main text, agents in the bottom of the wealth distribution are substantially richer than their real world counterparts, even if we focus on gross assets.

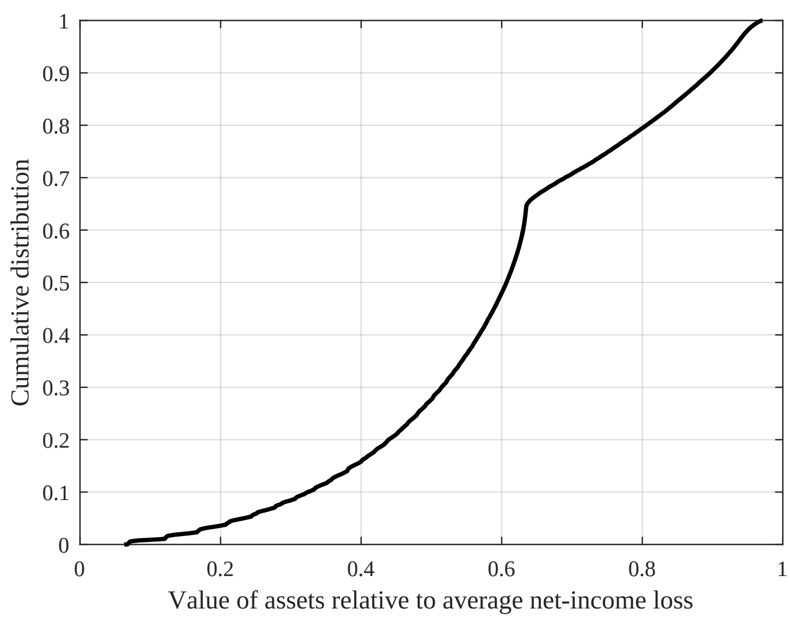

Figure 11: Financial assets at the beginning of an unemployment spell.

Portfolio composition and cash-on-hand levels. Figure 12 presents a scatter plot of the liquid asset's share in the agents' investment portfolios (y-axis) and the beginning-of-period cash-on-hand levels (x-axis). Although the pattern is somewhat intricate, the figure can be characterized reasonably well as follows. First, the fraction invested in money is higher at lower cash-on-hand levels. Second, conditional on the cash-on-hand level, this fraction also increases when an agent becomes unemployed. Third, conditional on the cash-on-hand level and employment status, this fraction increases when the economy enters a recession. These three properties imply that the portfolio share invested in money increases during a recession. Without large enough increases in money portfolio *shares*, aggregate demand for money would decrease during recessions, like it does in the representative-agent model. This is because the total amount of funds carried over into the next period decreases during recessions, which in turn implies that the value of agents' portfolios is lower.

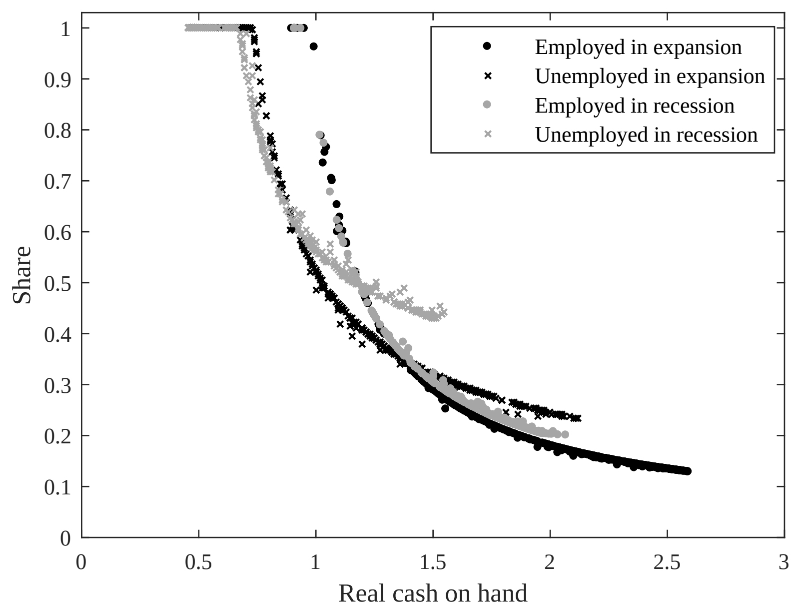

Figure 12: Portfolio shares in liquid asset.

Notes. This figure displays the fraction of financial assets invested in the liquid asset as a function of beginning-of-period cash on hand for workers of the indicated employment status and for both outcomes of aggregate productivity

Which forces explain the observed patterns? The first is that the transaction benefits of money are subject to diminishing returns. As a consequence, agents whose total demand for financial assets is high tend to invest a smaller fraction in money. This explains why the fraction invested in money is generally lower for agents with higher cash-on-hand levels. The second driving force is that money is less risky than equity. Therefore, agents whose total demand for financial assets is high relative to their non-asset income invest a *larger* fraction in money. For a given cash-on-hand level, this explains why the fraction invested in money increases when a worker becomes unemployed, and why the fraction increases when the economy enters a recession. The third driving force explains the non-monotonicity. If the amount invested is substantial relative to the agent's non-asset income, then equity is not appealing because of equity's risky returns. However, if the amount invested is small, then risk has only second-order consequences, whereas the higher return on equity has first-order benefits.

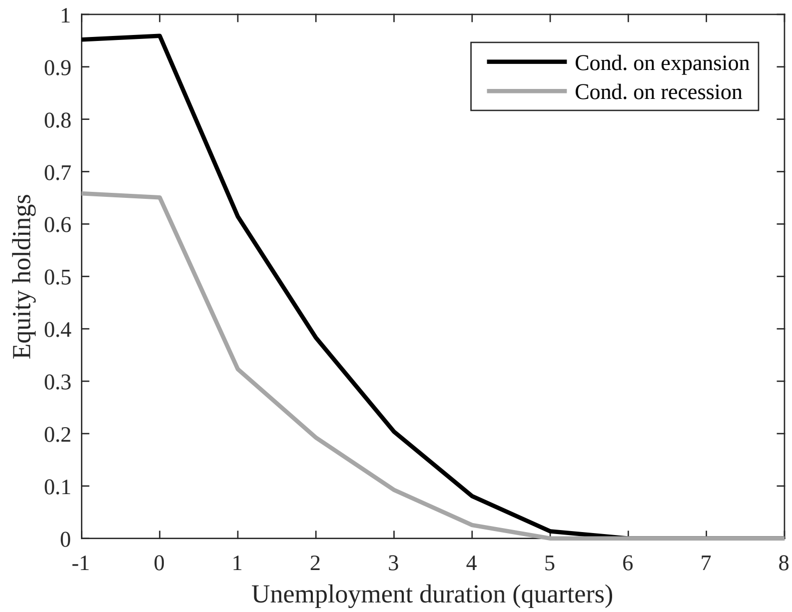

Figure 13: Post displacement equity holdings.

Notes. The black line illustrates the average path for equity holdings of an individual that becomes unemployed in period 1, conditional on being in an expansion at the time of displacement. The grey line illustrates the equivalent path conditional being in a recession.

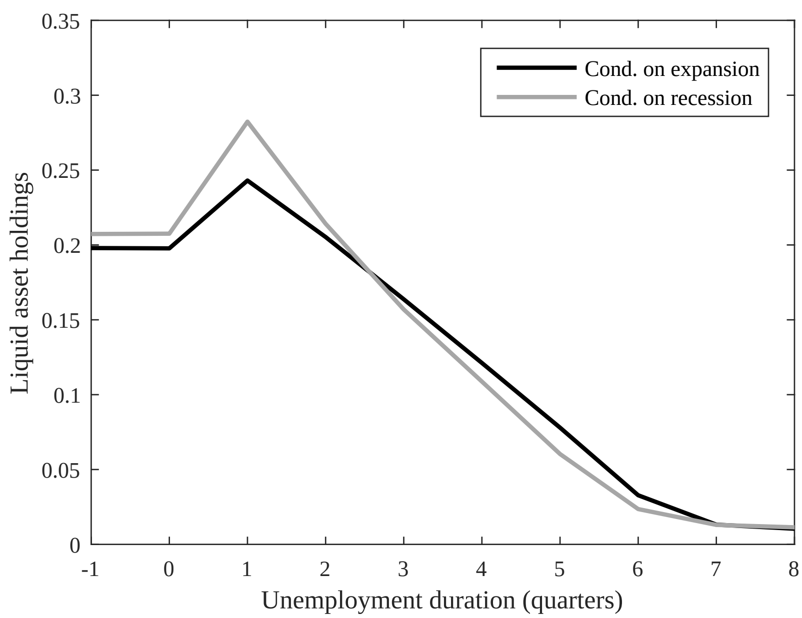

Figure 14: Post displacement money holdings.

Notes. The black line illustrates the average path for money holdings of an individual that becomes unemployed in period 1, conditional on being in an expansion at the time of displacement. The grey line illustrates the equivalent path conditional on being in a recession.

Financial assets during unemployment spells. Figures 13 and 14 document how the demand for equity and money holdings behave following a job displacement. The remarkable feature is that the demand for money actually increases during the first couple periods of an unemployment spell.

Unemployment benefits and unemployment duration. As discussed above, it is not clear from empirical studies whether changes in unemployment benefits affect wages. There is much more empirical support for the hypothesis that more generous benefits increase unemployment duration (see, for instance, Le Barbanchon (2012) for an overview). Several of these studies identify the effect of unemployment benefits on unemployment duration by considering changes in benefits that affect workers differently. These results may, thus, not be relevant for our general equilibrium experiment in which *everybody* is affected by the same increase in the replacement rate. If a large share of the unemployed search less intensely, then this provides improved opportunities of finding a job for those who actively search.[81]

In response to a 10% increase in the replacement rate, μ, from 0.5 to 0.55, our framework generates an increase in average unemployment duration of 1.7% when wages respond to the increase in μ.[82] Krueger and Meyer (2002) report that 0.5 is not an unreasonable rough summary of empirical estimates for the elasticity of unemployment duration with respect to unemployment benefits, but estimates vary. So even though search intensity is constant in our model and an increase in unemployment insurance leads to a sharp decrease in unemployment duration during recessions, our model can still explain a substantial part of the observed relationship between unemployment benefits and unemployment durations.[83]

E Solution algorithm

E.1 Solution algorithm for representative-agent model

E.1.1 Algorithm

To solve the representative-agent models, we use a standard projection method, which solves for q_t and P_t on a grid and approximates the outcomes in-between gridpoints with piecewise linear interpolation.

E.1.2 Accuracy

Petrosky-Nadeau and Zhang (2013) consider a search and matching model with a representative agent. They show that it is not a trivial exercise to solve this model accurately, even though fluctuations are limited. Our representative-agent model is even simpler than the one considered in Petrosky-Nadeau and Zhang (2013).

[81] Lalive, Landais, and Zweimller (2015) argue that these externalities are quantitatively important.

[82] Our framework can also generate an increase in average unemployment duration following an increase in μ when wages are not affected by changes in μ, but only when μ is above 0.6.

[83] The empirical literature focuses on changes in UI benefits on individual workers and changes in search effort are thought to be behind changes in unemployment duration. In our model, search effort is constant and the increase in unemployment duration is due to a reduction in the job creation, either because wages increase or because precautionary savings decrease.

Nevertheless, we document here that both the linear and the log-linear perturbation solution are clearly not accurate. We also document that the projection solution is accurate.

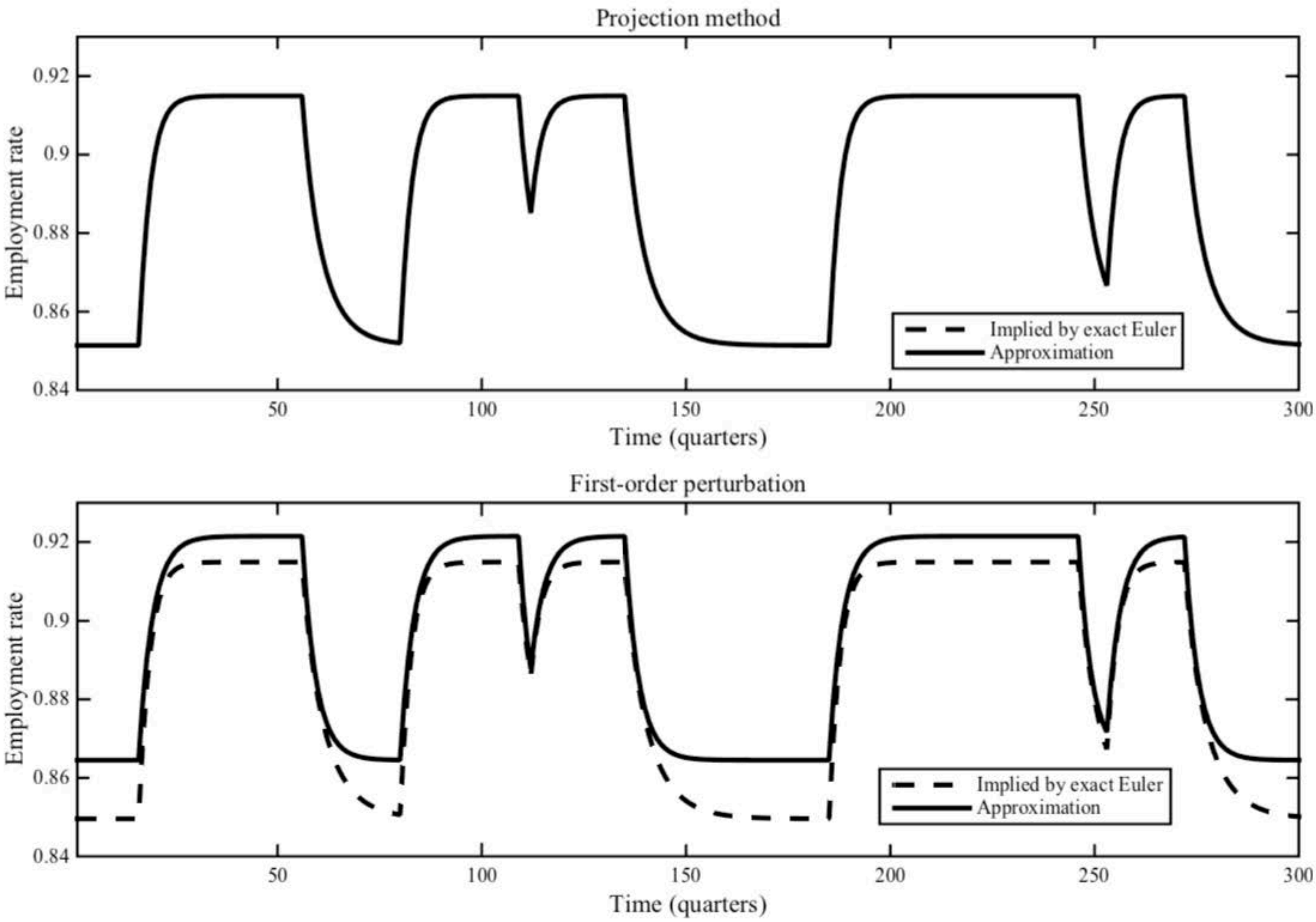

Figure 15: Accuracy representative-agent solution.

Notes. These graphs plot the time series for the employment rate generated with the indicated solution method and the exact solution according to the Euler equation when the approximation is only used to evaluate next period's choices.

To establish accuracy, we use the dynamic Euler-equation errors described in Den Haan (2010). The test compares simulated time series generated by the numerical solution for the policy rules with alternative time series. The alternative time paths are calculated using the *exact* equations of the model in each period; the approximation is not used, except when evaluating next period's choices inside the expectations operator. This test is similar to the standard Euler equation test, but reveals better whether (small) errors accumulate over time. If a numerical solution is accurate, then the two procedures generate very similar time paths.

Figure 15 displays part of the generated time series and clearly documents that the linear perturbation solution has a substantial systematic error, whereas our projection solution does not. Table 3 provides a more complete picture.

Table 3: Accuracy comparison - Representative Agent Model

	projection	linear pertubation	log-linear pertubation
average error (%)	0.84×10^{-5}	1.01	0.43
maximum error (%)	0.28×10^{-4}	1.76	0.74
average unemployment rate (%)	11.5	10.7	10.7
standard deviation employment	2.91	2.63	2.87

Notes: These results are based on a sample of 100,000 observations.

E.2 Solution algorithm for heterogeneous-agent model

In appendix E.2.1, we document how we solve the individual problem taking as given perceived laws of motion for prices and aggregate state variables. In appendix E.2.2, we document how to generate time series for the variables of this economy, including the complete cross-sectional distribution, taking the individual policy rules as given. The simulation is needed to update the laws of motion for the aggregate variables and to characterize the properties of the model. We make a particularly strong effort in ensuring that markets clear *exactly* such that there is no "leakage" during the simulation. This is important since simulations play a key role in finding the numerical solution and in characterizing model properties.[84]

E.2.1 Solving for individual policy functions

When solving for the individual policy functions, aggregate laws of motion as specified in appendix E.2.2 are taken as given. Let $\tilde{x}_i$ denote an individuals cash on hand at the perceived prices. That is,

$$\widetilde{x}_i = e_i(1-\tau)\frac{\widetilde{W}}{\widetilde{P}} + (1-e_i)\mu(1-\tau)\frac{\widetilde{W}}{\widetilde{P}} + q_i\left(\frac{\widetilde{D}}{\widetilde{P}} + (1-\delta)\frac{\widetilde{J}}{\widetilde{P}}\right) + \frac{L_i R_{-1}}{\widetilde{P}}. \tag{23}$$

Individual policy functions for equity, $q_i' = q(\widetilde{x}_i, e_i, q, z)$, and the liquid asset, $L_i' = L(\widetilde{x}_i, e_i, q, z)$, are obtained by iteration:

(i) Using initial guesses for q_i' and L_i', a policy function for consumption can be calculated from the agent's

[84] If the equilibrium does not hold exactly, then the extent to which there is a disequilibrium is likely to accumulate over time, unless the inaccuracy would happen to be *exactly* zero on average. Such accumulation is problematic, since long time series are needed to obtain accurate representations of model properties.

budget constraint:

$$c(\widetilde{x}_i, e_i, q, z) = \widetilde{x}_i - \frac{q_i' \widetilde{J} + L_i'}{\widetilde{P}}.$$

(ii) Conditional on the realizations of the aggregate shock and the agent's employment state, cash on hand and consumption in the next period can be calculated:

$$\widetilde{x}'(e_i', z') = e_i'(1-\tau')\frac{\widetilde{W}'}{\widetilde{P}'} + (1-e_i')\mu(1-\tau')\frac{\widetilde{W}'}{\widetilde{P}'} + q_i'\left(\frac{\widetilde{D}'}{\widetilde{P}'} + (1-\delta)\frac{\widetilde{J}'}{\widetilde{P}'}\right) + \frac{L_i'\widetilde{R}}{\widetilde{P}'}, \tag{24}$$

$$c'(e_i', z') = c(\widetilde{x}'(e_i', z'), e_i', q', z'). \tag{25}$$

(iii) Using the individual and aggregate transition probabilities, the expectations $\mathbb{E}\left[c'^{-\gamma}\frac{\widetilde{D}'+(1-\delta)\widetilde{J}'}{\widetilde{J}}\frac{\widetilde{P}}{\widetilde{P}'}\right]$ and $\mathbb{E}\left[c'^{-\gamma}\frac{\widetilde{P}}{\widetilde{P}'}\right]$, in the first-order conditions (3) and (4) can be calculated. Then, the first-order condition for equity holdings gives an updated guess for consumption of agents holding positive amounts of equity:

$$c^{new}(\widetilde{x}_i, e_i, q, z) = \left(\beta \mathbb{E}\left[c'^{-\gamma}\frac{\widetilde{D}' + (1-\delta)\widetilde{J}'}{\widetilde{J}}\frac{\widetilde{P}}{\widetilde{P}'}\right]\right)^{-\frac{1}{\gamma}}.$$

The first-order condition for the liquid asset gives an updated policy function for it:

$$L^{new}(\widetilde{x}_i, e_i, q, z) = \widetilde{P}\chi^{\frac{1}{\zeta}}\left(c^{new}(\widetilde{x}_i, e_i, q, z)^{-\gamma} - \beta\mathbb{E}\left[c'^{-\gamma}\frac{\widetilde{P}}{\widetilde{P}'}\right]\right)^{-\frac{1}{\zeta}}.$$

The budget constraint in the current period gives the updated policy function for equity:

$$q^{new}(\widetilde{x}_i, e_i, q, z) = \max\left(0, \frac{\widetilde{x}_i\widetilde{P} - c^{new}(\widetilde{x}_i, e_i, q, z)\widetilde{P} - L^{new}(\widetilde{x}_i, e_i, q, z)}{\widetilde{J}}\right).$$

For agents with a binding short-sale constraint, updated policy functions for consumption and liquid assets are instead calculated using only the first-order condition for liquid assets and the budget constraint:

$$c^{new,constraint}(\widetilde{x}_i, e_i, q, z) = \left(\beta\mathbb{E}\left[c'^{-\gamma}\frac{\widetilde{P}}{\widetilde{P}'}\right] + \chi\left(\frac{L_i'}{\widetilde{P}}\right)^{-\zeta}\right)^{-\frac{1}{\gamma}}, \tag{26}$$

$$L^{new,constraint}(\widetilde{x}_i, e_i, q, z) = \widetilde{x}_i\widetilde{P} - c^{new,constraint}(\widetilde{x}_i, e_i, q, z)\widetilde{P}. \tag{27}$$

(iv) A weighted average of the initial guesses and the new policy functions is used to update the initial guesses. The procedure is repeated from step (i) until the differences between initial and updated policy functions become sufficiently small.

E.2.2 Simulation and solving for laws of motion of key aggregate variables

The perceived laws of motion for the real stock price, $\widetilde{J}/\widetilde{P}$ and the price level, $\widetilde{P}$, are given by the following two polynomials (using a total of 12 coefficients):

$$\ln \widetilde{J}/\widetilde{P} = a_0(z) + a_1(z)\ln q + a_2(z)(\ln q)^2, \quad (28)$$

$$\ln \widetilde{P} = b_0(z) + b_1(z)\ln q + b_2(z)(\ln q)^2. \quad (29)$$

Note that q is not only the level of employment, but also the number of firms, and the aggregate amount of equity shares held. We only use the first moment of the distribution of equity holdings, as in Krusell and Smith (1997), but we use a nonlinear function.[85] To update the coefficients of this law of motion, we run a regression using simulated data. In this appendix, we describe how to simulate this economy taking the policy rules of the individual agents as given. We start by describing the general idea and then turn to the particulars.

General idea of the simulation part of the algorithm. Policy functions are typically functions of the state variables, that is, functions of *predetermined* endogenous variables and *exogenous* random variables. These functions incorporate the effect that prices have on agents' choices, but this formulation does not allow for prices to adjust if equilibrium does not hold *exactly* when choices of the individuals are aggregated. If we used the true policy functions, then the equilibrium would hold exactly by definition. Unfortunately, this will not be true for numerical approximations, not even for very accurate ones. Since long simulations are needed, errors accumulate, driving supply and demand further apart, unless these errors happen to be exactly zero on average. Our simulation procedure is such that equilibrium does hold exactly. The cost of achieving this is that actual prices, J and P, will be different from perceived prices, $\widetilde{J}$ and $\widetilde{P}$ and some of the actual individual choices will be different from those according to the original policy functions.[86] These are errors too, but there is no reason that these will accumulate. In fact, we will document that perceived prices are close to actual prices in appendix E.2.3.

Preliminaries. To simulate this economy, we need laws of motions for perceived prices, $\widetilde{J}(q,z)$ and $\widetilde{P}(q,z)$, as well as individual policy functions, $q_i' = q(\widetilde{x}_i, e_i, q, z)$ and $L_i' = L(\widetilde{x}_i, e_i, q, z)$. At the beginning of each period, we would also need the joint distribution of employment status, e_i, and cash on hand, x_i. This distribution is given by $\psi(\widetilde{x}_i, e_i)$, where the tilde indicates that cash on hand is evaluated at perceived prices. The distribution is such that,

$$\int_{e_i}\int_{\widetilde{x}_i} \tilde{x}_i d\psi_i = zq + (1-\delta)q\frac{\widetilde{J}}{\widetilde{P}} + \frac{\overline{M}}{\widetilde{P}}, \quad (30)$$

where the dependence of prices on the aggregate state variables has been suppressed. Below, we discuss how we construct a histogram for the cross-sectional distribution each period and show that this property is

[85]Note that the first-moment of liquid asset holdings only depends on last period's interest rate, since $R_{t-1}L_t$ is fixed and equal to $\overline{L}$.

[86]Throughout this appendix, perceived variables have a tilde and actual outcomes do not.

satisfied. We do not specify a joint distribution of equity and liqid asset holdings. As discussed below, we do know each agent's level of beginning-of-period equity holdings, q_i, and liqid asset holdings, L_i.

A household's cash-on-hand level is given by

$$\widetilde{x}_i = e_i(1-\tau)\frac{\widetilde{W}}{\widetilde{P}} + (1-e_i)\mu(1-\tau)\frac{\widetilde{W}}{\widetilde{P}} + q_i\left(\frac{\widetilde{D}}{\widetilde{P}} + (1-\delta)\frac{\widetilde{J}}{\widetilde{P}}\right) + \frac{L_i R_{-1}}{\widetilde{P}}, \tag{31}$$

and the household can spend this on consumption and asset purchases, that is,

$$\widetilde{x}_i = c_i + q_i'\frac{\widetilde{J}}{\widetilde{P}} + \frac{L_i'}{\widetilde{P}}. \tag{32}$$

The government has a balanced budget each period, that is,

$$\tau = \mu\frac{1-q}{q+\mu(1-q)} + \frac{\widetilde{R}-1}{\widetilde{R}}\frac{1}{q+\mu(1-q)}\frac{\overline{L}}{\widetilde{W}}. \tag{33}$$

Even if the numerical solutions for q_i', L_i', $\widetilde{J}$, and $\widetilde{P}$ are very accurate, it is unlikely that equilibrium is *exactly* satisfied if we aggregate q_i' and L_i' across agents. To impose equilibrium exactly, we modify the numerical approximations for equity and liquid asset holdings such that they are no longer completely pinned down by exogenous random variables and predetermined variables, but instead depend directly – to at least some extent – on prices.[87] In the remainder of this section, we explain how we do this and how we solve for equilibrium prices.

Modification and imposing equilibrium. To impose equilibrium we adjust q_i', L_i', $\widetilde{J}$, and $\widetilde{P}$. The equilibrium outcomes are denoted by $q_{i,+1}$, $L_{i,+1}$, J, and P. The individual's demand for assets is modified as follows:

$$q_{i,+1} = \frac{\widetilde{J}/\widetilde{P}}{J/P}q_i', \tag{34}$$

$$L_{i,+1} = \frac{P}{\widetilde{P}}L_i'. \tag{35}$$

We will first discuss how equilibrium prices are determined and then discuss why this is a sensible modification. An important accuracy criterion is that this modification of the policy functions is small, that is, actual and perceived laws of motions are very similar.[88]

We solve for the actual law of motion for employment, q_{+1}, the number of new firms created, h, the amount spent on creating new firms in real terms, $v = hJ/P$, the market clearing asset price, J, and the market

[87] The policy functions $q(\widetilde{x}_i, \varepsilon_i, q, z)$ and $L(\widetilde{x}_i, \varepsilon_i, q, z)$ *do* depend on prices, but this dependence is captured by the aggregate state variables.

[88] As explained above, it is important to do a modification like this to ensure that equilibrium holds *exactly*, even if the solution is very accurate and the modification small.

clearing price level, P, from the following equations:[89]

$$q_{+1} = (1-\delta)\,q + h, \tag{36}$$

$$h = \psi v^{\eta}\,(1-q)^{1-\eta}, \tag{37}$$

$$v = hJ/P, \tag{38}$$

$$\begin{aligned} h &= \int_{e_i}\int_{\widetilde{x}_i} \left(q_{i,+1}(\widetilde{x}_i, e_i, q, z) - (1-\delta)q_i\right) d\psi_i \\ &= \int_{e_i}\int_{\widetilde{x}_i} \left(\frac{\widetilde{J}/\widetilde{P}}{J/P} q(\widetilde{x}_i, e_i, q, z) - (1-\delta)\,q_i\right) d\psi_i, \end{aligned} \tag{39}$$

$$\frac{\overline{L}}{\widetilde{\widetilde{R}}} = \int_{e_i}\int_{\widetilde{x}_i} L_{i,+1}(\widetilde{x}_i, e_i, q, z) d\psi_i = \int_{e_i}\int_{\widetilde{x}_i} \frac{P}{\widetilde{\widetilde{P}}} L(\widetilde{x}_i, e_i, q, z) d\psi_i. \tag{40}$$

In particular, the distribution satisfies

$$\int_{e_i}\int_{\widetilde{x}_i} q_{i,+1} d\psi_i = q_{+1}. \tag{41}$$

Logic behind the modification. Recall that $q(\widetilde{x}_i, e_i, q, z)$ and $L(\widetilde{x}_i, e_i, q, z)$ are derived using perceived prices, $\widetilde{J}(q,z)$ and $\widetilde{P}(q,z)$. Now suppose that – in a particular period – aggregation of $q(\widetilde{x}_i, e_i, q, z)$ indicates that the demand for equity exceeds the supply for equity. This indicates that $\widetilde{J}(q,z)$ is too low in that period. By exactly imposing equilibrium, we increase the asset price and lower the demand for equity. Note that our modification is such that any possible misperception on prices does not affect the real amount each agent spends, but only the number of assets bought.

Throughout this section, the value of cash on hand that is used as the argument of the policy functions is constructed using *perceived* prices. In principle, the equilibrium prices that have been obtained could be used to update the definition of cash on hand and one could iterate on this until convergence. This would make the simulation more expensive. Moreover, our converged solutions are such that perceived and actual prices are close to each other, which means that this iterative procedure would not add much.

Equilibrium in the goods market. It remains to show that our modification is such that the goods market is in equilibrium as well. That is, Walras' law is not wrecked by our modification.

From the budget constraint we get that actual resources of agent i are equal to

$$x_i = e_i(1-\tau)\frac{W}{P} + (1-e_i)\mu(1-\tau)\frac{W}{P} + \left(\frac{D}{P} + (1-\delta)\frac{J}{P}\right) q_i + \frac{L_i R_{-1}}{P} \tag{42}$$

and actual expenditures are equal to

$$x_i = c_i + \frac{J}{P} q_{i,+1} + \frac{L_{i,+1}}{P}. \tag{43}$$

[89] Recall that we define variables slightly different and v is not the number of vacancies, but the amount spent on creating new firms.

The value of c_i adjusts to ensure this equation holds. Aggregation gives

$$x = zq + \frac{J}{P}(1-\delta)q + \frac{\overline{L}}{P\widetilde{R}} \tag{44}$$

and

$$x = c + \frac{J}{P}\int_{e_i}\int_{\widetilde{x}_i} q_{i,+1} d\psi_i + \frac{\int_{e_i}\int_{\widetilde{x}_i} L_{i,+1} d\psi_i}{P} = c + \frac{J}{P}q_{+1} + \frac{\overline{L}}{P\widetilde{R}}. \tag{45}$$

Equation (44) uses the definition of dividends together with equation (33). Equation (45) follows from the construction of J and P.

Since

$$\frac{J}{P}q_{+1} - \frac{J}{P}(1-\delta)q = v, \tag{46}$$

we get

$$zq = c + v, \tag{47}$$

which means that we have goods market clearing in each and every time period.

Implementation. To simulate the economy, we use the "non-stochastic simulation method" developed in Young (2010). This procedure characterizes the cross-sectional distribution of agents' characteristics with a histogram. This procedure would be computer intensive if we characterized the cross-sectional distribution of both equity and liquid asset holdings. Instead, we just characterize the cross-sectional distribution of cash-on-hand for the employed and unemployed. Let $\psi(\widetilde{x}_{i,-1}, e_{i,-1})$ denote last period's cross-sectional distribution of the cash-on-hand level and employment status. The objective is to calculate $\psi(\widetilde{x}_i, e_i)$.

(i) As discussed above, given $\psi(\widetilde{x}_{i,-1}, e_{i,-1})$ and the policy functions, we can calculate last period's equilibrium outcome for the total number of firms (jobs) carried into the current period, q; the job-finding rate, $h_{-1}/(1-q_{-1})$; last period's prices, J_{-1} and P_{-1}; and for each individual the equilibrium asset holdings brought into the current period, $q_i(\widetilde{x}_{i,-1}, e_{i,-1})$ and $L_i(\widetilde{x}_{i,-1}, e_{i,-1})$.

(ii) Current employment, q, together with the current technology shock, z, allows us to calculate perceived prices $\widetilde{J}$ and $\widetilde{P}$.

(iii) Using the perceived prices together with the asset holdings q_i and L_i, we calculate perceived cash on hand conditional on last-period's cash-on-hand level and both the *past* and the *present* employment status. That is,

$$\widetilde{x}(e_i, \widetilde{x}_{i,-1}, e_{i,-1}) = e_i(1-\tau)\frac{\widetilde{W}}{\widetilde{P}} + (1-e_i)\mu(1-\tau)\frac{\widetilde{W}}{\widetilde{P}} + q(\tilde{x}_{i,-1}, e_{i,-1})\left(\frac{\widetilde{D}}{\widetilde{P}} + (1-\delta)\frac{\widetilde{J}}{\widetilde{P}}\right) + \frac{L(\tilde{x}_{i,-1}, e_{i,-1})R_{-1}}{\widetilde{P}}.$$

(iv) Using last period's distribution $\psi(\widetilde{x}_{i,-1}, e_{i,-1})$ together with last-period's transition probabilities, we can calculate the joint distribution of current perceived cash on hand, $\widetilde{x}_i$, past employment status, and present employment status, $\widehat{\psi}(\widetilde{x}_i, e_i, e_{i,-1})$.

(v) Next, we retrieve the current period's distribution as

$$\psi(\widetilde{x}_i, 1) = \widehat{\psi}(\widetilde{x}_i, 1, 1) + \widehat{\psi}(\widetilde{x}_i, 1, 0), \tag{48}$$

$$\psi(\widetilde{x}_i, 0) = \widehat{\psi}(\widetilde{x}_i, 0, 1) + \widehat{\psi}(\widetilde{x}_i, 0, 0). \tag{49}$$

(vi) Even though we never explicitly calculate a multi-dimensional histogram, in each period we do have information on the joint cross-sectional distribution of cash on hand at perceived prices and asset holdings.

Details. Our wage-setting rule (7), contains $\overline{P}$, an indicator for the average price level. For convenience, we use the average between the long-run expansion and the long-run recession value.[90] Since it is a constant, it could be combined with the scaling factor, ω_0. The properties of the algorithm are improved by including $\overline{P}$. If a term like $\overline{P}$ was not included, then average wages would change across iteration steps. Moreover, without such a term, then recalibrating ω_0 would be more involved, for example, if one compares the case with and the case without aggregate uncertainty. We use a simulation of 2,000 observations to estimate the coefficients of the laws of motion for aggregate variables. The first 150 observations are dropped to ensure the results are not affected by the specification of the initial state. The histogram that we use to track the cross-sectional distribution has 2,000 grid points. Statistics reported in the main text that are obtained by simulation are from a sample of 11,000 observations for aggregate variables and from a sample of 11,000,000 observations for idiosyncratic variables.

E.2.3 Accuracy

Conditional on perceived laws of motion for the price level and the employment rate, individual policy rules can be solved accurately using common numerical tools even though the presence of a portfolio problem makes the individual optimization problem a bit more complex than the standard setup in heterogeneous-agent models. The key measure of accuracy is, therefore, whether the perceived laws of motion for the price level and the employment rate coincide with the corresponding laws of motion that are implied by the individual policy rules and market clearing. Figure 16 shows that both perceived laws of motion track the implied market clearing outcome very closely.

[90] This actually is a good approximation of the average price level.

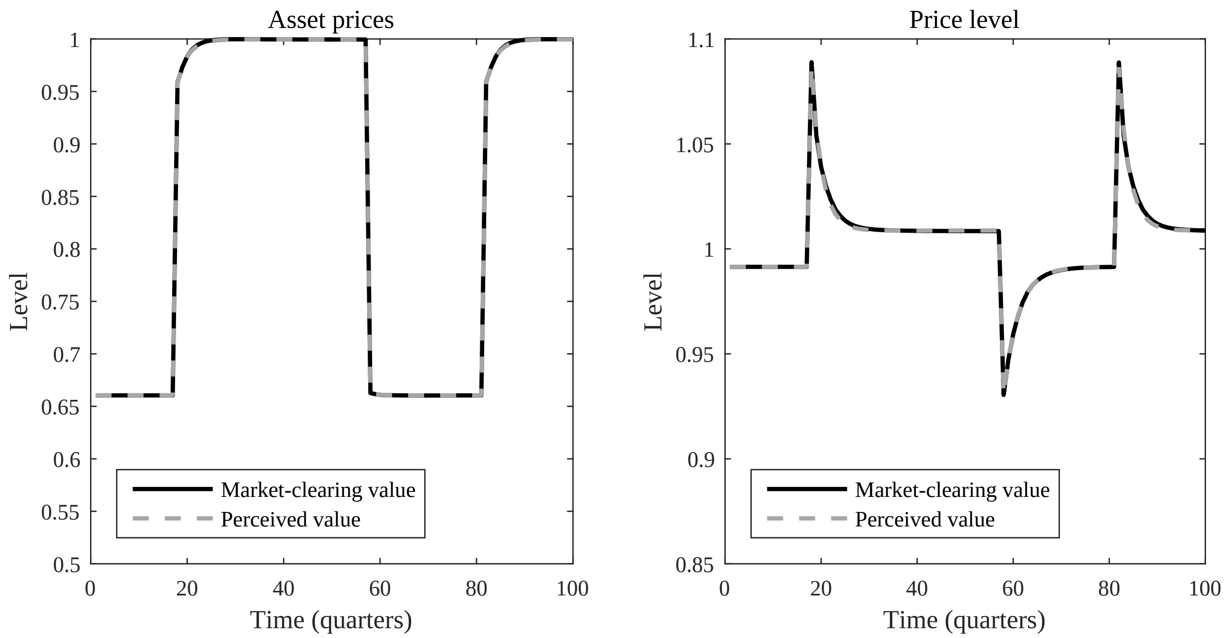

Figure 16: Accuracy heterogeneous-agent solution.

Notes. These graphs plot for the indicated variable the timeseries according to the perceived law of motion (used to solve for the individual policy rules) and the actual outcomes consistent with market clearing.

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