Welfare effects of wage rigidities and the financial accelerator*

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Abstract

We consider a RBC economy endowed with both financial and labor market frictions. We quantify the impact of real wage rigidities and other labor market imperfections after a financial shock, finding that the former substantially amplify fluctuations, whereas this is not the case of imperfections affecting the labor wedge. As large fluctuations do not necessarily correspond to large welfare costs, our main contribution is to quantify the welfare effects associated to those amplifications. We find that the impact of real wage rigidities on welfare is non negligible.

Jel codes: E32, E44.

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1 Introduction

The idea that imperfections in the financial sphere amplify the business cycle is an old one.[1] The notion of a financial accelerator by which large fluctuations in aggregate economic activity arise from seemingly small shocks dates back to Fisher (1933) and has been fully developed in a DSGE model by Bernanke *et al.* (1996).[2] Recently, after the eruption of the financial crisis, the possibility

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[1]Some empirical evidence on the relevance of credit market conditions for business cycle is provided by Bernanke *et al.* (1999), Gertler and Lown (1999), Mody and Taylor (2003), Mody *et al.* (2007).

[2]Their model is founded on Bernanke and Gertler (1989) and Kiyotaki and Moore (1997), who focus on the costs of borrowing and lending associated with asymmetric information.

that adverse conditions in the real economy and in financial markets mutually reinforce each other has been revisited by a number of authors. A new wave of models of economies with financial frictions has emerged where a formal bank channel is specifically considered.[3].

Our paper contributes to this literature by jointly considering labor and financial market frictions in an RBC model. This has already been done by other authors and the general result is that labor market frictions amplify the impact of financial imperfections, helping to match some labor market empirical evidence.[4] By considering the presence of endogenous search frictions *à la* Pissarides (2000) in both labor and credit markets, Wasmer and Weil (2004) e.g. shows that credit market imperfections exacerbate labor market frictions by restricting firms entry, with both short and long run effects on unemployment. More recently, Hristov (2010), Petrosky-Nadeau (2011), Kim and Seliski (2012), Chugh (2013) and Petrosky-Nadeau and Wasmer (2013) find similar results in more complex frameworks. All these models use a matching framework to describe the labor market frictions but introduce different kinds of financial frictions. Petrosky-Nadeau (2011) and Petrosky-Nadeau and Wasmer (2013) focus on asymmetric information and costly state verification between financial intermediaries and borrowers. Chugh (2013) considers a similar credit channel but builds a model with capital accumulation. Kim and Seliski (2012) introduces the credit channel developed by Jermann and Quadrini (2012).

We differ from the above literature because, following Gertler and Kiyotaki (2011), we consider an agency problem between banks and depositors rather than between banks and borrowers. In such a framework the amplification provided by the moral hazard problem in the bank-depositor relationship better allows the model to match the volatility of the external finance premium, investment and other variables relative to output in US data as compared to the traditional accelerator model (Rannenberg, 2012). Moreover, we evaluate the quantitative impact of real wage rigidities on accounting volatilities by considering a very general formalization (Hall, 2005) meant to capture the effect of more specific ones encountered for instance in models featuring matching or trade unions and insider-outsider mechanisms.[5]

Gertler and Kiyotaki themselves stress the potential relevance of labor market imperfections in their framework, although they do not formally model them. They admit that "to compensate partly for the absence of labor market frictions, we use a Frisch labor elasticity of ten, which is well above the range found in the business cycle literature, which typically lies between unity and three. We emphasize, though, that this compensation is only partial" (Gertler and Kiyotaki, 2011: 34). In this paper we thus aim to qualify and quantify the role played by labor market frictions – which we model in the double form of imperfections leading to a labor wedge and frictions leading to real wage rigidity – within the context of a financial accelerator model which heavily relies on Gertler and

[3]See e.g. Goodfriend and McCallum (2007), Angeloni and Faia (2009), Cùrdia and Woodford (2009), Christiano *et al.* (2010), Gertler and Kiyotaki (2010), Gerali *et al.* (2010), Meh and Moran (2010), Jermann and Quadrini (2012), Iacoviello (2013). See also Woodford (2010) for a survey.

[4]See Shimer (2005) and Fujita and Ramey (2007).

[5]The cost of our approach is that our mechanism is not explicitly micro-founded See Hall (2005), Blanchard and Gali (2007) and Christoffel and Linzert (2010), Rhee and Song (2013) for a discussion.

Kiyotaki (2011).[6]

Specifically, our analysis is focused on the assessment of the welfare impact of labor market frictions in the case of a financial crisis. First, we investigate the contribution of these frictions to business cycle volatility. We find that real wage rigidities substantially amplify this volatility, whereas this is not the case for imperfections affecting the labor wedge. Second, we quantify the effects associated to those amplifications by performing a welfare analysis. This is our main contribution. Besides the fact that there exists no unanimous consensus about the welfare effects of a relatively higher economic uncertainty in RBC models,[7] welfare analysis is particularly worthwhile in the present context as, although more wage rigidity induces a higher volatility of the main variables (e.g. output, investment and hours), we find a relatively low variability shift in consumption. In our welfare analysis we decompose welfare into first and second order effects for uncovering the mechanisms guiding the agents' choices and, in turn, the net welfare results.

It is worth noticing that, in order to focus on the relative effects of real rigidities on volatilities and welfare, we abstract from prices and nominal wage stickiness.[8]

The rest of the paper is organized as follows. Section 2 describes the model. Section 3 shows the results of model simulations and the welfare analysis. A final section concludes.

2 The model

Our core framework is a RBC model with distorted labor and financial markets and real wage rigidities, based on the financial accelerator model of Gertler and Kiyotaki (2011). We consider a simple setup assuming no idiosyncratic uncertainty for producing firms and homogeneous financial intermediaries.[9] Households consist of both workers and bankers and perfect consumption insurance among them is guaranteed. We consider a non-competitive labor market with strategic wage setters and real wage rigidities. In this market, workers supply hours to non-financial firms and return wages to the household. Similarly, bankers transfer profits earned from the financial activity back to their family. Homogeneous banks intermediate funds between households and non-financial firms in the financial market,[10] facing endogenously determined balance sheet

[6] See Layard *et al.* (1991) and Belot and Van Ours (2004) for a more detailed discussion about imperfections, real rigidities and labor market institutions. Regarding their empirical relevance, see e.g. ECB (2009), Du Caju *et al.* (2008), Christoffel *et al.* (2009), Guichard and Rusticelli (2010), Rumler and Scharler (2011), Knell (2013).

[7] See Cho and Cooley (2003) for a discussion on this issue.

[8] The effects on volatility and welfare of including price stickiness in a similar context have been investigated by Gertler and Karadi (2011), who however abstract from labor market imperfections.

[9] This setup developed by Gertler and Karadi (2011) mimics a frictionless interbank market with idiosyncratic shocks, as in the Lucas island model (see Gertler and Kiyotaki, 2011). Results can be easily extended to the case of interbank frictions. However, Gertler and Kiyotaki (2011) shows that this extension will only have quantitative effects with respect to the frictionless case (or homogeneous case).

[10] Households can lend money to the banks or fund the government debt. Both deposits and government debts are one period riskless financial activities, i.e. perfect substitutes. This implies that credit rationing only affects banks in collecting deposits, as household can lend to them or the government.

constraints due to an agency problem. Banks provide funds against future profits of the firms which are able to offer perfect state contingent debt. Thus we can think of the banks' claims as equities.[11] Competitive non-financial firms produce output by means of capital and labor. Finally, competitive capital producing firms owned by the households are also introduced.

2.1 Households

In the economy there is a continuum of infinitely lived households indexed by i on the unit interval $(0,1)$; each of them supplies a differentiated labor type. Preferences of households are defined over consumption $(C_{t,i})$ and hours worked $(L_{t,i})$:

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_{t,i}, L_{t,i}\right) = E_0 \sum_{t=0}^{\infty} \beta^t [\ln(C_{t,i} - hC_{t-1,i}) - \frac{\chi}{1+\varepsilon} L_{t,i}^{1+\varepsilon}] \tag{1}$$

with $\beta \in (0,1)$, h is the habits in consumption parameter, χ measures the relative weight of the labor argument and ε is the inverse Frisch elasticity of labor supply.

The household budget constraint at time t is:

$$C_{t,i} = \left(1 - \tau_L\right) W_{t,i} L_{t,i} + \Pi_{t,i} + R_t D_{t-1,i} - D_{t,i} - T_t \tag{2}$$

where $D_{t-1,i}$ is the total quantity of short term debt (deposits) the household acquires that pay the gross real return R_t over the period from $t-1$ to t; $W_{t,i}$ is the real wage, $\Pi_{t,i}$ is the net payout to the household from ownership of both non-financial and financial firms;[12] T_t is a lump sum tax (or subsidy); τ_L indicates the labor income tax rate.

Households' first order conditions imply a standard Euler condition:[13]

$$1 = \beta E_t \frac{U_{Ct+1}}{U_{Ct}} R_{t+1} \tag{3}$$

where U_C is the marginal utility of consumption which is defined as follows:

$$U_{Ct} \equiv \frac{1}{C_t - hC_{t-1}} - \frac{\beta h}{C_{t+1} - hC_t}. \tag{4}$$

Thus, $\Lambda_{t,t+1} = \beta \frac{U_{Ct+1}}{U_{Ct}}$ is the household's discount factor. The condition about the optimal labor supply will be introduced at a later stage, when we consider the labor market.

2.2 The real sector

2.2.1 Final good producing firms

The economy is populated by a continuum of symmetric competitive good producing firms indexed by f on the unit interval $(0,1)$; they employ both capital

[11] In other words, bank loans have the same value as firms' equities.

[12] Note that $\Pi_{t,i}$ is net of the transfer the household gives to its members that enter banking at time t.

[13] Index i is dropped for simplicity.

(K_t) and labor (L_t) as inputs. Each firm produces perfectly substitutable goods given a Cobb-Douglas production function:

$$Y_{t,f} = A_t K_{t,f}^{\alpha} {L_{t,f}}^{1-\alpha} \tag{5}$$

where $A_t = exp\,(a_t)$ is an aggregate productivity shock, with $a_t = \rho_a\, a_{t-1} + u_t$, and u_t a *i.i.d.* normal variable and $L_{t,f}$ denotes a labor bundle of imperfect substitutable labor types distributed over a unit interval, represented by:

$$L_{t,f} = \left[\int_0^1 L\,(i)_{t,f}^{\frac{\eta-1}{\eta}}\; di \right]^{\frac{\eta}{\eta-1}} \tag{6}$$

where η is a measure of the wage setters' monopoly power (i.e., the intra-temporal elasticity of substitution across different labor inputs).

For any given level of its labor demand, $L_{t,f}$, each firm must decide the optimal allocation across labor inputs, subject to the aggregation technology (6). From the minimization cost problem solution, demand for labor type i by firm f is then:

$$L(i)_{t,f} = \left(\frac{W_t\,(i)}{W_t} \right)^{-\eta} L_{t,f} \tag{7}$$

where

$$W_t = \left[\int_0^1 W_t\,(i)^{1-\eta}\; di \right]^{\frac{1}{1-\eta}} \tag{8}$$

is the average real wage index.

Firms equate the marginal productivity of labor to the wage. As firms are symmetric we can just drop the index f and obtain aggregate labor demand:

$$L_t = \left(\frac{(1+\tau_S)\, W_t}{A_t K_t^{\alpha}\,(1-\alpha)} \right)^{-\frac{1}{\alpha}} \tag{9}$$

where τ_S is a payroll tax, or:

$$W_t = \frac{1-\alpha}{1+\tau_S} \frac{Y_t}{L_t}. \tag{10}$$

As far as capital services demand is concerned, we observe that the gross profit per unit of capital Z_t is given by:

$$Z_t = \frac{Y_t - (1+\tau_S)\, W_t L_t}{K_t} = \alpha A_t \left(\frac{L_t}{K_t} \right)^{1-\alpha}. \tag{11}$$

Firms are financed by banks, which collect the savings of households. Firms buy new capital goods from capital producers by issuing state-contingent equities at price Q_t and committing to pay the flow of future gross capital profits to the banks.

2.2.2 Capital producing firms

There is a continuum of length one of competitive capital producing firms.[14] They transform one unit of final good into one unit of capital good (priced

[14] Firms' indices are dropped for simplicity.

Q_t) subject to a flow adjustment cost. Thus, the representative capital producing firm maximizes the following expected present discounted value of future profits:[15]

$$E_t \sum_{t=0}^{\infty} \Lambda_{t,t+1} \left((Q_t - 1) I_t - f\left(\frac{I_t}{I_{t-1}}\right) I_t \right)$$

where I_t is the production (i.e., investment) and $f(.)$ is the adjustment cost function. We assume that $f(1) = f'(1) = 0$ and $f''(I_t/I_{t-1}) > 0$; $f(I_t/I_{t-1})\, I_t$ is physical adjustment costs.

Profit maximization implies:

$$Q_t = 1 + f\left(\frac{I_t}{I_{t-1}}\right) + \frac{I_t}{I_{t-1}} f'\left(\frac{I_t}{I_{t-1}}\right) - E_t \Lambda_{t,t+1} f'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2. \quad (12)$$

The law of motion for capital is given by:

$$K_{t+1} = \Psi_{t+1}\left(I_t + K_t\, (1-\delta)\right) \quad (13)$$

where δ is the capital depreciation rate and $\Psi_t = exp\,(\psi_t)$ is a capital quality shock, i.e., an exogenous source of variation in the value of capital;[16] $\psi_t = \rho_\psi\, \psi_{t-1} + \varepsilon_t$ and ε_t is a *i.i.d.* normal variable with zero mean and finite variance, σ^2.

2.2.3 Labor markets

Differently from Gertler and Kiyotaki (2011), we explicitly introduce labor market imperfections in the model by assuming that the labor market is not competitive as each worker sells a different kind of labor. We follow, among others, Erceg *et al.* (2000) and Galí (2011a, 2011b) by focusing on Nash wage bargaining in a standard monopolistic competition context. Specifically, we assume that wage setters internalize the expected consequences of their actions over the life of the future contract, but not those arising from the actions of the others. Each wage-setter in fact bargains over the real wage, taking other workers' decisions as given. However, wage setting might be coordinated to various degrees.

The coordination degree is captured by the parameter n^{-1} in the following way.[17] Each wage-setter (indexed by j, with $j = 1, ...n$) acts on behalf of a length n^{-1} of workers. More specifically, each union j sets the wage $W_{t,j}$ of the agent $i \in j$, (i.e., $W_{t,i} = W_{t,j}$ if $i \in j$) so as to maximize his utility in (1), subject to the budget constraint (2), (7) and (9).

In fact, by (8), in the decentralized equilibrium each union j anticipates that

$$\frac{\partial W_t}{\partial W_{t,j}} = \frac{\partial}{\partial W_{t,j}} \left[\int_{i \in j} W_t(i)^{1-\eta} di + \int_{i \notin j} W_t(i)^{1-\eta} di \right]^{\frac{1}{1-\eta}} = \quad (14)$$
$$\frac{1}{n}\left(\frac{W_{t,j}}{W_t}\right)^{-\eta}.$$

[15] Capital producing firms earn no profits in steady state. When fluctuations occur they redistribute profits directly to the households who own capital producing firms.

[16] See Gertler and Karadi (2011), Gertler and Kiyotaki (2011), and references therein.

[17] See, e.g., Gnocchi (2009) for a similar framework. See also Soskice and Iversen (1998), Zanetti (2007), Lippi (2003).

In the appendix we show that at the symmetric equilibrium,[18] the wage-setters' first order conditions yield:

$$E_t\left[\frac{1}{C_{t,i}-hC_{t-1,i}}-\frac{\beta h}{C_{t+1,i}-hC_{t,i}}\right]\left[(1-\eta)+\frac{\left(\eta-\alpha^{-1}\right)}{n}\right]=$$
$$=-\frac{\chi L_t^{\varepsilon}\left[\eta-\left(\eta-\alpha^{-1}\right)n^{-1}\right]}{\left(1-\tau_L\right)W_t}. \quad (15)$$

This implies that labor supply is

$$W_t^*=-\upsilon\frac{U_{Lt}}{U_{Ct}}\frac{1}{1-\tau_L} \quad (16)$$

where $\upsilon=\frac{\eta n-\eta+\alpha^{-1}}{(\eta-1)n-\eta+\alpha^{-1}}$ denotes the gross wage markup. Observe that our formulation nests alternative labor market regimes, ranging from perfect competition (n, $\eta\rightarrow\infty$, $\upsilon=1$) to monopolistic competition ($n\rightarrow\infty$, $1<\eta<\infty$, $\upsilon=\eta\left(\eta-1\right)^{-1}$), to strategic wage setting ($1\leq n<\infty, 1<\eta<\infty$).

Moreover, following Blanchard and Galì (2007) and Christoffel and Linzert (2010), we assume that real wages respond sluggishly to labor market conditions. Specifically, we assume the following partial adjustment model:

$$W_t=\left(W_{t-1}\right)^{\kappa}\left(W_t^*\right)^{1-\kappa} \quad (17)$$

where κ is an index of real rigidities. Note that equation (17) is compatible with different theoretical specifications of the labor market. Thus, it permits us to consider the effects of real wage rigidities from a general perspective, i.e., abstracting from their specific sources.[19]

The labor market clearing condition, given (10) and (17) will be influenced by the sluggishness in real wages. Because of the labor market imperfections, in the steady state the ratio between the marginal rate of substitution ($-U_L/U_C$) and the marginal product of labor (MPL) will be different from one, i.e. a *labor wedge* ϑ will arise:

$$MPL=-\vartheta\frac{U_L}{U_C} \quad (18)$$

where $\vartheta\equiv\upsilon\frac{1+\tau_S}{1-\tau_L}$. This wedge is an increasing function of η and n[20] (i.e., the elasticity of substitution of wage-setters' coordination) and of the tax rates (τ_S and τ_L). In other words, the labor wedge reflects, on the one hand, the labor market institutions and the productive structure of the economy and, on the other hand, the taxation and social security system. In our setup, an increase in the gross wage markup or in the tax wedge raises the cost of labor (and real wages) and, *coeteris paribus*, lowers employment.[21]

The parameter ϑ is thus a measure of the (permanent) labor market imperfections, whereas κ measures the (temporary) rigidities in the wage adjustment process, as described above.

[18] We restrict attention to symmetric equilibria where all wage-setters claim the same real wage.

[19] On the different sources of real wage rigidities (including right-to-manage, social norms, matching models) see, among others, Blanchard and Katz (1999), Christoffell *et al.* (2006, 2009), Hall (2005), Hall and Milgrom (2008), Christoffel and Linzert (2010).

[20] For reasonable values of α and η.

[21] Of course, our simplified model does not capture all relevant channels. For instance, the ultimate effects of tax wedges on employment cannot be unambiguously inferred without considering that the labor taxes might be used to finance policies that foster labor supply.

2.3 The financial sector

As already mentioned, the representation of the financial sector is borrowed from Gertler and Karadi (2011) and Gertler and Kiyotaki (2011) . Banks are owned by households. Each period a fraction σ of bankers survives while a fraction $1-\sigma$ exits and is replaced.[22] Each banker's objective is then to maximize the expected discounted present value of its future flows of net worth n_t, that is:

$$V_t = E_t \sum_{i=1}^{\infty} (1-\sigma)\sigma^{i-1} \Lambda_{t,t+i} n_{t+i}. \tag{19}$$

Bankers can either loan the sum of the bank net worth n_t and deposits d_t to firms or divert a fraction θ of this sum to their family. Diverting assets can be profitable for the banker who, afterwards, would default on his debt and shut down, and correspondingly represents a loss for creditors who, at most, could reclaim the fraction $1-\theta$ of assets. As a consequence, depositors would restrict their credit to the banks as they realize that the following incentive constraint must hold for the banks in order to prevent them from diverting funds:

$$V_t(s_t, d_t) \geqslant \theta\,(n_t + d_t) \tag{20}$$

i.e., the value of the bank must always be greater than the amount the banks can divert.

Each period, the value of loans funded, $Q_t\, s_t$, must equal the sum of the bank net worth n_t and deposits d_t:

$$Q_t\, s_t = n_t + d_t \tag{21}$$

where s_t is the volume of loans funded. Recall that the bank's loans can be interpreted as firms' equities owned by the bank.

The net worth for the single bank evolves according to:

$$n_t = \Psi_t[Z_t + (1-\delta)\; Q_t]s_{t-1} - R_t d_{t-1} \tag{22}$$

where Z_t is the dividend payment at t on the loans the bank funded at time $t-1$. It is worth noticing that Ψ_t affects the value of the capital of the non financial firms and, in turn, the value of the equities held by the bank.

The solution of the above dynamic optimization problem implies[23]

$$Q_t\, s_t = \phi_t n_t \tag{23}$$

as

$$\mu_t \equiv \frac{v_{st}}{Q_t} - v_t > 0 \tag{24}$$

$$\phi_t = \frac{v_t}{\theta - \mu_t} \tag{25}$$

where ϕ_t is the leverage ratio of the bank; v_{st} is the marginal value of assets for the banks; and v_t is the marginal value of deposits to the bank at time t.

[22] New bankers are endowed with a fraction $\zeta/(1-\sigma)$ of the value of the assets intermediated by the existing bankers. Indeed, there are different ways to model bankers turnover. See Gertler and Kiyotaki (2011: 10) for a discussion.

[23] See Appendix B for details on the derivation.

As banks are constrained on the retail deposit market, there will be a positive difference between the marginal value and cost of loans for the banks. Moreover, the marginal value of net worth Ω_t and the gross rate of return on bank assets R_{kt} must obey the following conditions:

$$v_t = E_t\,\Lambda_{t,t+1}\Omega_{t+1}R_{t+1} \tag{26}$$

$$\mu_t = E_t\,\Lambda_{t,t+1}\Omega_{t+1}(R_{kt+1} - R_{t+1}) \tag{27}$$

with[24]

$$\Omega_{t+1} = 1 - \sigma + \sigma(v_{t+1} + \phi_{t+1}\mu_{t+1}) \tag{28}$$

$$R_{kt+1} = \Psi_{t+1}\frac{Z_{t+1} + (1-\delta)Q_{t+1}}{Q_t}. \tag{29}$$

It follows that there will always be an excess return of assets over deposits:

$$E_t\,\Lambda_{t,t+1}\Omega_{t+1}R_{kt+1} > E_t\,\Lambda_{t,t+1}\Omega_{t+1}R_{t+1} \tag{30}$$

Aggregating (23) over all banks,[25] we obtain the sector balance sheet and the demand for assets from the banks:

$$Q_t\,S_t = N_t + D_t \tag{31}$$

$$Q_t\,S_t = \phi_t N_t. \tag{32}$$

The overall bank lending capacity depends on the aggregate bank capital which, in turn, may be affected by the changing value of the funded assets.

The aggregate net worth (N_t) evolves according to

$$N_t = (\sigma + \zeta)\,\Psi_t[Z_t + (1-\delta)\,Q_t]S_{t-1} - \sigma R_t D_{t-1.} \tag{33}$$

The above expression is determined by a double aggregation. We compute the aggregate net worth of new and old bankers using (22) twice and then we sum them up. In detail, we know that the new individual bankers are endowed with a fraction $\zeta/(1-\sigma)$ of the value of the asset intermediated by the exiting bankers (i.e., $(1-\sigma)\,[Z_t + (1-\delta)\,Q_t]S_{t-1}$) while the surviving bankers' net worth is equal to $\sigma[Z_t + (1-\delta)\,Q_t]S_{t-1}$.

The securities markets clear when:

$$S_t = I_t + (1-\delta)K_t. \tag{34}$$

This completes the description of the set-up of the model.

2.4 Government

Government expenditure consists in general wasteful spending - defined as an exogenous fraction ($\overline{g}$) of income. On the revenues side, there are proceedings from lump-sum taxes (T_t) and from distortionary taxes (τ_L, τ_S). For simplicity we abstract from public debt issuing, i.e. we assume a continuously balanced government budget as follows:

$$\overline{g}Y_t = T_t + (\tau_L + \tau_S)W_t L_t. \tag{35}$$

[24] The term $\Lambda_{t,t+1}\Omega_{t+1}$ can be thought of as the *augmented stochastic* discount factor since it accounts for the stochastic marginal value of the net worth (Ω_{t+1}).

[25] Aggregate values for financial assets are indicated by capital letters.

2.5 Aggregate Resource Constraint

The resulting economy-wide resource constraint can be derived by considering the households' balance sheet:

$$C_t + T_t = (1-\tau_L) W_t L_t + \Pi_t + R_t D_{ht-1} \tag{36}$$

where the net profit transfer from capital goods producers and financial firms to the households Π_t is defined as:

$$\begin{aligned}\Pi_t \;\; = \;\; & Q_t I_t - f\left(\frac{I_t}{I_{t-1}}\right) I_t - \zeta \left[Z_t + (1-\delta)\ Q_t\right] \Psi_t S_{t-1} + \\ & + (1-\sigma)\left\{\left[Z_t + (1-\delta)\ Q_t\right] \Psi_t S_{t-1} - R_t D_{t-1}\right\},\end{aligned}$$

together with the market clearing conditions, (18), (34), (**??**), and the equilibrium paths for the endogenous variables listed in the next subsection. We obtain that total output is divided between consumption, investment and public consumption, i.e.:

$$C_t = Y_t - I_t \left[1 + f\left(\frac{I_t}{I_{t-1}}\right)\right] - Y_t\, \bar{g}. \tag{37}$$

2.6 Equilibrium and model solution

A competitive equilibrium is a set of plans $\{C_t,\ L_t,\ I_t,\ K_t,\ Q_t,\ Z_t,\ R_{kt},\ R_t,\ N_t,\ W_t,\ D_t,\ S_t,\ v_t,\ \Omega_t,\ \phi_t,\ \mu_t\}$ satisfying the following conditions derived above:[26]

$$
\begin{aligned}
1 &= \beta E_t \frac{U_{Ct+1}}{U_{Ct}} R_{t+1} && (38)\\
L_t &= \left(\frac{(1+\tau_S)\, W_t}{A_t K_t^{\alpha}\,(1-\alpha)}\right)^{-\frac{1}{\alpha}} && (39)\\
Z_t &= \alpha A_t \left(\frac{L_t}{K_t}\right)^{1-\alpha} && (40)\\
Q_t - 1 &= f\left(\frac{I_t}{I_{t-1}}\right) + \frac{I_t}{I_{t-1}} f'\left(\frac{I_t}{I_{t-1}}\right) - E_t \Lambda_{t,t+1} f'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2 && (41)\\
K_{t+1} &= \Psi_{t+1}\left(I_t + K_t\,(1-\delta)\right) && (42)\\
W_t &= (W_{t-1})^{\kappa}\left(-\upsilon E_t \frac{U_{Lt}}{U_{Ct}} \frac{1}{1-\tau_L}\right)^{\kappa-1} && (43)\\
C_t &= A_t K_t^{\alpha} L_t^{1-\alpha}\,(1-\bar{g}) - I_t\left[1 + f\left(\frac{I_t}{I_{t-1}}\right)\right] && (44)\\
\phi_t &= \frac{v_t}{\theta - \mu_t} && (45)\\
v_t &= E_t\, \Lambda_{t,t+1} \Omega_{t+1} R_{t+1} && (46)\\
\mu_t &= E_t\, \Lambda_{t,t+1} \Omega_{t+1} (R_{kt+1} - R_{t+1}) && (47)\\
\Omega_{t+1} &= 1 - \sigma + \sigma(v_{t+1} + \phi_{t+1}\mu_{t+1}) && (48)\\
R_{kt+1} &= \Psi_{t+1} \frac{Z_{t+1} + (1-\delta) Q_{t+1}}{Q_t} && (49)\\
Q_t\, S_t &= N_t + D_t && (50)\\
\phi_t &= \frac{Q_t\, S_t}{N_t} && (51)\\
N_t &= (\sigma + \zeta)\, \Psi_t [Z_t + (1-\delta)\ Q_t] S_{t-1} - \sigma R_t D_{t-1} && (52)\\
S_t &= I_t + (1-\delta) K_t && (53)
\end{aligned}
$$

given the exogenous process $\{\Psi_t\}$ and the economy initial conditions for the endogenous state variables.

In the absence of a closed form solution, the equilibrium conditions are approximated around the deterministic steady state up to the second-order. In particular, the second- order accurate solution is computed via DYNARE (Adjemian *et al.*, 2011) which employs a perturbation solution method.[27]

2.7 Calibration

For most parameters we follow the calibration at a quarterly frequency of Gertler and Kyiotaki (2011) for the US economy. Parameters related to real variables

[26] Note that (44) is obtained aggregating (5) and substituting it into (37); equation (38) derives from (16) and (17); v_{st} can be obtained from (24); U_{Ct} and $\Lambda_{t,t+1}$ have been already defined and $f\,(.)$ will be specified in the next section.

[27] Second-order approximation solution methods are especially recommended for welfare analysis. See below for more details.

are chosen in order to match the regularities of the post World War II period, whereas those related to the financial sectors are selected in order to reflect the magnitude of some phenomena occurred during the 2007 global financial crisis. The discount factor (β) is set at a value consistent with a real interest rate of 4% per year. We set the Frisch labor supply elasticity ($1/\varepsilon$) equal to 2, while the parameter χ of the utility function is chosen so that households devote about one third of their time to paid work in the deterministic steady state, normalizing the total time to one. The habits parameter (h) is set at an intermediate level of 0.5.[28] The depreciation rate (δ) is 0.025 and the capital share (α) is 0.33. We assume that the adjustment cost is

$$f\left(\frac{I_t}{I_{t-1}}\right) = \frac{\gamma}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2$$

which satisfies the properties mentioned in Section 2.2.2 where $1/\gamma$ represents the elasticity of investment to the price of capital, which we set equal to 0.4, in line with Altig *et al.* (2011).[29]

In the labor market, as a benchmark, we set the intra-temporal elasticity of substitution across labor inputs (η) to 6, and a degree of workers' coordination in setting their actions corresponding to $1/n = 0.33$. The wage mark-up is then equal to 1.25. We also consider a tax wedge equal to 1.20. We consider flexible real wages, i.e., $\kappa = 0$, as benchmark, and then compare the baseline case, where real wages do not adjust immediately, to rigid labor markets by introducing different assumptions about κ, ranging 0 from to 0.7.

Regarding the financial sector, we calibrate σ to obtain an average banks survival period of ten years; θ and ζ to meet an economy-wide leverage ratio of about four and an average credit spread of one hundred basis points per year.[30] We finally assume that in the steady state government consumption represents 20% of value added ($\overline{g} = 0.2$).

The values we assign to the structural parameters in the baseline calibration of the model are summarized in Table 1.

[28] As Gertler and Kiyotaki (2011), Christiano *et al.* (2005) consider a value equal to 0.65.

[29] Results are robust with respect to different calibrations. Elasticity of investment to the price of capital ($1/\gamma$) usually ranges between 0.1-0.6. Further simulations are available upon request.

[30] See Gertler and Kiyotaki (2011) for a discussion.

β	0.99	Discount rate
ε	0.5	Inverse Frisch labor supply elasticity
χ	5.584	Relative utility weight of labor
h	0.5	Habits parameter
α	0.33	Effective Capital share
δ	0.025	Depreciation rate
$1/\gamma$	0.4	Elasticity of investment to the price of capital
η	6	Elasticity of substitution across labor inputs
$1/n$	0.33	Union density
$\frac{1+\tau_S}{1-\tau_L}$	1.2	Tax wedge
κ	0	Real wage rigidity
θ	0.383	Fraction of divertable assets
σ	0.972	Survival rate of bankers
$\frac{\zeta}{1-\sigma}$	0.107	Transfer to new entering bankers
$\bar{g}$	0.2	Steady state government consumption
ρ_ψ	0.75	Persistence of the capital quality shock

Table 1 – Baseline parameter values

3 Financial shocks and labor market rigidities

3.1 Simulations

Our main results are described in Figure 1, that shows the impulse responses triggered by a negative financial shock in our economy under different degrees of real wage rigidities.[31] We compare our baseline calibration (flexible real wages, $\kappa = 0$) to an intermediate level of real wage rigidity ($\kappa = 0.4$) and to an economy with a still slower adjustment process for real wages ($\kappa = 0.7$). The latter is in line with the US evidence about real wage rigidities.[32] As in Gertler and Kiyotaki (2011), the financial shock triggers a financial accelerator that implies a fall in the investment activity as well as in the other real variables because of the reduction in the value of the net worth of banks (which entails a rise in the external finance premium) and thus in their capacity of collecting deposits. The fall in investment amplified by the reduction of financial intermediation lead to a marked fall in labor demand and a consequent fall in output and consumption.

[31] The figure displays per cent deviations from the steady state. Output responses are computed from the production function, after aggregation.

[32] See Christoffel and Linzert (2010). In their baseline calibration, Blanchard and Gali (2007) sets it equal to 0.8. For a theoretical discussion and evidence for Europe, see Knell (2013).

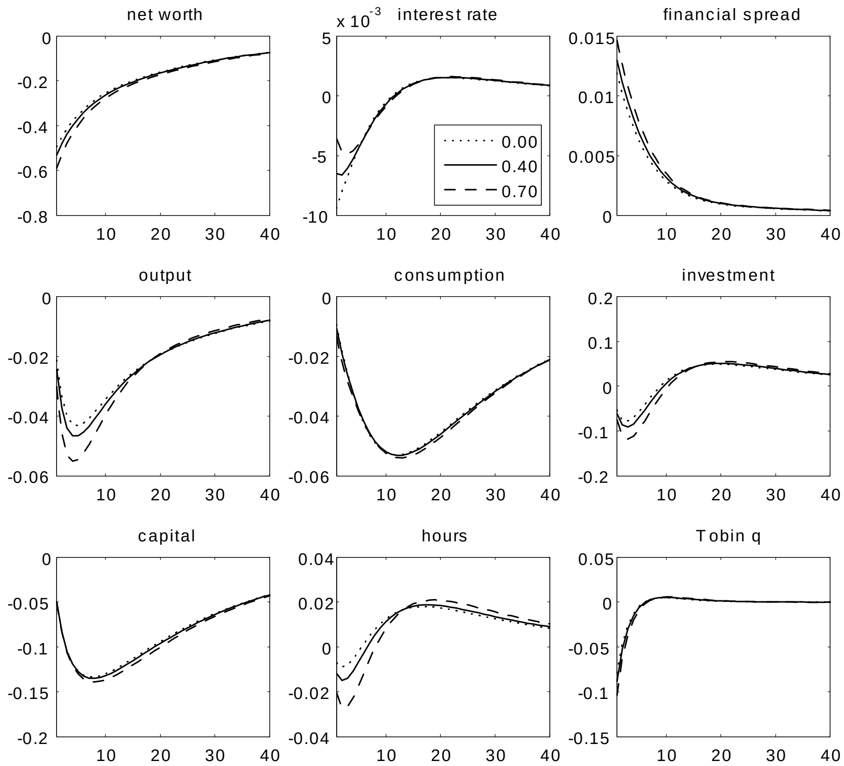

Figure 1 - Financial shock and real wage rigidities

Real wage rigidities clearly amplify the effects of the financial crisis. In particular, they amplify the dynamics of investment, output and hour dynamics. Larger real wage rigidities are associated with both deeper fluctuations and slower recoveries of the variables with respect to their steady state path.[33] In fact, these rigidities interact with financial frictions by affecting the net worth of the banks, thus worsening the reaction of the economy to a negative financial shock. Our result can be intuitively explained as follows: when the quality of capital worsens, the marginal productivity of labor decreases, if the real wage is not free to fall in parallel to this; employment and, therefore, the productivity of capital fall more than when the real wage is flexible. The effect is a marked reduction in the rate of return of capital, which further worsens the banks' balance sheets, leading to a deepening of the credit contraction.

Concerning labor market imperfections, different elasticities of substitution among labor types (η), different degrees of interaction among wage setters (n) and tax rates (τ_S and τ_L) clearly affect the steady state: economies with more imperfections of this type will be characterized by lower levels of capital and labor at the steady state and thus will suffer less the financial shock at the levels. However, they have no impact on the dynamics of the model; in fact,

[33]It is worth noticing that larger welfare losses are associated to larger fluctuations (see, for a discussion, Gertler and Karadi, 2011; Gertler and Kiyotaki, 2011).

impulse reaction functions, reported in Figure 1, are unaffected by changes in the labor wedge. Thus, a sort of neutrality of these labor market institutions with respect to the propagation in the economy of financial disturbances arises. However, although they do not affect the business cycle, all the aforementioned factors clearly reduce the welfare by implying steady state distortions.

Figure 1 shows that real wage rigidities matter for the dynamics of the model. Their quantitative impact is illustrated in Table 2. The table reports the volatilities of output, consumption, investment and hours (rows) for each different degree of wage rigidity (columns).[34] The first column reports the variance (σ^2) of the variables in the baseline case, i.e., no real rigidity ($\kappa = 0$); other columns report variances (σ^2) and per cent differences in variances ($\Delta\sigma^2\%$) with respect to the baseline case ($\kappa = 0$) when $\kappa = 0.4$ and $\kappa = 0.7$.

	baseline	$\kappa = 0.4$		$\kappa = 0.7$	
	σ^2	σ^2	$\Delta\sigma^2$	σ^2	$\Delta\sigma^2$
Output	0.73	0.87	19%	1.21	66%
Consumption	0.67	0.69	3%	0.34	9%
Investment	0.19	0.23	21%	0.73	19%
Hours	0.07	0.08	14%	0.11	57%

Table 2 – 2nd moments[35] and real rigidities

Table 2 shows that the economies characterized by more rigid labor markets experience higher volatilities associated to financial instability and that the differences are not negligible. However, the variability of consumption is rather low, thus it is interesting to evaluate the welfare effects of financial shocks. We notice that in order to mimic the volatility exhibited by macroeconomic variables after the 2007-8 crisis Gertler and Kiyotaki (2011) assume a very high Frisch elasticity (as already said, they set it equal to 10). However introducing - as we do - rigidities in the labor market, such assumption is no longer needed for that purpose.

3.2 Welfare analysis

We compare the welfare effects of a financial shock that are associated to different levels of real wage rigidities, characterized by different volatilities. Again we compare our baseline calibration ($\kappa = 0$) to an intermediate level of real wage rigidity ($\kappa = 0.4$) and to an economy with a still slower adjustment process for real wages ($\kappa = 0.7$).

Welfare is computed as the conditional expectation on the deterministic steady state of the present discounted value of the aggregate lifetime utility to take into account the transitional dynamics.[36] Formally, conditional welfare W_t at a generic time $t = 0$ is defined as the expected lifetime utility conditional on

[34] The table is built by considering 200.000 simulations for each different degree of wage rigidity.

[35] Variances reported are multiplied by 100.

[36] It is quite conventional to choose the deterministic steady state as initial condition of the economy for welfare evaluation purpose (see e.g. Schmitt-Grohé and Uribe, 2004).

the information available at that period, i.e.:

$$W_0 \equiv E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t - hC_{t-1}, L_t\right) \tag{54}$$

where $U\left(C_t - hC_{t-1}, L_t\right)$ is the aggregate counterpart of (1).

In order to find a second-order accurate approximation to $W_{0,}$[37] we take a second-order Taylor expansion of our utility function with respect to its arguments, we obtain the following expression:

$$\begin{aligned} W_0 \quad \approx \quad & \frac{\log(1-h)\overline{C} - \frac{\chi}{1+\varepsilon}\overline{L}^{1+\varepsilon}}{(1-\beta)} + E_0 \sum_{t=o}^{\infty} \beta^t \left[\frac{\widehat{C}_t - h\widehat{C}_{t-1}}{1-h} - \chi \overline{L}^{\varepsilon+1} \widehat{L}_t \right] \quad (55) \\ & + E_0 \sum_{t=o}^{\infty} \beta^t \left[-\frac{\widehat{C}_t{}^2}{2(1-h)^2} - \frac{h^2 \widehat{C}_{t-1}{}^2}{2(1-h)^2} + \frac{h\widehat{C}_t \widehat{C}_{t-1}}{(1-h)^2} - \frac{1}{2}\varepsilon\chi\overline{L}^{\varepsilon+1}\widehat{L}_t^2 \right] \end{aligned}$$

where the first term on the r.h.s. represents the sum of steady-state discounted utilities $U\left(\overline{C}, \overline{L}\right)$, the second and the third terms include the conditional first and second moments of consumption and hours worked, and where $\widehat{C}_t$ and $\widehat{L}_t$ represent the percentage deviations of consumption and labor from the deterministic steady state. Second-order approximations show that the optimal decision of the agents depends both on the level of variables and on the uncertainty of the economy.

The computation of the welfare cost of the business cycle is commonly based on a consumption-equivalent metric (Lucas, 1987). Given a level of welfare under an inefficient scenario, say W_0^R , the welfare cost of that scenario is calculated as the fraction ω_ι of the consumption process necessary under the inefficient regime for the agents to be as well off as under a benchmark scenario.[38]

In formulas, given the definition of the welfare associated to the baseline policy regime, say the scenario without real wage rigidities, i.e.:

$$W_0^A \equiv E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t^A - hC_{t-1}^A, L_t^A\right) \tag{56}$$

where C_t^A and L_t^Adenote the contingent plans for consumption and hours, and given the welfare definition under the regime with RWR as:

$$W_0^R \equiv E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t^R - hC_{t-1}^R, L_t^R\right), \tag{57}$$

the conditional welfare cost (ω_ι) of the real wage rigidities in the economy is implicitly defined by the following:

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t^R - hC_{t-1}^R, L_t^R\right) = E_0 \sum_{t=0}^{\infty} \beta^t U\left(\left(C_t^A - hC_{t-1}^A\right)(1+\omega_\iota), L_t^A\right). \tag{58}$$

[37]Since the contribution by Kim and Kim (2003), it is well-known that first-order-accurate approximation techniques are not suitable to handle utility-based welfare calculations across alternative policy or economic environments.

[38]It is worth stressing that alternative policy regimes can be directly compared because the underlying economies share the same non-stochastic steady state equilibrium that we consider as the initial state for our conditional welfare measures. The consistency of our analysis is hence guaranteed, as we are comparing economies beginning from the same initial point under all possible regimes. (See Schmitt-Grohé and Uribe, 2004).

Given our utility specification (logarithmic in consumption), we obtain the following expression for ω_ι in percentage terms:

$$\omega_\iota = \left\{ \exp\left[(1-\beta)(W_0^R - W_0^A)\right] - 1 \right\} \times 100. \tag{59}$$

Negative values of ω_ι mean that agents must give up a fraction of consumption under the baseline scenario to be equally happy as in the baseline regime with real wage rigidities, so that real wage rigidities are welfare suboptimal.

Besides the overall welfare cost (55), we also keep track of the first and second order components into which the welfare cost can be decomposed: i.e. a first order component due to changes in means of consumption and labor, and a second order component due to the magnitude of fluctuations in labor. In formulas:

$$W_0^{First} = \frac{U\left(\overline{C}, \overline{L}\right)}{(1-\beta)} + E_0 \sum_{t=o}^{\infty} \beta^t \left[(\widehat{C}_t - h\widehat{C}_{t-1}) - \chi \overline{L}^{\varepsilon+1} \widehat{L}_t \right] \tag{60}$$

$$W_0^{Second} = \frac{U\left(\overline{C}, \overline{L}\right)}{(1-\beta)} - E_0 \sum_{t=o}^{\infty} \beta^t \left[\frac{1}{2} \varepsilon \chi \overline{L}^{\varepsilon+1} \right] \widehat{L}_t^2 \tag{61}$$

that can be respectively employed in (59) in order to compute the contribution of the first (ω_ι^{First}) and the second (ω_ι^{Second}) order welfare components.

The welfare analysis allows us to quantitatively asses the cost of real wage rigidities. *Coeteris paribus* we find that higher rigidities are associated with higher losses. In particular, we consider three cases: a) first we compare the welfare associated to a low real wage rigidity ($\kappa = 0.4$) to that obtained when rigidities are absent, i.e.$\kappa = 0$; b) similarly, we consider the cost of a high real wage rigidity ($\kappa = 0.7$); c) finally, we compute the welfare cost associated to the difference between the high and low real wage rigidity simulations. Table 3 displays our results.

	Welfare Cost	First Order Effect	Second Order Effect
Case 1 ($\kappa = 0.4$ vs. $\kappa = 0$)	0.139	0.042	0.097
Case 2 ($\kappa = 0.7$ vs. $\kappa = 0$)	0.494	0.163	0.331
Case 3 ($\kappa = 0.7$ vs. $\kappa = 0.4$)	0.355	0.121	0.234

Table 3 – Welfare analysis cost (values are in per cent)

The table shows that the overall welfare cost in terms of consumption equivalent of the baseline economy amounts to almost 0.14% when $\kappa = 0.4$, and to almost 0.5% when $\kappa = 0.7$. Moreover, comparing the economy with relatively higher rigidities ($\kappa = 0.7$) to the one with less rigidities ($\kappa = 0.4$), we find a welfare cost of 0.35%. The first order effects (ω_ι^{First}) report an efficiency loss which is increasing in the degree of rigidities. Likewise, concerning the second order welfare components, we obtain negative values of ω_ι^{Second}: real wage rigidities cause a variability cost essentially due to a larger employment volatility. Indeed, due to the fact that our utility function is logarithmic in consumption, its second order approximation features only second order terms in hours, so that consumption volatility is irrelevant with respect to the welfare cost measure.[39]

[39] See Appendix D for more details on the algebra of the utility function approximation.

Thus, it is not a higher, though limited, shift in consumption volatility (see Table 2) but, rather, a higher employment variability due to wage rigidities that causes a volatility cost.

The rationale behind such results can be summarized as follows: a relatively higher degree of employment volatility induces the agents to reallocate their time from leisure to work, so that a higher capital accumulation will be experienced in the economy with higher real wage rigidities, compared to the case of less real wage rigidities. However, even if such precautionary behavior will lead to a higher consumption level in the stochastic long-run steady state, the welfare-augmenting effect of such (long-run) benefit is dampened by discounting so that welfare will not vary proportionally to it. By contrast, compared to it, welfare more closely reflects the adverse effect of a rise in hours occurring over the short-run, as this effect is less discounted.

Hence, we conclude that, according to our framework, more volatility entails larger efficiency losses and larger overall welfare losses. However, the quantitative evaluation of these losses show small welfare costs and, therefore, a limited scope for policies designed to mitigate the effects of financial disturbances.

4 Conclusions

By augmenting the recent Gertler and Kiyotaki's (2011) RBC setup with a general formalization of real wage rigidities and other labor market imperfections, this paper has explored the interaction between distortions in labor market institutions and those in the financial sector. Our main contribution has consisted in quantifying the impact of real wage rigidities after a financial shock in terms of both fluctuation amplification and the welfare cost associated to those amplifications.

First, we have found that real wage rigidities matter, as they amplify the effects of financial imperfections, whereas labor market imperfections determining the labor wedge – deriving from labor taxes, workers' monopoly power and/or strategic interactions among wage setters – do not. We have shown that real wage rigidities can help the Gertler and Kiyotaki (2011) model to better match business cycle moments – without resorting to an ad-hoc calibration of the labor supply compensated elasticity as they do – as labor market frictions have a significant qualitative effect in increasing the business cycle volatilities.

Second, as is well known that large fluctuations do not necessarily correspond to large welfare costs, we have performed a welfare analysis. We have found that, in the aftermath of a financial crisis, additional costs induced by a relatively more rigid economy, though limited, are non negligible. Moreover, by decomposing the welfare cost measure in its first and second-order components, we have found that the cost associated to the augmented uncertainty in the economy (i.e. to second-order welfare effects) is only due to the increased employment volatility, reflecting the precautionary behavior of the agents that reallocate their choices from leisure to work.

We conclude that, in our framework, real wage rigidities exacerbate the effects of a financial crisis and are welfare-diminishing. However, given the limited size of the implied welfare losses, they can be considered a minor policy problem, at least if we abstract from prices and nominal wage stickiness as we do in the present framework.

Appendix A – Unions' problem

Each union j sets the wage $W_{t,j}$ of the agent $i \in j$, (i.e., $W_{t,i} = W_{t,j}$ if $i \in j$) so as to maximize its utility in (1), subject to the budget constraint (2), and the constraints (8), (7) and (9). Using the last two equations we can write $L_{t,i} = \left(\frac{W_t(i)}{W_t}\right)^{-\eta}\left(\frac{1+\tau_s}{A_t K_t^\alpha (1-\alpha)} W_t\right)^{-\frac{1}{\alpha}}$. Substituting this expression for $L_{t,i}$ in (1) and (2), we see that choosing $W_{t,j}$ so as to equalize in expectation the marginal cost and the marginal benefit of working implies maximizing w.r.t. $W_{t,j}$ the following expected value:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[-\frac{\chi}{1+\varepsilon} W_{t,j}^{-\eta(1+\varepsilon)} W_t^{\left(\eta - \frac{1}{\alpha}\right)(1+\varepsilon)} (1+\tau_s)^{-\frac{1+\varepsilon}{\alpha}} \left[A_t K_t^\alpha (1-\alpha)\right]^{\frac{1+\varepsilon}{\alpha}} + \right.$$
$$\left. U_{Ct} (1+\tau_s)^{-\frac{1}{\alpha}} (1-\tau_l) W_t^{\eta - \frac{1}{\alpha}} W_{t,j}^{1-\eta} \left(A_t K_t^\alpha (1-\alpha)\right)^{\frac{1}{\alpha}} \right]$$

given (8). Equating to zero the derivative of this expected value w.r.t. $W_{t,j}$,using (14) we find:

$$-\frac{\chi \left[A_t K_t^\alpha (1-\alpha)\right]^{\frac{1+\varepsilon}{\alpha}}}{(1+\tau_s)^{\frac{1+\varepsilon}{\alpha}}} \left[-\eta W_{t,j}^{-\eta(1+\varepsilon)-1} W_t^{\left(\eta-\frac{1}{\alpha}\right)(1+\varepsilon)} + \right.$$
$$\left. + \left(\eta - \frac{1}{\alpha}\right) \frac{W_{t,j}^{-\eta(1+\varepsilon)} W_t^{\left(\eta-\frac{1}{\alpha}\right)(1+\varepsilon)-1}}{n} \left(\frac{W_t}{W_{t,j}}\right)^{-\eta} \right] +$$
$$\frac{U_{Ct} \left(A_t K_t^\alpha (1-\alpha)\right)^{\frac{1}{\alpha}} (1-\tau_l)}{(1+\tau_s)^{\frac{1}{\alpha}}} \left[(1-\eta) W_{t,j}^{-\eta} W_t^{\eta-1/\alpha} + \right.$$
$$\left. + \left(\eta - \frac{1}{\alpha}\right) \frac{W_{t,j}^{1-\eta} W_t^{\eta-1/\alpha-1}}{n} \left(\frac{W_t}{W_{t,j}}\right)^{-\eta} \right] = 0.$$

In a symmetric equilibrium $\frac{W_t}{W_{t,j}} = 1$, so after some simplifying we can write this as:

$$\chi \left[A_t K_t^\alpha (1-\alpha)\right]^{\frac{\varepsilon}{\alpha}} (1+\tau_s)^{-\frac{\varepsilon}{\alpha}} \left[\eta W_t^{-\frac{\varepsilon}{\alpha}-1} - \frac{\eta - \alpha^{-1}}{n} W_t^{-\frac{\varepsilon}{\alpha}-1} \right] +$$
$$+ U_{Ct}(1-\tau_l) \left[(1-\eta) + \frac{\eta - \alpha^{-1}}{n} \right] = 0$$

or using again (9) to eliminate $A_t K_t^\alpha (1-\alpha) = (1+\tau_S) W_t L_t^\alpha$ and simplifying:

$$\chi W_t^{-1} L_t^\varepsilon \left(\eta - \frac{\eta - \alpha^{-1}}{n} \right) + (1-\tau_l) U_{Ct} \left((1-\eta) + \frac{\eta - \alpha^{-1}}{n} \right) = 0.$$

This, recalling (4), gives us (15) in the text.

Appendix B – Financial sector appendix

B1 – Banker's maximization problem

The objective of the bank at the end of period $t-1$ is the expected present value of future dividends, as follows:

$$V_{t-1}(s_{t-1}, d_{t-1}) = E_{t-1}\sum_{i=1}^{\infty}(1-\sigma)\sigma^{i-1}\Lambda_{t,t-1+i}n_{t-1+i}. \tag{62}$$

Given the (sequence of) balance sheets constraints:

$$Q_{t-1}s_{t-1} - n_{t-1} = d_{t-1} \tag{63}$$

we can formulate the following Bellman equation:

$$V_{t-1}(s_{t-1}, d_{t-1}) = E_{t-1}\Lambda_{t-1,t}\{(1-\sigma)n_t + \sigma[\underset{s_t,d_t}{Max} V_t(s_t, d_t)]\}. \tag{64}$$

The net worth at t, n_t, i.e. the gross payoff from assets funded at $t-1$, net of borrowing costs, evolves according to

$$n_t = \psi_t[Z_t + (1-\delta)\ Q_t]s_{t-1} - R_t d_{t-1}. \tag{65}$$

By combining (63) and (65), we can then write:

$$Q_t s_t - d_t = d_{t-1} = \psi_t[Z_t + (1-\delta)\ Q_t]s_{t-1} - R_t d_{t-1}. \tag{66}$$

Given the incentive constraint stemming from the agency problem:

$$V_{t-1}(s_{t-1}, d_{t-1}) \geqslant \theta Q_{t-1}s_{t-1}, \tag{67}$$

to solve the maximization problem of the banker we define the Lagrangian L:

$$L = E_{t-1}\Lambda_{t-1,t}[((1-\sigma)\psi_t[Z_t + (1-\delta)\ Q_t]s_{t-1} - R_t d_{t-1}) + \\ + \sigma\{V_t(s_t, d_t) + \lambda_t[V_t(s_t, d_t) - \theta Q_t s_t]\}]. \tag{68}$$

This has to be maximized given the constraint (66).To do so we formulate the following guess for the value function:

$$V_t(s_t, d_t) = v_{st}s_t - v_t d_t. \tag{69}$$

The derivative of (68) with respect to d_t (of which s_t is a function, given (66)) must equal zero, for an interior solution. This gives us, by using (66) to calculate the derivative of s_t with respect to d_t, the following condition:

$$E_{t-1}\Lambda_{t-1,t}\left(-\lambda_t\theta - \frac{\partial V_t(s_t, d_t)}{\partial d_t}(1+\lambda_t)\right) = 0 \tag{70}$$

or, assuming (69):

$$-\theta\lambda_t + v_t(1+\lambda_t) = 0. \tag{71}$$

The constraint (67) can be written, using (69), as $v_{st}s_t - v_t d_t \geq \theta Q_t s_t$ and, by (by using (63)):

$$v_t n_t \geq Q_t s_t\left(\theta + v_t - \frac{v_{st}}{Q_t}\right) \tag{72}$$

so assuming this constraint holds as an equality we deduce: $V_t(s_t, d_t) = v_{st}s_t - v_t\left(Q_t s_t - n_t\right) = \frac{(v_{st}-v_tQ_t)v_tn_t}{Q_t\left(\theta+v_t-\frac{v_{st}}{Q_t}\right)} + v_tn_t$. Hence:

$$V_t(s_t, d_t) = v_tn_t\left(\frac{\mu_t}{\theta-\mu_t}+1\right) \tag{73}$$

where $\mu_t = \frac{v_{s_t}}{Q_t} - v_t > 0$.

If we define:

$$\phi_t \equiv \frac{v_t}{\theta-\mu_t} \tag{74}$$

it follows that

$$V_t(s_t, d_t) = n_t\left(\mu_t\phi_t + v_t\right). \tag{75}$$

By substituting the above expression (75) for $V_t(s_t, d_t)$ in (64), we have:

$$V_t(s_t, d_t) = E_t\Lambda_{t+1,t}\left[(1-\sigma)n_{t+1} + \sigma n_{t+1}\left(\mu_{t+1}\phi_{t+1} + v_{t+1}\right)\right]$$

or

$$V_t(s_t, d_t) = E_t\Lambda_{t,t+1}\Omega_{t+1}n_{t+1} \tag{76}$$

where

$$\Omega_{t+1} = (1-\sigma) + \sigma\left(\mu_{t+1}\phi_{t+1} + v_{t+1}\right) \tag{77}$$

and using (65):

$$V_t(s_t, d_t) = E_t\Lambda_{t,t+1}\Omega_{t+1}\left(\psi_{t+1}[Z_{t+1} + (1-\delta)\ Q_{t+1}]s_t - R_{t+1}d_t\right). \tag{78}$$

So by the method of undetermined coefficients it follows that:

$$v_t = E_t\Lambda_{t,t+1}\Omega_{t+1}R_{t+1} \tag{79}$$

and

$$v_{st} = E_t\Lambda_{t,t+1}\Omega_{t+1}\left\{\psi_{t+1}[Z_{t+1} + (1-\delta)\ Q_{t+1}]\right\}. \tag{80}$$

B2 – Assets demand

We can rewrite (72), given (24), as:

$$\left(\theta-\mu_t\right)Q_ts_t = v_tn_t. \tag{81}$$

The individual bank total demand for assets $Q_t\, s_t$ can then be written, using (24) as:

$$Q_t\, s_t = \phi_tn_t \tag{82}$$

which, at the aggregate level, turns out to be:

$$Q_t\, S_t = \phi_tN_t. \tag{83}$$

Appendix C – Steady state

In the steady state the model is defined by the following two blocks of equations. Concerning the real part of the economy, from equations (38)-(44), we have:

$$R = \frac{1}{\beta} \tag{84}$$

$$L = \left(\frac{1+\tau_S}{AK^{\alpha}(1-\alpha)}W\right)^{-\frac{1}{\alpha}} \tag{85}$$

$$Z = \alpha A\left(\frac{L}{K}\right)^{1-\alpha} \tag{86}$$

$$Q = 1 \tag{87}$$

$$I = \delta K \tag{88}$$

$$W = \frac{\upsilon\chi L^{\varepsilon}}{1-\tau_L}\frac{(1-h)C}{1-\beta h} \tag{89}$$

$$C = \left[(1-\bar{g})A\left(\frac{L}{K}\right)^{1-\alpha} - \delta\right]K \tag{90}$$

Concerning the financial sector of the economy, from equations (45)-(53), we have:

$$\phi = \frac{v}{\theta-\mu} \tag{91}$$

$$v = \Omega \tag{92}$$

$$\mu = \Omega(\beta R_k - 1) \tag{93}$$

$$\Omega = 1-\sigma+\sigma(v+\phi\mu) \tag{94}$$

$$R_k = Z+(1-\delta) \tag{95}$$

$$S = N+D \tag{96}$$

$$\phi = S/N \tag{97}$$

$$N = (\sigma+\zeta)[Z+(1-\delta)]S-(\sigma/\beta)D \tag{98}$$

$$S = K \tag{99}$$

Some cumbersome algebra is then requested to obtain the steady state.

By using equations (93), (92), (91), one obtains:

$$\phi = \frac{\Omega}{\theta-\Omega(\beta R_k-1)} \tag{100}$$

which substituted in (94) yields:

$$\Omega = 1-\sigma+\frac{\sigma\Omega\theta}{\theta-\Omega(\beta R_k-1)}. \tag{101}$$

Combining (84), (95), (96) and (98) gives:

$$N = \frac{(\sigma+\zeta)R_k-(\sigma/\beta)}{1-(\sigma+\zeta)R_k}D$$

which solved for D and substituted in (96), given (99), after rearranging yields:

$$K = \left[1 + \frac{1 - (\sigma + \zeta) R_k}{(\sigma + \zeta) R_k - \sigma/\beta}\right] N \tag{102}$$

that combined with (97) and (99) yields:

$$\phi = 1 + \frac{1 - (\sigma + \zeta) R_k}{(\sigma + \zeta) R_k - \sigma/\beta}. \tag{103}$$

By combining (100) and (103), we get the following expression for R_k:

$$R_k = \frac{\beta\Omega + \theta(\beta - \sigma)}{(\zeta + \beta) \Omega\beta}. \tag{104}$$

Equations (101) and (104) are a two equation system in two unknowns, Ω and R_k. The solution of the system clearly gives the steady state values for these two variables.

By substituting (104) into (101), one obtains the following second order polynomial equation in Ω:

$$\zeta\Omega^2 + [\zeta(\theta - 1)(1 - \sigma)\theta\sigma(1 - \beta)]\Omega - (1 - \sigma)(\zeta + \sigma)\theta = 0 \tag{105}$$

whose positive solution is chosen and substituted in (104) to obtain R_k. Once system (101) and (104) is solved, the steady-state values for μ, ϕ, v are obtained straightforwardly.

Finally, by combining (89), (85), (90), and using (86) and (95), after cumbersome algebra, we get the expression for L only in terms of R_k:

$$L = \left(\frac{(1 - \tau_L)(1 - \alpha)\left(\frac{R_k - 1 + \delta}{\alpha}\right)\frac{1 - \beta\gamma}{1 - \gamma}}{\upsilon(1 + \tau_S)\chi\left[(1 - \bar{g})\frac{R_k - 1 + \delta}{\alpha} - \delta\right]}\right)^{\frac{1}{1+\varepsilon}}. \tag{106}$$

Combining (86) and (95), and using the steady-state values for L and R_k, K is also obtained. Other steady-state values (S, I, C, W, D, N, Z) are then easily found recursively.

Appendix D – Second-order approximation of the utility function

A second-order Taylor expansion to the utility function is needed in order to calculate the welfare associated to each policy rule considered. In particular we take a second-order Taylor expansion of $U(C_t - hC_{t-1}, L_t)$, with respect to its arguments around the deterministic steady-state values $\left(\overline{C}, \overline{L}\right)$ and express it in algebraic percent deviations ($\widehat{C}_t - h\widehat{C}_{t-1}$, $\widehat{L}_t$):

$$\begin{aligned} U(C_t, L_t) \quad \approx \quad & \overline{U}(\overline{C}, \overline{L}) + \left[U_C(\overline{C}, \overline{L})\ \overline{C}\right]\ (\widehat{C}_t - h\widehat{C}_{t-1}) + \left[U_L(\overline{C}, \overline{L})\ \overline{L}\ \right] \widehat{L}_t + \\ & + \frac{1}{2}\left\{\left[U_{CC}(\overline{C}, \overline{L})\ \overline{C}^2\right](\widehat{C}_t - h\widehat{C}_{t-1})^2 + 2\left[U_{CL}(\overline{C}, \overline{L})\ \overline{CL}\right](\widehat{C}_t - h\widehat{C}_{t-1})\widehat{L}_t + \right. \\ & \left. + \left[U_{LL}(\overline{C}, \overline{L})\ \overline{L}^2\right]\widehat{L}_t{}^2\right\}. \end{aligned} \tag{D.1}$$

Given the functional form of our utility, this formula is reduced to the following:

$$U(C_t,L_t) \approx U\left(\overline{C},\overline{L}\right) + (\widehat{C}_t - h\widehat{C}_{t-1}) - \chi\overline{L}^{\varepsilon+1}\widehat{L}_t - \frac{1}{2}\varepsilon\chi\overline{L}^{\varepsilon+1}\widehat{L}_t^2 \qquad \text{(D.2)}$$

which is employed in (55). It is worth noticing that, due to separability in consumption and labor, the fifth term in (D.1) is dropped in the last equation. Besides, due to the fact that utility is logarithmic in consumption, the variability of consumption does not directly influence lifetime utility so that also the fourth term in (D.1) disappears in the approximation of our utility function and only squared percent deviation in hours are retained.

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