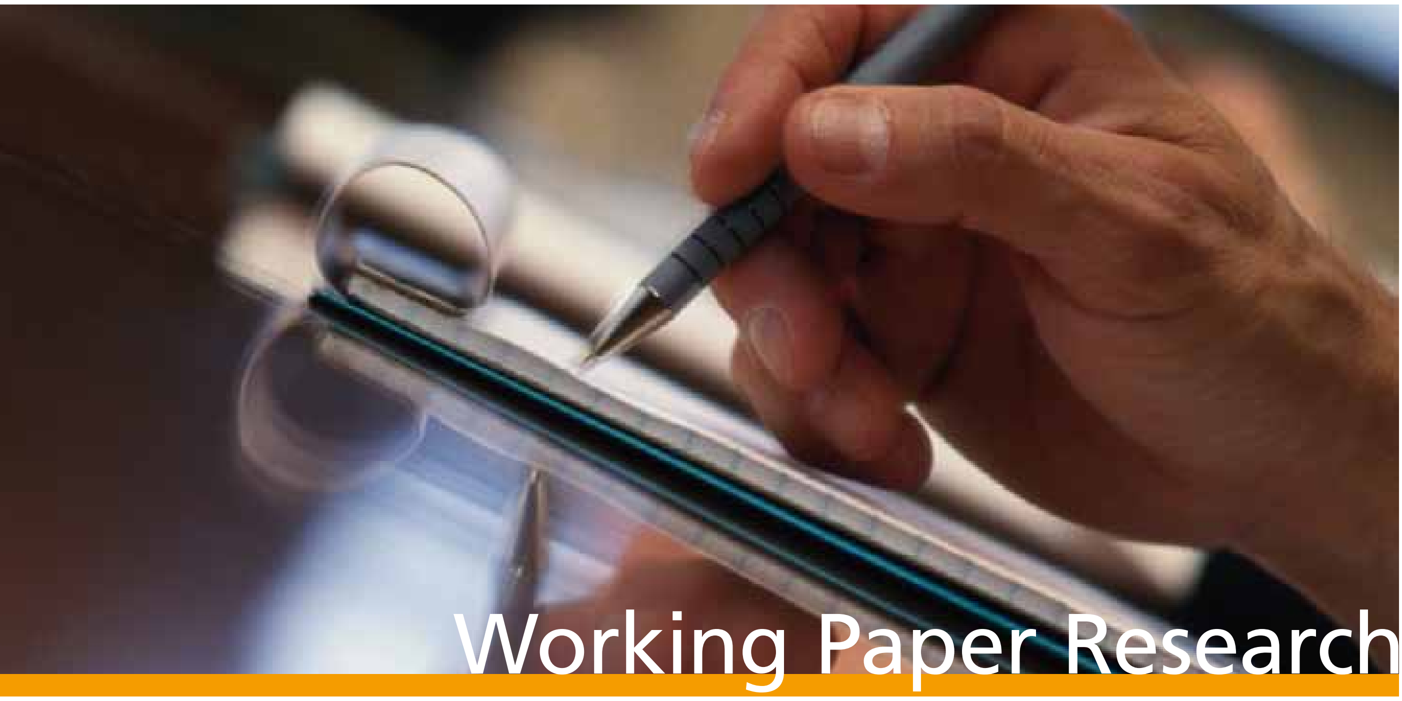
The Taylor principle and (in-)determinacy in a New Keynesian model with hiring frictions and skill loss



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Abstract

We introduce skill decay during unemployment into Blanchard and Gali's (2008) New-Keynesian model with hiring frictions and real-wage rigidity. Plausible values of quarterly skill decay and real-wage rigidity turn the long-run marginal cost-unemployment relationship positive in a "European" labour market with little hiring but not in a fluid "American" one. If the marginal cost-unemployment relationship is positive, determinacy requires a passive response to inflation in the central bank's interest feedback rule if the rule features only inflation. Targeting steady state output or unemployment helps to restore determinacy.

Under indeterminacy, an adverse sunspot shock increases unemployment extremely persistently.

Key Words: E24, E52, E32, J64.

JEL Classification: Monetary policy rules, Taylor principle, Determinacy, Hysteresis, Skill decay.

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1 Introduction

The Taylor principle states that, in response to an increase in inflation, the central bank should eventually increase the nominal interest rate more than one for one. The conventional wisdom in monetary economics says that, to ensure a unique and stable equilibrium, monetary policy should follow the Taylor principle. We show that an active monetary policy may instead induce indeterminacy if unemployed workers lose a fraction of their skills per quarter of unemployment, the real wage responds only imperfectly to changes in the worker's skill level, and labour market flows are low.

The framework we develop adds skill decay during unemployment along the lines of Pissarides (1992) to the New Keynesian model with hiring frictions and real-wage rigidity of Blanchard and Gali (2008). In this environment, the marginal cost-unemployment relationship turns from negative to positive if quarterly skill decay and real-wage rigidity are sufficiently high. Plausible values of quarterly skill decay and real-wage rigidity generate a positive long-run marginal cost-unemployment relationship if the job finding probability is calibrated to the OECD-European median. This change in sign affects the determinacy requirements on the interest feedback rule of the central bank: A positive long- run marginal cost-unemployment relationship almost always requires a coefficient on inflation less than unity if the central bank responds only to inflation. This does not depend on whether the central bank responds to current, expected future, or lagged inflation. The reason appears to be that with a positive long-run marginal cost-unemployment relationship, a persistent increase in unemployment will ultimately increase marginal cost and thus inflation. If the central bank responds more than one-for-one to inflation, this would increase the real interest rate, subsequently lowering demand and thus validating the increase in unemployment: Hence there is a self-fulfilling prophecy. The response of the economy to an adverse sunspot shock confirms this intuition.

By contrast, for a high "American" calibration of the job-finding probability, the long-run marginal cost-unemployment relationship never becomes negative for plausible values of skill decay even if the real wage is perfectly rigid. Correspondingly, a coefficient on inflation larger than one guarantees determinacy.

Furthermore, adding the output gap to the policy rule solves the determinacy problem under the "European" calibration if the central bank targets steady state output. Adding unemployment has a similar effect. By contrast, targeting flexible price output decreases the determinacy region further if skill decay and real- wage rigidity are such that the long-run marginal cost-unemployment relationship is positive.

Our results extend an evolving literature arguing that an active monetary policy may induce indeterminacy if the interest rate set by the central bank has some indirect or direct effect on marginal cost. Such a channel may arise because the interest rate affects capital accumulation, job creation in models with matching frictions, or the cost of working capital needed to fund the wage bill. In such environments, some upper bound on the inflation coefficient in the interest feedback rule is frequently necessary to ensure determinacy if the central bank responds only to expected inflation, while responding to current inflation is still stabilising.[1] A notable exception is Christiano et al. (2010), who find that under reasonable calibrations, even an active response to current inflation induces indeterminacy if firms use

[1] Examples are Kurozumi and van Zandweghe (2008a), Carlstrom and Fuerst (2005) and Duffy and Xiao (2008) for models with capital, Kurozumi and van Zandweghe (2008b) who consider a sticky price matching model, and Surico (2008) and Llosa and Tuesta (2009) for models with Ravenna and Walsh (2006)-type working capital.

their own final output as an input and have to borrow to pay in advance a fraction of their cost of labour and materials. However, the typical finding in the literature is that the determinacy problem is caused by the timing subscript of inflation in the interest feedback rule but not by the active response to inflation per se. By contrast, in the model developed below, it is the Taylor principle itself—the idea that an increase in inflation should sooner or later cause an increase in the real interest rate—which creates scope for self-fulfilling prophecies.

The remainder of the paper is structured as follows. Section 2 derives the model. Section 3 shows how the long-run effect of a permanent increase in unemployment on marginal cost is affected by the introduction of skill decay. Section 4 explores the conditions for determinacy and how they are affected by skill decay. Section 5 discusses the response of the model under the European calibration to an adverse sunspot shock. Section 6 concludes.

2 The Model

2.1 Households

The economy is populated by a continuum of infinitely lived households. A household consists of a continuum of members who may be employed or unemployed but are all allocated the same level of consumption. The households period t income derives from total wage payments WP_t earned by the employed members, nominal interest payments i_{t-1} on holdings of a nominal risk-less bond, and firms' profits F_t. It allocates its income to buying a CES basket of consumption goods C_t and the risk-less bond B_t to maximise

$$E_t \sum_{t=0}^{\infty} \log C_t$$

subject to the budget constraint

$$WP_t + \frac{B_{t-1}}{P_t}(1 + i_{t-1}) + F_t \geq C_t + \frac{B_t}{P_t}$$

where P_t and N_t denote the price level of the CES basket and hours worked by the members of the household, respectively.

2.2 Firms

There are two types of firms. Final goods firms indexed by i produce the varieties in the CES basket of goods consumed by households. They use the intermediate good $X_t(i)$ in the linear technology

$$Y_t(i) = X_t(i)$$

The demand curve for variety i resulting from the household spreading its expenditures across varieties in a cost minimising way is given by $c_t(i) = C_t \left(\frac{p_t(i)}{P_t}\right)^{-\theta}$, where $c_t(i)$, $p_t(i)$ and P_t denote consumption and price of variety i and the price level of the consumption basket, respectively. Final goods firms face nominal rigidities in the form of Calvo (1983) contracts, i.e. only a randomly chosen fraction $1-\omega$ of firms can re-optimise its price in a given period.

They accordingly maximise

$$E_t\left[\sum_{i=0}^{\infty}(\omega\beta)^i\frac{C_t}{C_{t+i}}C_{t+i}\left[\left(\frac{p_t(j)}{P_{t+i}}\right)^{1-\theta}-mc_{t+i}\left(\frac{p_t(j)}{P_{t+i}}\right)^{-\theta}\right]\right]$$

where mc_t denotes real marginal costs. The price level evolves according to $P_t^{1-\theta}=(1-\omega)\left(p_t^*(j)\right)^{1-\theta}+\omega\left(P_{t-1}\right)^{1-\theta}$, where $p_t^*(j)$ denotes the price set by those firms allowed to reset their price in period t.

The intermediate goods firms employ labour to produce intermediate goods $X_t(j)$. Intermediate goods firms operate under perfect competition and are owned by households. A fixed fraction δ of jobs is destroyed each period. Thus employment of firm j evolves according to $N_t(j)=(1-\delta)N_{t-1}(j)+H_t(j)$ where $H_t(j)$ denotes the amount of hiring in firm j. Aggregate hiring is accordingly given by

$$H_t=N_t-(1-\delta)N_{t-1} \tag{1}$$

Note that the lower is δ, the more H_t will depend on the change as opposed to the level of employment. The number of job seekers at the beginning of the period is defined as U_t. U_t consists of those workers who did not find a job at the end of period $t-1$ and those whose jobs were destroyed at the beginning of t:

$$U_t=1-N_{t-1}+\delta N_{t-1}=1-(1-\delta)N_{t-1} \tag{2}$$

As in Blanchard and Gali (2008), we assume that every hire generates a cost G_t which is proportional to the productivity of a newly hired worker

$$G_t = A_t B' x_t^{\alpha} \tag{3}$$

where A_t denotes the average productivity of newly hired workers, to be defined below, B' is a constant, and x_t denotes labour market tightness, defined as the ratio between aggregate hiring H_t and U_t:

$$x_t = \frac{H_t}{U_t} \tag{4}$$

The intuition behind (3) is that if hiring is high relative to the number of job seekers, it takes on average longer to fill a vacancy. Since posting a vacancy is costly, hiring costs increase in x_t.[2] We interpret labour-market tightness x_t as the probability of an unemployed person to move into employment in period t.

Following Pissarides (1992), we assume that the productivity of a newly hired worker is the product of exogenous technology A_t^P and his skill level. An unemployed worker loses a fraction $\delta_s \in [0,1]$ of his skill per quarter of his unemployment spell. Hence the skill level of a worker with unemployment spell i is denoted by β_s^i, where $\beta_s = 1 - \delta_s$ and $\delta_s \in [0,1]$. i equals zero if the newly hired worker lost his previous job in period t, one if he lost his job in period $t-1$, and so on. Thus the productivity of a worker with unemployment duration i is given by $A_t^P \beta_s^i$.

We assume further, following Pissarides (1992), that the unemployed regain all their skills after one quarter of employment, that when intermediate goods firms make the decision

[2] Hence equation (3) can be viewed as a short cut to a model which would specify a matching function and thus allow to derive the expected time necessary to fill a vacancy and hence the expected cost of filling a vacancy. See Blanchard and Gali (2008), p. 8.

whether to hire or not and thus pay the hiring cost G_t, they know the state of exogenous technology A_t^P but not the type of worker with whom they are going to be matched and that they meet workers according to the share of these workers among job seekers.[3] Furthermore, for simplicity, we assume that a firm does not hire individual workers, but only a group of workers sufficiently large for the distribution of skills in the group to match the distribution of skills in the job seeking population U_t. This ensures that the average skill level of the group hired by the firm equals the average skill level in the job seeking population.[4]

We denote the average skill level in the job seeking population as A_t^L, implying that the average productivity of newly hired workers is given by

$$A_t = A_t^P A_t^L \tag{5}$$

while A_t^L is given by

$$A_t^L = \sum_{i=0}^{\infty} \beta_s^i s_t^i \tag{6}$$

where s_t^i denotes the share of those unemployed i periods among job seekers. Note that $A_t^L < 1$ if $\delta_s > 0$ while for $\delta_s = 0$, we have $\beta_s = A_t^L = 1$. The shares of the various types of workers among the total number of job seekers U_t is denoted as s_t^i, and is defined by

$$s_t^i = \frac{\delta N_{t-i-1} \prod_{j=1}^{i} (1 - x_{t-j})}{U_t} \tag{7}$$

Note that δN_{t-i-1} represents all those workers who had a job in period $t-i-1$ but lost it

[3]See Pissarides (1992), pp. 1371-1391.

[4]This assumption rules out the possibility that, after paying the hiring cost, a firm meets an individual worker which it might not want to hire because due to skill decay, his productivity is too low relative to the wage it has to pay him. The subsequent analysis will be substantially simplified by this assumption.

in period $t-i$, while $\prod_{j=1}^{i}(1-x_{t-j})$ represents the fraction of those workers laid off in period $t-i$ who are still unemployed at the end of period $t-1$. Hence the numerator consists of all workers laid off in period $t-i$ and still unemployed in period $t-1$.

As in Blanchard and Gali (2008), who in turn follow the seminal contribution of Hall (2005), we assume that the real wage of a worker is rigid. The wage W_t^i of a worker who has been unemployed for i periods is given by $W_t^i = \Theta' \left(\beta_s^i\right)^{1-\gamma} \left(A_t^P\right)^{1-\gamma_P}$, with $0 \leq \gamma \leq 1$ and $0 \leq \gamma_P \leq 1$. Hence for $\gamma > 0$ or $\gamma_P > 0$ an increase in the worker's skill level or an increase in technology will cause a less-than-proportional increase in his real wage. While the degree of real-wage rigidity with respect to technology γ_P does not actually matter for the determinacy results which are the subject of this paper, the degree of rigidity with respect to the workers skill level γ will have an effect. By assumption, Hall's (2005) "fixed wage rule", as well as Blanchard and Gali's real wage schedule, lies always inside the bargaining set. This implies that it neither prevents the formation of matches with a positive surplus nor results in inefficient separations.[5] Under our assumption that firms are restricted to hiring a representative sample of job seekers, this condition is satisfied in our model as well.

Hall (2005) interprets his constant wage rule as a social norm along the lines of Bewley (1998,1999), who forms part of a growing literature arguing that employers are reluctant to lower real wages and, what is more, to pay lower wages to newly hired employees than to their existing workforce because doing so would hurt morale and thus productivity.[6] Hence the evidence suggests that employers will likely not adjust the wage of a new hire in full

[5] See Hall (2005), p.56.

[6] See Fabiani et al. (2010), pp. 501-502 and Galuščák et al. (2010), p. 11-12. Similar survey results are obtained by Agell and Lundborg (2003) in a survey of 157 Swedish manufacturing firms and by Fehr and Falk (1999) from an experiment.

proportion to the loss in productivity induced by his unemployment duration, i.e. γ will be positive. We will consider a wide range of values for this parameter in section 4.

The average real wage of the group the firm hires is given by

$$W_t = \Theta' \left(\sum_{i=0}^{\infty} \beta_s^{i(1-\gamma)} s_t^i \right) \left(A_t^P \right)^{1-\gamma_P} \tag{8}$$

Θ' is backed out to support a desired steady state combination of x, δ and N.This is shown in appendix A. For future reference, we denote the skill dependent part of the average real wage as

$$W_t^L = \left(\sum_{i=0}^{\infty} \beta_s^{i(1-\gamma)} s_t^i \right) \tag{9}$$

The intermediate goods firms will hire additional groups until the hiring cost of an additional group equals the present discounted value of the profits generated by this group. However, unlike in the Blanchard and Gali model, we have to take into account the fact that the skill level of the workforce hired in period t as well as their wage change in period $t+1$. This change arises because all hired workers who remain employed upgrade to the full skill level after one quarter. Thus we have

$$G_t = \frac{P_t^I}{P_t} A_t^P A_t^L - W_t + E_t \left[\sum_{i=1}^{\infty} (1-\delta)^i \beta^i \frac{u_C(C_{t+i})}{u_C(C_t)} \left(\frac{P_{t+i}^I}{P_{t+i}} A_{t+i}^P - W_{t+i}^0 \right) \right]$$

where $\frac{P_t^I}{P_t}$ denotes the real price of intermediate goods while $\beta^i \frac{u_C(C_{t+i})}{u_C(C_t)}$ denotes the stochastic discount factor of the representative household.

The terms $\frac{P_t^I}{P_t} A_t^P A_t^L - W_t$ and $E_t \left[\sum_{i=1}^{\infty} (1-\delta)^i \beta^i \frac{u_C(C_{t+i})}{u_C(C_t)} \left(\frac{P_{t+i}^I}{P_{t+i}} A_{t+i}^P - W_{t+i}^0 \right) \right]$ represent the flow profit generated in period t (when the group has just been hired) and the present discounted value of profits generated in period $t+1$ and after, respectively. Note that due to our assumption that a worker regains all his skills after one period, the expression for the flow profit in period t is different from the expression for the flow profit in period $t+1$ and after. Rewriting this equation as a difference equation, noting that the real price of intermediate goods firms equals the marginal cost of final goods firms (hence $\frac{P_t^I}{P_t} = mc_t$) and that with log utility, $\frac{u_C(C_{t+i})}{u_C(C_t)} = \frac{C_t}{C_{t+i}}$, we have

$$mc_t A_t^P A_t^L = W_t + G_t \tag{10}$$
$$-\beta(1-\delta) E_t \left[\frac{C_t}{C_{t+1}} \left(G_{t+1} + mc_{t+1} A_{t+1}^P - W_{t+1}^0 - \left(mc_{t+1} A_{t+1}^P A_{t+1}^L - W_{t+1} \right) \right) \right]$$

The left-hand side represents the real marginal revenue product of labour, which depends on the period t average skill level among applicants. Clearly, an increase in the quality of the average period to job seeker A_t^L will reduce period t marginal cost. The right hand side features the period t real wage W_t and the period t hiring costs G_t, and, with a negative sign, the present expected value of hiring costs saved (G_{t+1}) by hiring the group in t rather than $t+1$. While an increase in hiring cost today means increasing production is more costly, an increase in future expected hiring costs will induce intermediate goods firms to shift hiring into the present, thus lowering the price of intermediate goods and thus marginal cost.

In addition, the right hand side also includes the present expected value of the $t+1$ difference between the real profit generated by a fully skilled group (with productivity A_{t+1}^P and real wage W_{t+1}^0) and a $t+1$ newly hired group (with productivity $A_{t+1}^P A_{t+1}^L$ and real wage W_{t+1}). This represents an additional benefit of hiring today rather than tomorrow not present in the Blanchard and Gali model. For further reference note that this benefit decreases in A_{t+1}^L and increases in W_{t+1} and mc_{t+1}. Thus an expected higher $t+1$ skill level will increase marginal cost in period t (since it reduces the benefit from hiring today), while a higher expected average real wage for the $t+1$ newly hired and a higher expected $t+1$ price of intermediate goods (i.e. higher $t+1$ marginal cost) will decrease it.

The average productivity of the whole workforce after adding the newly hired A_t^A and the production functions of gross output Y_t (i.e. output including hiring costs) and consumption goods C_t are then given by (where s_t^N denotes the share of the newly hired in the workforce)

$$A_t^A = A_t^P \left[s_t^N A_t^L + \left(1 - s_t^N\right)\right] \; , \; s_t^N = \frac{H_t}{N_t} = \frac{N_t - (1-\delta) N_{t-1}}{N_t} \tag{11}$$

$$Y_t = A_t^A N_t \tag{12}$$

$$C_t = A_t^A N_t - B' x_t^\alpha A_t^P A_t^L H_t = A_t^A N_t - B' x_t^\alpha A_t^P A_t^L \left(N_t - (1-\delta) N_{t-1}\right) \tag{13}$$

3 Marginal Cost and Unemployment in the Presence of Skill Loss

Let us now characterize the long-run relationship between marginal cost and unemployment in the presence of hiring frictions, skill decay and real-wage rigidity in order to build the intuition for the effects of skill decay on determinacy we will discuss in section 4. We will ignore the state of technology in what follows since it does not matter for determinacy. Combining log-linear approximations of equations (1) to (13) allows one to express the percentage deviation of marginal cost from its steady state as a function of unemployment:

$$\begin{aligned}
\widehat{mc}_t &= -a_1^L \widehat{a}_t^L + w_1^L \widehat{w}_t^L + a_2^L E_t \widehat{a}_{t+1}^L - w_2^L E_t \widehat{w}_{t+1}^L - h_c E_t \widehat{mc}_{t+1} && (14)\\
&\quad -\frac{h_0^{'}}{1-u}\widehat{u}_t - \frac{h_L^{'}}{1-u}\widehat{u}_{t-1} - \frac{h_F^{'}}{1-u}E_t \widehat{u}_{t+1} \\
&\quad \textit{where } a_1^L,\ a_2^L,\ w_1^L,\ w_2^L,\ p_0,\ p_1,\ h_0^{'},\ h_c > 0,\ h_L^{'},\ h_F^{'} < 0 \\
\widehat{a}_t^L &= -\sum_{i=1}^{\infty} a_i^u \widehat{u}_{t-i},\ a_i^n > 0 && (15)\\
\widehat{w}_t^L &= -\sum_{i=1}^{\infty} w_i^u \widehat{u}_{t-i},\ w_i^n > 0 && (16)
\end{aligned}$$

A lower case variable with a hat denotes the percentage deviation of the respective upper case variable from its steady state, with the exception of $\widehat{u}_t$, which denotes the percentage point deviation of unemployment from its steady state. The definitions of the various coefficients are displayed in table 1. Note while the average skill level among job seekers in period t $\widehat{a}_t^L$ negatively affects marginal cost, the period $t+1$ average skill level $E_t \widehat{a}_{t+1}^L$ enters with a positive sign because, as was discussed above, a higher average period $t+1$ skill level reduces the benefit from hiring today rather than tomorrow and thus increases marginal cost. Analogously, an increase in $E_t \widehat{w}_{t+1}^L$ lowers $\widehat{mc}_t$.

It is easily shown that with no skill decay (i.e. for $\delta_s = 0$), we have $a_i^n = w_i^n = \widehat{a}_t^L = \widehat{w}_t^L = h_c = 0$ and thus (14) collapses to the marginal cost equation in Blanchard and Gali (2008):

$$\widehat{mc}_t = \frac{-h_0}{(1-u)}\widehat{u}_t + \frac{-h_L}{(1-u)}\widehat{u}_{t-1} + \frac{-h_F}{(1-u)}E_t \widehat{u}_{t+1} - p_0 \widehat{a}_t$$

where the coefficients are exactly as in Blanchard and Gali (2008). Note that marginal cost depends negatively on current unemployment but positively on lagged and lead unemployment due to the effect of unemployment on the cost of hiring an additional worker. A decrease in $\widehat{u}_t$ increases period t hiring and thus labour market tightness and the cost of hiring. A decrease in $\widehat{u}_{t-1}$ lowers period t hiring for a given $\widehat{u}_t$ and thus period t hiring cost. A decrease $E_t\widehat{u}_{t+1}$ increases period $t+1$ hiring and hiring cost, thus increasing the benefit of creating jobs today and correspondingly reducing marginal cost today. The effects of lagged and lead unemployment increase in absolute value as the job destruction rate δ falls since this increases the effect of past employment on current hiring and of current employment on future hiring, respectively, as can be obtained from (1) .Therefore, the effect of a permanent increase in unemployment on marginal cost becomes less negative as δ increases. Nevertheless, it always remains negative because the negative effect of current unemployment on marginal cost always dominates the positive effects of lagged and lead unemployment, as $-\frac{h_0}{(1-u)} - \frac{h_L}{(1-u)} - \frac{h_F}{(1-u)} < 0$.[7]

As we will see shortly, this is no longer always true in the presence of skill decay and real-wage rigidity. Let us denote reductions of the skill level of the average job seeker and the average real wage caused by a one percentage point increase in unemployment as $a^u = \sum_{i=1}^{\infty} a_i^u$ and $w^u = \sum_{i=1}^{\infty} w_i^u$, respectively. The following proposition summarises the properties of these reductions and their derivatives with respect to δ_s and γ:

[7] This is easily shown: We want to prove that $\frac{1}{1-u}(h_0 + h_L + h_F)$ $= \frac{1}{1-u}\frac{\alpha g M}{\delta}\left(1 + \beta(1-\delta)^2(1-x) - (1-\delta)(1-x) - \beta(1-\delta)\right) > 0$. Using the fact that that $1-\delta = \frac{N-x}{N(1-x)}$, this can be simplified to $(1-N)x^2 + (N-x)N(1-\beta) > 0$. This holds for all permissible values of x, β and N since the maximum value x can take without violating $\delta \leq 1$ is N.

Proposition 1 *Let* $a^u = \sum_{i=1}^{\infty} a_i^u$ *and* $w^u = \sum_{i=1}^{\infty} w_i^u$ *the decline of the average skill level and the average real wage, respectively, caused by a permanent one percentage point increase in unemployment. Then it is possible to prove the following three results:*

(i) $a^u > w^u > 0$ *if and only if* $\gamma > 0$ *and* $\delta_s > 0$. ***Intuition**: An increase in unemployment increases the share of workers with longer unemployment durations and -with skill decay* ($\delta_s > 0$)*- lower skill levels and thus lower real wages in the job seeking population. If the wage of a worker only imperfectly adjusts to movements in his individual skill level* ($\gamma > 0$)*, the average real wage of job seekers declines by a smaller percentage than their average skill level.*

(ii) $\frac{\partial a^u}{\partial \delta_s} > \frac{\partial w^u}{\partial \delta_s} > 0$ *if* δ_s *is close to 0 and* $\gamma > 0$. ***Intuition:** A higher* δ_s *lowers the skill level of the long-term unemployed. Hence an increase in the share of the long-term unemployed among job seekers causes a faster decline in the average skill level and the average real wage if* δ_s *is higher. Real-wage rigidity (* $\gamma > 0$) *implies that the the decline in the average skill level is accelerated by more than the decline in the average real wage.*

(iii) $\frac{\partial w^u}{\partial \gamma} < 0$ *if and only if* $\delta_s > 0$ *and* $\gamma < 1$. ***Intuition:** The higher* γ*, the lower the response of a worker's real wage to movements in his skill level. Hence the reduction in the average real wage associated with an increase of the share of the long-term unemployed de-accelerates.*

Proof: Appendix B.

Hence in the presence of real-wage rigidity ($\gamma > 0$) and positive skill loss ($\delta_s > 0$) a "permanent" increase in unemployment increases the ratio between the (average) wage of the newly hired and their average productivity. The size of the increase of the ratio between the real wage and productivity increases in δ_s and falls in γ.

Hence skill decay in combination with real-wage rigidity creates a channel via which a permanent increase in unemployment increases marginal cost, the more so the higher δ_s and γ. One can see that more formally by writing the long-run marginal cost-unemployment relationship as

$$\begin{aligned} \lambda\widehat{mc} &= -\kappa\widehat{u} \\ \kappa &= \frac{\frac{h_0^{'}+h_L^{'}+h_F^{'}}{(1-u)} - \left[a^u\left(a_1^L - a_2^L\right) - w^u\left(w_1^L - w_2^L\right)\right]}{(1+h_c)}\lambda \end{aligned} \tag{17}$$

A detailed derivation can be found in appendix C. $-\kappa$ gives the effect of a "permanent" increase in unemployment on marginal cost. Most conveniently, substituting the definitions of $h_0^{'}$, $h_L^{'}$ and $h_F^{'}$ shows that $h_0^{'}+h_L^{'}+h_F^{'}$ exactly equals, $h_0+h_L+h_F$ and is thus always positive and independent of δ_s. Hence only the term in the squared brackets and h_c actually depend on skill loss.

The squared bracket encapsulates the "skill loss channel" from unemployment to marginal cost. It will be zero if $\delta_s = 0$, implying that $\kappa > 0$ and thus a negative effect of a "permanent" increase in unemployment on marginal cost. The first term represents the decline of the skill level of the average applicant caused by the increase in $\widehat{u}$ (a^u) times the net effect of a permanent skill level decline on marginal cost ($\left(a_1^L - a_2^L\right)$). The second term represents the decline of the skill-dependent real wage caused by the increase in $\widehat{u}$ (w^u) times the net effect of a permanent decline in the skill dependent real wage on marginal cost (-$\left(w_1^L - w_2^L\right)$). From table 1 we obtain $a_1^L > a_2^L$ and $w_1^L > w_2^L$ since the gain from hiring today rather than tomorrow is uncertain ($\delta > 0$) and is discounted ($\beta > 0$). Furthermore, $a_1^L - a_2^L$ and

$w_1^L - w_2^L$ will be quite close for sensible calibrations. Proposition 1, then, would imply that for positive δ_s and γ the squared bracket is positive and increases in δ_s and γ. Thus skill decay and real-wage rigidity would indeed render the effect of unemployment on marginal cost less negative, the more so the higher δ_s and γ.We confirm this by proving the following proposition:

Proposition 2 *Let κ, formally defined in (17), be the decline in marginal cost caused by a permanent one percentage point increase in unemployment and let δ_s close to zero. Then $\frac{\partial \kappa}{\partial \delta_s} < 0$ if $\gamma > \frac{B' x^{\alpha} M \beta (1-\delta)}{1 - B' x^{\alpha} M (1 - \beta(1-\delta))}$.*[8] *Furthermore, $\frac{\partial \kappa}{\partial \gamma} < 0$ if and only if $\delta_s > 0$, $\gamma < 1$ and $x(1-\delta)\beta + \frac{x(1-(1-\delta)\beta)}{\left(1-(1-x)\beta_s^{1-\gamma}\right)} > (1-x)\left(1-\beta_s^{1-\gamma}\right)$ Proof: Appendix C.*

The conditions under which $\frac{\partial \kappa}{\partial \delta_s} < 0$ and $\frac{\partial \kappa}{\partial \gamma} < 0$ are easily fulfilled for the calibrations we will adopt later.

Hence our model features two long-run effects of unemployment on marginal cost. The first is the "hiring cost channel" of Blanchard and Gail (2008) (i.e. $\frac{h_0' + h_L' + h_F'}{(1-u)}$) , which is always negative but decreases as the job destruction rate δ and thus -at a given level of employment- the job finding probability x decrease. The second is the skill decay channel (i.e. $a^n \left(a_1^L - a_2^L\right) - w^n \left(w_1^L - w_2^L\right)$) which arises if there is real-wage rigidity and skill decay. It's strength increases δ_s if $\gamma > 0$ and in γ if $\delta_s > 0$. If the skill decay channel effect dominates the hiring cost channel, an increase in unemployment will increase marginal cost and inflation. This has consequences for the determinacy properties of the interest feedback rule of the central bank, as we show in the next section.

[8] A more general proof without restrictions on δ_s would have been desirable but struck us as impossible due to the complexity of the expression resulting from $\frac{\partial \kappa}{\partial \delta_s}$.

4 Determinacy

In this section we explore how the conditions for determinacy in the above model are shaped by skill decay and real-wage rigidity. After discussing the calibration of the non-policy parameters in section 4.1, we show in section 4.2 that if labour market flows are low and real-wage rigidity and skill decay are sufficiently high, responding more than one for one to inflation induces indeterminacy. In section 4.3, we check the merit of several possible remedies for the indeterminacy problem. The linearised model consists of the following equations (technology is again suppressed since it is irrelevant for determinacy):

$$\pi_t = \beta E_t \pi_{t+1} + \lambda \widehat{mc}_t \tag{M1}$$

$$\lambda \widehat{mc}_t = -a^* \widehat{a}_t^L + w^* \widehat{w}_t^L - \kappa_0^* \widehat{u}_t + \kappa_L^* \widehat{u}_{t-1} + \kappa_F^* E_t \widehat{u}_{t+1} - h_c E_t \lambda \widehat{mc}_{t+1} \tag{M2}$$

$$\widehat{a}_t^L = (1-x)\left(-(1-\beta_s)\frac{\widehat{u}_{t-1}}{u(1-u)} + \beta_s \widehat{a}_{t-1}^L\right) \tag{M3}$$

$$\widehat{w}_t^L = (1-x)\left(-\left(1-\beta_s^{1-\gamma}\right)\frac{\widehat{u}_{t-1}}{u(1-u)} + \beta_s^{1-\gamma} \widehat{w}_{t-1}^L\right) \tag{M4}$$

$$\widehat{c}_t = \widehat{a}_t^P + c_L \widehat{a}_t^L - c_0^* \widehat{u}_t - c_1^* \widehat{u}_{t-1} \tag{M5}$$

$$\widehat{c}_t = E_t \widehat{c}_{t+1} - \left(\widehat{i}_t - E_t \pi_{t+1}\right) \tag{M6}$$

$$\widehat{i}_t = \phi_\pi E_t \pi_{t+j}, \;\; \phi_\pi \geq 0, \;\; -1 \leq j \leq 1 \tag{M7}$$

$(M1)$ is the New Keynesian Phillips curve. $(M3)$ and $(M4)$ are merely quasi-differenced versions of (15) and (16). $(M2)$ is the result of combining $(M3)$ and $(M4)$ with (14). $(M5)$ is derived by linearising equations $(11)-(13)$ and combining the resulting expressions.[9] The definitions of all reduced form coefficients can be found in table 1. $(M6)$ is the consumption

[9] Throughout we use $\widehat{n}_t = \frac{-\widehat{u}_t}{1-u}$.

Euler equation while ($M7$) is the interest feedback rule of the central bank, which may be current, forward or backward looking. Unfortunately, we cannot establish the conditions for determinacy analytically.[10] Therefore, we solve the model numerically using the software Dynare.

4.1 Calibration of Non-Policy Parameters

The calibration is displayed in table 2. In line with the literature, we set $\beta = 0.99$. Similar to Blanchard and Gali, the steady state job finding probability and unemployment rate x and u are allowed to take two values, a high "American" and a low (OECD-) "European" one. Hobijn and Sahin (2009) estimate average job finding probabilities for advanced OECD economies.[11] For the United States, their (monthly) estimate corresponds to a quarterly rate of 0.9.[12] The median job finding rate for the European countries included in Hobijn and Sahin's sample is 0.2, while the mean is 0.26. We set $x = 0.2$, which also happens to equal their estimate for Germany and is very close to their estimate for France. Below we will also show how our results are affected by varying x between 0.2 and 0.9, covering both Blanchard and Gali's preferred calibrations of x for Europe and for the United States of 0.25 and 0.7, respectively, as well as Shimer's (2005) estimate for the United States of 0.8. The

[10] In the absence of skill decay ($\delta_s = 0$), it is possible to analytically establish the conditions for determinacy for an interest feedback rule where the central bank responds only to inflation, as we show in Rannenberg (2009) by reducing it to a system of two jump variables and one predetermined variable and then applying conditions derived by Woodford (2003) for such systems. By contrast, with skill decay the model has three forward looking variables and three state variables. As far as we are aware, there is no straightforward way to analytically determine the eigenvalues of a 6x6 system.

[11] The countries inlcuded in the study are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finaland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom and the United States.

[12] Hobijn and Sahin (2009) estimate a monthly job finding rate x_m of 0.56. Following Blanchard and Gali (2008), we convert their estimates into quarterly numbers using the formula $x = x_m + x_m (1 - x_m) + x_m (1 - x_m)^2$.

steady state unemployment rate u is set equal to 0.1 for Europe and to 0.05 for the United States. Note, however, that for a given value of x, whether u is set equal to 0.1 or 0.05 has only marginal effect on our results. The calibrated values of x and u imply the values for δ displayed in the table.

We follow Blanchard and Gali (2008) in setting the parameters pertaining to the hiring cost α and B' and the coefficient on marginal cost in the Phillips curve λ. A value of $\alpha = 1$ is consistent with estimates of matching functions. Setting $B' = 0.12$ implies a fraction of hiring costs in GDP of about one percent under the American calibration, and correspondingly a lower fraction under the continental European calibration since x is lower.[13] $\lambda = 0.08$ implies that prices remain fixed on average for about four quarters.

Calibrating the degree of real-wage rigidity with respect to the individual skill level γ is difficult because we lack hard evidence. Hall (2005) assumes the real wage to be constant, corresponding to $\gamma = 1$. The survey evidence we cited above suggests that firms are highly reluctant to pay lower wages to newly hired workers, so this value may well be adequate. Blanchard and Gali (2008) simply set $\gamma = 0.5$ since it is the midpoint of the admissible range. In order to obtain some guidance, we log and HP filter data on real wages and labour productivity for the United States and Germany from 1970q1 and 1991q4 and regress the former on the later.[14] The point estimate of the coefficients on the log of productivity are 0.5 for the United States and 0.34 for Germany, respectively. If we impose the restriction $\gamma = \gamma_P$,

[13] See Blanchard and Gali (2008), p.27.

[14] This follows Hagededorn and Mankowskii (2008), who use this procedure to obtain a target value for elasticity of the real wage with respect to labour productivity. Labour productivity is measured as output per person in the non farm business sector, while the real wage is measured as productivity times the the labour share in the non-farm business sector, following Hagedorn and Mankowskii (2008). For the United States, the data is taken from the BLS Major Sector Productivity and Cost programm. For Germany, the data is taken from Statistisches Bundesamt Wiesbaden (2006).

i.e., assume that workers' wages are equally inflexible with respect to skill and technology, this would roughly corresponds to values of γ of 0.5 and 0.66, respectively.[15] However, since the restriction $\gamma = \gamma_P$ might well be invalid and since the regression exercise probably takes our simple model of wage formation a bit too seriously, we will allow γ to vary between zero and one in every grid search conducted below.

For guidance on how to calibrate quarterly skill decay δ_s we draw on the literature on wage loss upon worker displacement. This literature has produced evidence based on panel regressions showing that the wage upon reemployment depends negatively on the duration of the unemployment spell. Skill decay during unemployment is usually seen as one of the factors causing this relationship, although the evolution of the reservation wage due to other factors (for instance, depletion of an unemployed person's wealth) would be expected to play a role as well. Evidence along these lines include Addison and Portugal (1989) for American male workers, Pichelmann and Riedel (1993) for Austrian workers, Gregory and Jukes (2001) for British male workers, Gregg and Tominey (2005) for male youths, and Gangji and Plasman (2007) for Belgian workers. They find that a one-year unemployment spell reduces the real wage by 39%, 24%, 11%, 10% and 8% respectively.[16] Furthermore, Nickell et al. (2002),

[15] The correspondence between the elasticity of the average wage with respect to average productvity and γ is not perfect, but very close in this case. Across all the calibrations we consider in this paper, the aggregate elasticity is always slightly larger than γ.

[16] For Addison and Portugal (1989), we have calculated the annual earnings penalty using the lower coefficient on log(duration) in their two preferred specifications (Table 3, columns 5 and 6), p. 294. Duration is measured in weeks. For Pichelmann and Riedel (1993), we had to resort to the same procedure, see p. 8 in that paper for the results. Their coefficient estimates for the effect on the real wage is reported in table 2, p. 8. The results of Gregory and Jukes (2001) are reported on page F619, while the results of Gangji and Plasman (2007) are reported on page 18, table 2.

Pichelmann and Riedel (1993) explicitly ask whether the earnings penalty arising from duration diminishes during the two years following the unemployment spell and find that it does not. Gregg and Tominey (2005) find that the wage penalty associated with a year of youth unemployment is still present at age 42. Hence our assumption that workers regain their full skill level after one quarter of employment might downward bias the true effects of skill decay. See Gregg and Tominey (2005), p. 502 and pp. 505-506.

looking at British male workers, asks how the earnings loss is changed if the unemployment spell exceeded six months and find an additional permanent earnings loss between 6.8% and 10.6%.[17] Based on these estimates we will allow δ_s to vary between 0 and 0.07 (step size: 0.005) in every grid search, implying that a one-year unemployment spell reduces a worker's skill level by between 0 and 25%.

Unless otherwise mentioned in this section or below, the stepsize used in the parameter intervals of the gridsearches conducted below is always 0.1.

4.2 Skill Decay and the Merits of an active Response to Inflation

We set $\phi_\pi = [0, 3]$. For the American calibration, we find that determinacy requires $\phi_\pi > 1$ for all values of skill decay δ_s and real-wage rigidity γ we consider in the grid search, i.e. following the Taylor principle guarantees a unique equilibrium. By contrast, $\phi_\pi > 1$ is not always sufficient to induce determinacy under the European calibration. Table 3 displays the determinacy requirements on ϕ_π for the current looking rule for the values of δ_s and γ included in the gridsearch. While for very flexible real wages ($\gamma \leq 0.1$) $\phi_\pi > 1$ is sufficient for determinacy, for $\gamma = 0.2$ and $\delta_s \geq 0.055$, ϕ_π starts being bounded above. What is more, for $\gamma = 0.3$ and $\delta_s \geq 0.03$, the determinacy requirement switches to $\phi_\pi < 1$: The central bank now has to lower the real interest rate in response to an increase in inflation. Indeed, for every value of γ larger or equal to 0.3, there exists a *critical threshold value* of δ_s. If δ_s equals or exceed this value, determinacy requires a passive response to inflation. The critical threshold value declines as γ increases. For instance, for $\gamma = 0.5$, the degree of real-wage rigidity assumed by Blanchard and Gali (2008), the critical value of δ_s equals 0.015, while

[17] See Nickel et al. (2001), p. 17.

for $\gamma \geq 0.7$ it is reduced to 0.01. The determinacy regions for the backward and forward looking rules (not shown) are almost identical. In particular, the critical values of δ_s are identical across the three rules. This suggests that it is not the timing of the active response to inflation but the active response to inflation per se which induces indeterminacy.

The critical values of δ_s and the annual skill loss implied by these quarterly values are displayed in table 4. The implied annual skill losses seem moderate compared with the evidence on the effect of unemployment duration on the reemployment wage cited in section 4.1.

To gain some intuition for why for some values of γ and δ_s an active monetary policy is destabilising under the European calibration, we draw on the long-run relationship between marginal cost and unemployment. As discussed in section 3, this relationship is always negative for $\delta_s = 0$ (i.e. $\kappa > 0$) but becomes less so as δ_s increases since $\frac{\partial \kappa}{\partial \delta_s} < 0$ if there is some real-wage rigidity. Indeed, as we increase δ_s, κ may ultimately turn negative, implying a positive marginal cost-unemployment relationship. However, under the American calibration, κ never turns negative for the combinations of γ and δ_s in our grid. By contrast, under the European calibration, κ does turn negative for some combination of γ and δ_s. Figure 1 plots κ against δ_s for the European calibration. Each line corresponds to a different value of γ. For $\gamma = 0$, κ is essentially flat, while it decreases in δ_s for $\gamma \geq 0.1$. Furthermore, for any given $\delta_s > 0$, higher values of γ are associated with lower values of κ, as we would expect from proposition 2.

κ never turns negative for $\gamma \leq 0.1$. Hence κ never turns negative for those degrees of real-wage rigidity for which ϕ_π is never bounded above. Furthermore, note that for $\gamma \geq 0.3$, i.e. the range of γ for which a critical value of δ_s exists, the value of δ_s which turns κ negative equals this critical value of δ_s. An intermediate case appears to be constituted by $\gamma = 0.2$: Here κ turns negative for $\delta_s = 0.05$ but, as we saw above, the determinacy requirement does not switch to $\phi_\pi < 1$, although ϕ_π becomes bounded above for $\delta_s \geq 0.055$. However, by and large, we can conclude that if marginal costs, and thus inflation, increase in response to a persistent increase in the unemployment rate -because δ_s exceeds the respective critical level and thus we have $\kappa < 0$-, the central bank should lower the real interest rate to ensure a unique equilibrium.

This prescription should rule out self-fulfilling prophecies. In response to a sunspot driven persistent decrease in demand and increase in unemployment the central bank would increase demand and hence would not validate the increase in unemployment. By contrast, with $\phi_\pi \geq 1$, there is scope for sunspot equilibria if δ_s exceeds its respective critical value: A persistent increase in unemployment will ultimately lead to an increase in inflation and (as $\phi_\pi \geq 1$) the real interest rate, irrespective of whether the central bank responds to lagged, current or expected future inflation. This lowers demand and thus validates the increase in unemployment. In the next section, when we display the impulse response function to a sunspot shock, we show that this is in fact exactly what happens.

This leaves the question why this critical value is so much higher for the American than for the continental European calibration. The chief reason for this is that due to the more fluid labour market associated with the American calibration, for any combination of γ and δ_s, κ is a lot higher than under the continental European calibration. The intuition for that was discussed in section 3: The higher the job finding rate x and thus the higher job destruction probability δ, the lower is the effect of lagged and lead unemployment on period t marginal cost. The reason is that with higher δ, period t hiring and thus period t hiring cost depend less on period $t-1$ employment since more jobs are destroyed as we move from period $t-1$ to period t. Similarly, the possibility to save hiring costs by moving job creation from $t+1$ to t is also reduced since fewer jobs survive from period t to $t+1$. Hence the effect of $t+1$ hiring costs and thus period t employment on marginal cost is reduced as well.

We now check whether the interpretation of our results offered above is consistent with results based on a wider range of x values and how robust they are. We repeat the above gridsearch for values of x between 0.2 and 0.9, with a step size of 0.05.[18] The results reported here are based on a steady state unemployment rate of 0.05, but the results differ only marginally if we use the "European" value of 0.1. It turns out that the critical values of δ_s are again the same across all three policy rules. Hence, even for this wider range of x values, δ_s seems to affect the stabilising properties of an active response to inflation per se rather than the stabilising properties of the timing of such a response.

For each value of x, figure 2 plots the critical values of δ_s against γ. Each line consists of a set of critical values of δ_s associated with a given value of x. Hence the region equal to or above a given line consists of the combinations of γ and δ_s for which determinacy requires $\phi_\pi < 1$. The lowest line corresponds to $x = 0.2$ while the line in the upper right corner of the graph (which consists only of a single point) corresponds to $x = 0.65$. No critical values exist for $x \geq 0.7$. For each value of x, the critical value of δ_s declines in γ. Furthermore, as we would expect from our comparison of the American and the European calibration, for each value of γ the critical value of δ_s increases in x. For instance, for $\gamma = 0.5$, the critical values are 0.01 for $x = 0.2$, 0.025 for $x = 0.25$ (the value of x in Blanchard and Gali's European calibration), 0.035 for $x = 0.3$, 0.05 for $x = 0.35$ and 0.07 for $x = 0.4$.

[18] It is understood that increasing x implies increasing the separation rate δ as well.

Moreover, we again observe a strong correspondence between a determinacy requirement of $\phi_\pi < 1$ and a positive long-run relationship between marginal costs and unemployment, i.e. a negative value of κ. If uniqueness requires $\phi_\pi < 1$, we always have $\kappa < 0$. At the same time, $\kappa < 0$ does almost always imply $\phi_\pi < 1$. There are ten combinations of γ and x for which the value of δ_s turning κ negative is not a critical value. However, in nine of these cases, the critical value δ_s is only slightly higher than this value.

Finally, note that our above result that a determinacy requirement of $\phi_\pi < 1$ is likely for Europe but does not occur for the United States is robust against using Blanchard and Gali's European and American calibration of x, respectively. For Blanchard and Gali's preferred European value of $x = 0.25$, plausible critical values of δ_s exist for $\gamma = [0.3, 1]$, just as for our preferred value of 0.2. At the same time, no critical value of δ_s exists for Blanchard and Gali's preferred American value of $x = 0.7$.

4.3 How to restore Determinacy under the European Calibration

We now investigate whether the determinacy issues caused by an aggressive response to inflation under the European calibration can be resolved by adding other variables to the policy rule. As in the previous section, we set $\phi_\pi = [0,\ 3]$ and consider separately the merits of a response to the lagged interest rate, the output gap and unemployment in addition to inflation.

To allow for interest rate smoothing we replace M8 with $\widehat{i}_t = (1 - \rho_i)\, \phi_\pi E_t \pi_{t+j} + \rho_i \widehat{i}_{t-1}$, $j = 0, 1$ and $\widehat{i}_t = (1 - \rho_i)\, \phi_\pi \pi_{t-1} + \rho_i \widehat{i}_{t-1}$, and set $\rho_i = [0,\ 0.9]$. We find that the critical values of δ_s are exactly those listed in table 4. This result is in line with the intuition given above as even with interest rate smoothing, if $\phi_\pi > 1$, an increase in inflation ultimately increases the real interest rate.

When examining the stabilising properties of a response to the output gap, we consider two concepts of target output. The first follows Woodford (2003) and Gali (2001) in defining (gross) target output Y_t^n as the output level in the absence of nominal rigidities, i.e. flexible price output. This is the level of output at which final goods firms charge their desired mark-up, implying that marginal cost is at its steady state and inflation is zero if output is expected to remain at Y_t^n in the future as well. The associated unemployment rate is denoted as u_t^n. As marginal cost is affected by both lead unemployment and lead marginal cost, when deriving u_t^n, we assume that if unemployment is at its natural level in period t, it will be expected to be at its natural level in period $t+1$ as well. Hence, in the above system, we replace $(M7)$ with a policy rule featuring the output gap and add equations for actual and potential gross output as well as natural unemployment:

$$
\begin{aligned}
\widehat{i}_t &= \phi_\pi E_t \pi_{t+j} + \phi_y \left(\widehat{y}_t - \widehat{y}_t^n \right), \phi_\pi, \phi_y \geq 0, \ j = 0, 1 \\
\widehat{y}_t &= y^L \widehat{a}_t^L - y_0 \widehat{u}_t - y_1 \widehat{u}_{t-1}, \ y^L, \ y_0, \ y_1 > 0 \\
\widehat{y}_t^n &= y^L \widehat{a}_t^L - y_0 \widehat{u}_t^n - y_1 \widehat{u}_{t-1} \\
\widehat{u}_t^n &= \frac{\kappa_F^* E_t \widehat{u}_{t+1}^n + \kappa_L^* \widehat{u}_{t-1} + -a^* \widehat{a}_t^L + w^* \widehat{w}_t^L - \lambda p_0 \widehat{a}_t^P - \lambda p_1 E_t \widehat{a}_{t+1}^P}{\kappa_0^*}
\end{aligned}
$$

The equation for $\widehat{u}_t^n$ was derived by setting $\widehat{mc}_t = \widehat{mc}_{t+1} = 0$ and $\widehat{u}_{t+1} = \widehat{u}_{t+1}^n$ in the marginal cost equation. Clearly $\widehat{u}_t^n$ depends on past values of actual unemployment as well as its own future value. The second concept of target output simply assumes that the central bank targets the steady state output level Y. Hence we merely need to replace $(M7)$ with $\widehat{i}_t = \phi_\pi E_{t+j} \pi_t + \phi_y \widehat{y}_t$, $j = 0, 1$. We set $\phi_y = [0, \ 1]$ for each case.

If the central bank targets output under flexible prices, it turns out that for each value of γ, responding to the output gap extends the determinacy region whenever δ_s is below its respective critical value as listed in table 4 but reduces it whenever δ_s is equal to or larger than its critical value. More precisely, if δ_s is below its critical value and $\phi_y = 0$, determinacy requires $\phi_\pi > 1$. Increasing ϕ_y reduces the lower bound on ϕ_π to values below one. By contrast, if δ_s is above its critical value and $\phi_y = 0$, determinacy requires $\phi_\pi < 1$. Increasing ϕ_y reduces the upper bound on ϕ_π to values below one.

Intuition for this result can be gained from the long-run effect of actual unemployment on natural unemployment. It is easy to see that $\widehat{y}_t - \widehat{y}_t^n = -y_0\left(\widehat{u}_t - \widehat{u}_t^n\right)$. Hence the output gap depends positively on $\widehat{u}_t^n$. Solving $\widehat{u}_t^n$ forward yields $\widehat{u}_t^n = \sum_{i=0}^{\infty}\left(\frac{\kappa_F^*}{\kappa_0^*}\right)^i\left[\kappa_L^*\widehat{u}_{t-1} + a^*\widehat{a}_t^L - w^*\widehat{w}_t^L\right]$. Setting $\widehat{u}_{t+i} = \widehat{u}$ yields $\widehat{u}^n = \frac{\kappa_L^* + a^*\frac{(1-\beta_s)(1-x)}{u(1-u)(1-(1-x)\beta_s)} - w^*\frac{\left(1-\beta_s^{1-\gamma}\right)(1-x)}{u(1-u)\left(1-(1-x)\beta_s^{1-\gamma}\right)}}{\kappa_0^* - \kappa_F^*}\widehat{u}$. If $\frac{\partial\widehat{u}^n}{\partial\widehat{u}} < 1$, then an increase in unemployment increases natural unemployment less than one for one. It thus lowers the output gap and tends to lower real interest rate. This should stabilise unemployment. By contrast, if $\frac{\partial\widehat{u}^n}{\partial\widehat{u}} > 1$, an increase in unemployment will increase $\widehat{u}^n$ more than one for one and thus tend to increase the real interest rate. In this case responding to the output gap is actually making self-fulfilling prophecies more likely. Moreover, note that $\frac{\partial\widehat{u}^n}{\partial\widehat{u}} > 1 \Leftrightarrow \frac{h_0' + h_L' + h_F'}{(1-u)} - \left[a^u\left(a_1^L - a_2^L\right) - w^u\left(w_1^L - w_2^L\right)\right] < 0$, implying that $\kappa < 0$. As was shown in section 4.2, this will be true if δ_s exceeds its critical level. Hence if the central bank targets flexible price output, responding to the output gap will tend to destabilise the economy precisely when responding more than one for one to inflation tends to destabilise the economy as well.

We would expect these considerations not to apply if the central bank instead targets the steady state output level or steady state unemployment. By definition, the steady state levels of output and unemployment are fixed and thus do not depend on past deviations of unemployment from its steady state. It indeed turns out that if the central bank targets the steady state, responding to the output gap has a strong stabilising effect. However, the higher γ and/ or δ_s, the higher has to be the value of ϕ_y which guarantees determinacy. Table 5 reports for each combination of γ and δ_s the value of ϕ_y necessary to guarantee determinacy if $\phi_\pi \leq 2$. For $\gamma = [0, 0.4]$, $\phi_y = 0.1$ guarantees determinacy for the full range of δ_s values. For $\gamma = 0.5$, $\phi_y = 0.1$ guarantees determinacy for $\delta_s \leq 0.045$, while for $\delta_s > 0.045$, determinacy requires $\phi_y = 0.2$. If the real wage does not respond to changes in an individual worker's skill level at all ($\gamma = 1$), ϕ_y would have to increase up to 0.5 if $\delta_s \geq 0.06$. Table 6 shows that the value of ϕ_y necessary to guarantee determinacy also increases in ϕ_π. It reports the values of ϕ_y necessary to guarantee determinacy for $\phi_\pi \leq 3$. For each combination of γ and δ_s, the minimum value ϕ_y required for determinacy is often considerably larger and never smaller than its value for $\phi_\pi \leq 2$. Targeting the steady state unemployment rate, i.e. replacing $(M7)$ with $\widehat{i}_t = \phi_\pi E_{t+j}\pi_t - \phi_u \widehat{u}_t$, $j = 0, 1$ and $\phi_u = [0,\ 1]$, has a very similar but slightly weaker effect.[19]

Hence the introduction of skill decay strengthens the argument made by Blanchard and Gali (2008) saying that if there is little hiring and firing, the central bank should focus more on stabilising unemployment and less on stabilising inflation than if the labour market is very fluid. Their optimal simple rule puts a much smaller weight on inflation stabilisation under the European than under the American calibration.[20] In the presence of skill decay

[19] For $\phi_u = \phi_y = k$, with $k = [0,\ 1]$, the associated upper bound on ϕ_π will frequently be lower by about 0.1-0.3 if the central bank responds to unemployment as compared to when it responds to the deviation of output from its steady state.

[20] See Blanchard and Gali (2008), p. 30

and real-wage rigidity, a passive response to inflation or a sufficiently aggressive response to unemployment is necessary to rule out multiple equilibria, which clearly is a precondition for optimality.

5 Dynamics under Indeterminacy

In section 4.2, we suggested that the intuition why a value of δ_s equal to or above the respective critical level combined with $\phi_\pi > 1$ induces indeterminacy is as follows: A sunspot driven persistent decrease in demand and thus increase in unemployment will ultimately increase marginal cost and inflation since $\kappa < 0$. If $\phi_\pi > 1$, this will ultimately increase the real interest rate, thus validating the original increase in unemployment. In this section we confirm that this is exactly what happens by investigating the response of the model under the European calibration to a sunspot shock, with $\gamma = 0.3$ and skill decay δ_s being at the corresponding critical level of 0.03.

To solve the indeterminate model, we follow a solution method proposed by Lubik and Schorfheide (2003) who extend an approach by Sims (2002). Lubik and Schorfheide propose to solve linear rational expectation (RE) models by solving for the vector of expectational errors $\widetilde{\eta}_t = q_t - E_{t-1}q_t - v_t$, where q_t is a vector of variables over which agents form expectations and v_t is a sunspot shock. If the solution to the model is not unique, v_t can trigger self-fulfilling prophecies. Lubik and Schorfheide (2003) show that any linear rational expectations model can be cast into the following form:

$$\Gamma_0 y_t = \Gamma_1 y_{t-1} + \begin{bmatrix} \Psi & \Pi \end{bmatrix} \begin{bmatrix} \varepsilon_t \\ \upsilon_t \end{bmatrix} + \Pi \widetilde{\eta}_t \tag{18}$$

where ε_t denotes an i.i.d. vector of structural shocks and all variables with a t and $t-1$ subscript are observable at time t, and all variables with a $t-1$ subscript are predetermined. Lubik and Schorfheide suggest to interpret the vector υ_t as belief shocks that trigger reversion of forecasts of the endogenous variables between $t-1$ and t.[21] We assume that the effects of the sunspot shock υ_t and the structural shock ε_t to the forecast error are orthogonal to each other. This is a standard assumption in the literature on indeterminate linear rational expectations models and allows to easily solve the model by casting $M1$ to $M8$ in the form of (18). The vectors y_t, ε_t and υ_t as well as the matrices Γ_0, Γ_1, Ψ and Π are displayed in appendix D.

We assume that the central bank responds only to inflation and set $\phi_\pi = 1.5$. We consider the effects of a -2% belief shock to consumption, i.e. $\upsilon_0^c = -0.02$. Figure 3 displays the deviation of unemployment from its steady state (in percentage points) and consumption (in percent). Unemployment increases by about 0.9 percentage point, while consumption declines by a bit less than 0.9% and then declines somewhat further. The increase in unemployment is very persistent: after ten years, unemployment is still about 0.8 percentage points above its steady state while after 25 years (100 quarters) it still exceeds its steady state by 0.7%.

Figure 4 shows that $\lambda \widehat{mc}_t$ falls by 0.07% on impact and then starts increasing and turns positive in quarter 16. Since we have chosen a value of δ_s such that κ is smaller than zero (see

[21]See Lubik and Schorfheide (2003), p. 279.

Figure 1, the line for $\gamma = 0.3$), we would expect the persistent increase in unemployment to ultimately turn marginal cost positive. However, as long as the history of high unemployment is short, the skill loss among job seekers has not yet sufficiently built up to dominate the hiring cost channel and thus turn marginal cost positive. To illustrate how the dynamic of the skill decline matches with sign change and dynamic of $\lambda\widehat{mc}_t$, note that the skill level in response to a "permanent" change in the unemployment rate in period $t-1$ evolves as $\widehat{a}_t^L = -a^u\left(\left(1-x\right)^t \beta_s^t - 1\right)\widehat{u}$, where a^u denotes the decrease of the the skill level of the average applicant caused by a permanent increase in unemployment and is defined in proposition 1. In Figure 5, we plot $\widehat{a}_t^L$ (as defined in this equation) as a percentage of the change of $\widehat{a}_\infty^L$ after an infinite number of periods, i.e. $\left(1-\left(1-x\right)^t \beta_s^t\right) \times 100$. The curve is rather steep at the beginning but then flattens out. With an unemployment history of 15 quarters, which happens to be the case in quarter 16, the decline in $\widehat{a}_t^L$ has reached 97.8% of its total and the rate of change has decreased to about 0.5 percentage points. Thus $\lambda\widehat{mc}_t$ turns positive after the decline in the skill level has almost reached its maximum. Note also that the dynamics of $\lambda\widehat{mc}_t$ and $\widehat{a}_t^L$ are similar in that the rate of increase of $\lambda\widehat{mc}_t$ is at its highest during those first 15 quarters but then gradually declines.

Inflation declines to -0.08% on impact but turns positive in quarter four. It then keeps rising until it reaches a plateau at 0.003% in quarter 19. Inflation is pushed faster above zero because it responds not just to current but also to expected future values of marginal costs. Correspondingly, we would expect the ex ante real interest rate ultimately to increase as well. Figure 6 shows that $(i_t - E_t\pi_{t+1})$ declines on impact but begins to increase in quarter two and begins to exceed its steady state value in quarter five and then remains persistently above it, if only by a very small amount. The persistent increase in the real interest rate validates the initial decline in consumption and the associated increase in unemployment. Hence the response of consumption, unemployment, marginal cost, inflation and the real interest rate to the sunspot shock is just as we would expect from our discussion in section 4.2.

6 Conclusion

This paper adds duration-dependent skill decay during unemployment as an additional labour-market friction to the sticky price model with hiring costs and real-wage rigidity developed by Blanchard and Gali (2008) and shows the implications of this modification for determinacy. We find that, while without skill decay, an active monetary policy ensures equilibrium uniqueness, this is not true in the presence of skill decay. For a job finding probability calibrated at the OECD-European median and very moderate real-wage rigidity, there exists a critical threshold level of skill decay. If the quarterly skill decay percentage is increased to or above this level and the central bank responds only to inflation, determinacy requires a coefficient on inflation in the interest feedback rule smaller than one. This holds regardless of whether the central bank responds to current, lagged or expected future inflation. The critical skill decay percentage decreases in the degree of real-wage rigidity and increases in the job finding probability. If the job finding probability is set to a higher "American" value, no critical value exists within a reasonable range of values for δ_s.

Apparently the switch in the determinacy requirement is related to the effect of skill decay on the long-run relationship between marginal cost and unemployment. We show this relationship to be always negative in the absence of skill decay. However, a sufficient increase in skill decay or an increase in the degree of real-wage rigidity if $\delta_s > 0$ weakens the relation and may even turn it positive. The respective critical skill decay percentage typically equals or is very close to the value of δ_s turning the relationship positive. In such a world, a persistent increase in unemployment will ultimately increase inflation. If the central bank responds more than one-for-one to inflation, the real interest rate increases, which lowers demand and thus validates the increase in unemployment: Hence we have a self-fulfilling prophecy. Consistent with this intuition, under the American calibration, the long-run marginal cost-unemployment relationship never turns positive for reasonable values of δ_s because it is much more negative than under the European calibration due to interaction of the size of labour market flows under the two calibrations with costly hiring.

The indeterminacy problem under the European calibration can be solved by adding the output gap to the policy rule if the right target level for output is used. If the central bank targets the steady state level of output, then a sufficient response to the output gap induces determinacy even if skill decay is above its respective critical level. By contrast, targeting flexible price output will increase the indeterminacy region. Adding unemployment to the policy rule is also stabilising.

Finally, we compute the response of the economy to an adverse consumption sunspot shock under the European calibration, an active monetary policy and skill decay above its respective critical level. It turns out that the path of consumption, unemployment, marginal cost, inflation and the real interest rate is in line with our intuition for why an active monetary policy induces indeterminacy under such a parameterization. Further, the response of unemployment to the sunspot shock is very persistent.

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A Steady State Values and reduced Form Coefficients

As was mentioned in the text, we start by assuming values for u and x. This allows to write the steady state values of δ, s^i, A^L, A^A, W and W^L

$$\delta = \frac{ux}{(1-u)(1-x)}, \; s^i = x(1-x)^i, \quad A^L = \sum_{i=0}^{\infty} s^i \beta_s^i = \frac{x}{1-(1-x)\beta_s}, \; W = \Theta' \sum_{i=0}^{\infty} s^i \beta_s^{i(1-\gamma)} = \Theta' W^L$$

$$W^L = \sum_{i=0}^{\infty} s^i \beta_s^{i(1-\gamma)} = \frac{x}{1-(1-x)\beta_s^{1-\gamma}}, \; A^A = s^N A^L + \left(1 - s_t^N\right) = \delta A^L + 1 - \delta$$

We can now back out Θ by first noting that in the steady state, we can write (10) as

$$A^L \left[\frac{1}{M} - g(1-\beta(1-\delta))\right] + \beta(1-\delta)\left[\frac{1-A^L}{M}\right] = \Theta' \left[\beta(1-\delta) + \frac{W}{\Theta'}(1-\beta(1-\delta))\right]$$

Using $W^L = W/\Theta'$, we have

$$\Theta' = \frac{A^L 1 \left[1/M - g(1-(1-\delta)\beta)\right] + \frac{(1-\delta)\beta}{M}\left(1-A^L\right)}{(1-\delta)\beta + \frac{x}{1-(1-x)\beta_s^{1-\gamma}}(1-(1-\delta)\beta)}$$

B Proof of Proposition 1

If $a^u = \sum_{i=1}^{\infty} a_i^u$ and $w^u = \sum_{i=1}^{\infty} w_i^u$, we have $a^u = \frac{1-x}{u(1-u)} \frac{1-\beta_s}{1-(1-x)\beta_s}$, $w^u = \frac{1-x}{u(1-u)} \frac{1-\beta_s^{1-\gamma}}{1-(1-x)\beta_s^{1-\gamma}}$. Then $a^u > w^u$ if and only if $\frac{1}{\beta_s} > 1$, which will be true only if $\gamma > 0$ and $\beta_s < 1$. Furthermore, $\frac{\partial a^u}{\partial \delta_s} = \frac{1-x}{u(1-u)} \frac{x}{(1-(1-x)\beta_s)^2} > 0$ and $\frac{\partial w^u}{\partial \delta_s} = \frac{1-x}{u(1-u)}(1-\gamma)\frac{x\beta_s^{-\gamma}}{\left(1-(1-x)\beta_s^{1-\gamma}\right)^2} > 0$. $\frac{\partial a^u}{\partial \delta_s} > \frac{\partial w^u}{\partial \delta_s}$ if $\frac{1}{(1-(1-x)\beta_s)^2} > (1-\gamma)\frac{\beta_s^{-\gamma}}{\left(1-(1-x)\beta_s^{1-\gamma}\right)^2}$. This will be true if β_s is close to 1 and $\gamma > 0$. Finally, $\frac{\partial w^u}{\partial \gamma} = \frac{1-x}{u(1-u)} \ln\left(\beta_s^{1-\gamma}\right)\beta_s^{1-\gamma}\frac{x}{(1-(1-x)\beta_s)^2}$. $\ln\left(\beta_s^{1-\gamma}\right) < 0$ if and only if $\beta_s^{1-\gamma} < 0$. Hence $\frac{\partial w^u}{\partial \gamma} < 0$ if and only if $\beta_s < 1$ and $\gamma < 1$.

C Proof of Propositions 2

First, in (14), (15) and (16) we set $\widehat{mc}_{t+1} = \widehat{mc}_t = \widehat{mc}$, $\widehat{u}_{t+1} = \widehat{u}_t = \widehat{u}_{t-1} = \widehat{u}$, $\widehat{a}^L_t = \widehat{a}^L_{t-1} = \widehat{a}^L$ and $\widehat{w}^L_t = \widehat{w}^L_{t-1} = \widehat{w}^L$ and combine the resulting expressions, which yields

$$\begin{aligned}
\lambda\widehat{mc} &= -\frac{\begin{array}{c}\frac{\alpha M B' x^\alpha}{(1-u)}\left[(1-u-x)(1-\beta)+ux\right] \\ +(1-x)\left[1-\beta(1-\delta)\right]\left[\frac{-(1-\beta_s)(1-Bx^\alpha M)}{(1-(1-x)\beta_s)} + \frac{\left(1-\beta_s^{1-\gamma}\right)\frac{WM}{A^L}}{\left(1-(1-x)\beta_s^{1-\gamma}\right)}\right]\end{array}}{u(1+h_c)(1-u)}\lambda\widehat{u} \\
&= -\kappa\widehat{u} \\
\kappa &= \frac{\left[\begin{array}{c}\frac{\alpha M B' x^\alpha}{(1-u)}\left[(1-u-x)(1-\beta)+ux\right]+ \\ (1-x)\left[1-\beta(1-\delta)\right]\left[\frac{-(1-\beta_s)(1-B'x^\alpha M)}{(1-(1-x)\beta_s)} + \frac{\left(1-\beta_s^{1-\gamma}\right)WM}{A^L\left(1-(1-x)\beta_s^{1-\gamma}\right)}\right]\end{array}\right]}{u(1+h_c)(1-u)}\lambda
\end{aligned}$$

Note that for $\beta_s = 1$, we have $\kappa > 0$ since $\delta \leq 1$ implies $1 \geq u + x$.

We will now show that $\frac{\partial\kappa}{\partial\delta_s} < 0$ if β_s is close to 1 (or δ_s close to zero). A more general proof seems impossible. We have

$$\begin{aligned}
\frac{\partial\kappa}{\partial\delta_s} &= \frac{\frac{\partial h_c}{\partial\beta_s}\kappa}{1+h_c} \\
&\quad -\frac{\lambda(1-x)}{u(1-u)}\left[\frac{\left[1-\beta(1-\delta)\right]}{(1+h_c)}\left[\begin{array}{c}\frac{(1-B'x^\alpha M)\left[(1-(1-x)\beta_s)-(1-\beta_s)(1-x)\right]}{(1-(1-x)\beta_s)^2} + M \\ \frac{\left[-\beta_s^{-\gamma}(1-\gamma)W + \left(1-\beta_s^{1-\gamma}\right)\frac{\partial W}{\partial\beta_s}\right] A^L\left(1-(1-x)\beta_s^{1-\gamma}\right) - \left(1-\beta_s^{1-\gamma}\right)W\left[\begin{array}{c}\frac{\partial A^L}{\partial\beta_s}\left(1-(1-x)\beta_s^{1-\gamma}\right) \\ -A^L(1-x)(1-\gamma)\beta_s^{-\gamma}\end{array}\right]}{\left(A^L\left(1-(1-x)\beta_s^{1-\gamma}\right)\right)^2}\end{array}\right]\right]
\end{aligned}$$

It is easily shown that $\frac{\partial h_c}{\partial \beta_s} = -\beta(1-\delta)\frac{\partial A^L}{\partial \beta_s}\frac{1}{(A^L)^2} < 0$. For $\kappa > 0$, this implies that $\frac{\frac{\partial h_c}{\partial \beta_s}\kappa}{1+h_c} < 0$. Furthermore, the range of values of β_s we are interested in here is the one for which κ is positive, or "just" negative. Hence $\frac{\frac{\partial h_c}{\partial \beta_s}\kappa(1+h_c)}{(1+h_c)^2} < 0$. Setting $\beta_s = 1$ yields $W = \Theta' = \frac{1}{M} - g[1-\beta(1-\delta)]$, $\left(1-\beta_s^{1-\gamma}\right) = 0$ and $\left(1-(1-x)\beta_s^{1-\gamma}\right) = x$, implying that for $\frac{\partial \kappa}{\partial \delta_s} < 0$, we must have

$$\gamma > \frac{B' x^{\alpha} M \beta(1-\delta)}{1 - B' x^{\alpha} M(1-\beta(1-\delta))}$$

This is easily fulfilled under the calibrations considered in this paper.[22]

To derive the effect of γ on κ let us rewrite κ as

$$\kappa = \frac{\left[\begin{array}{c} \frac{\frac{\alpha M B' x^{\alpha}}{(1-u)}[(1-u-x)(1-\beta)+ux]}{(1-u)} + \\ \\ [1-\beta(1-\delta)]\left[-a^u\left(1-B' x^{\alpha} M\right) + w^u \frac{WM}{A^L}\right] \end{array}\right]}{(1+h_c)}\lambda$$

Note that in this expression, only the $w^n W$ term depends on γ. Let $f(\gamma) = w^n W$. Then $\frac{\partial \kappa}{\partial \gamma} < 0$ if and only if $f'(\gamma) < 0$. It will be convenient to take the log of $f(\gamma)$ before taking the derivative with respect to γ, which yields

$$\frac{f'(\gamma)}{f(\gamma)} = \frac{\frac{\partial w^n}{\partial \gamma}}{w^n} + \frac{\frac{\partial W}{\partial \gamma}}{W}$$

Using proposition 1 yields $\frac{\frac{\partial w^u}{\partial \gamma}}{w^u} = \frac{\ln\left(\beta_s^{1-\gamma}\right)\beta_s^{1-\gamma} x}{\left(1-\beta_s^{1-\gamma}\right)(1-(1-x)\beta_s)}$. This is always negative if $\gamma < 1$ and

[22] One might wonder why the condition in the proposition does not simply say $\gamma > 0$. Note first that this is merely a sufficient, not a necessary and sufficient condition. The necessary and sufficient value of γ would be lower. Furthermore, it can obtained from (10) that even if there is no real-wage rigidity and thus W_t would move by the same percentage as A_t^L the effects of a decline or increase in the average skill level would not be neutral. This is because the t+1 flow profit associated with hiring in t $mc_{t+1}A_{t+1}^P - W_{t+1}^0$ does not depend on the skill level of the average applicant. Thus a permanent decline in A_t^L affect mc_t in some way even if there is no real-wage rigidity. The resulting effect can be obtained from (17) by setting $\gamma = 0$ in the squared bracket: $\left(\left(a_1^L - a_2^L\right) - \left(w_1^L - w_2^L\right)\right)\frac{(1-x)}{u}\frac{(1-\beta_s)}{(1-(1-x)\beta_s)}$.

$\beta_s < 1$, but would be zero for $\gamma = 1$ or $\beta_s = 1$. Since $W = \Theta' W^L = \frac{xA^L 1[1/M - g(1-(1-\delta)\beta)] + x\frac{(1-\delta)\beta}{M}\left(1-A^L\right)}{\left(1-(1-x)\beta_s^{1-\gamma}\right)(1-\delta)\beta + x(1-(1-\delta)\beta)}$, we have $\frac{\frac{\partial W}{\partial \gamma}}{W} = -\frac{(1-x)\ln\left(\beta_s^{1-\gamma}\right)\beta_s^{1-\gamma}}{\left(1-(1-x)\beta_s^{1-\gamma}\right)(1-\delta)\beta + x(1-(1-\delta)\beta)}$. This is always positive if $\gamma < 1$ and $\beta_s < 1$. Hence we note that $\gamma < 1$ and $\beta_s < 1$ is a necessary condition for $f'(\gamma) < 0$ and thus $\frac{\partial \kappa}{\partial \gamma} < 0$, though not sufficient. Plugging $\frac{\frac{\partial w^n}{\partial \gamma}}{w^n}$ and $\frac{\frac{\partial W}{\partial \gamma}}{W}$ into $\frac{f'(\gamma)}{f(\gamma)} < 0$ yields

$$\ln\left(\beta_s^{1-\gamma}\right)\beta_s^{1-\gamma}\left[\frac{x}{\left(1-\beta_s^{1-\gamma}\right)\left(1-(1-x)\beta_s^{1-\gamma}\right)} - \frac{1-x}{\left(1-(1-x)\beta_s^{1-\gamma}\right)(1-\delta)\beta + x(1-(1-\delta)\beta)}\right] < 0$$

For $\gamma < 1$ and $\beta_s < 1$, this implies that $f'(\gamma) < 0$ if and only if

$$x(1-\delta)\beta + \frac{x(1-(1-\delta)\beta)}{\left(1-(1-x)\beta_s^{1-\gamma}\right)} > (1-x)\left(1-\beta_s^{1-\gamma}\right)$$

This condition is easily met for the calibrations used in this paper.

D Model Equations in the Form required by Sims' (2000) Code

We first use the interest feedback rule to substitute $\widehat{i}_t$ out of the Euler equation. We can then write the system in the form

$$\Gamma_0 y_t = \Gamma_1 y_{t-1} + \begin{bmatrix} \Psi & \Pi \end{bmatrix}\begin{bmatrix} \varepsilon_t \\ v_t \end{bmatrix} + \Pi \widetilde{\eta}_t$$

with $y_t = \begin{bmatrix} x_t^\pi & x_t^u & x_t^{mc} & x_t^n & x_t^c & \widehat{a}_t^P & \pi_t & \widehat{u}_t & \widehat{mc}_t' & \widehat{u}_t^n & \widehat{c}_t & \widehat{a}_t^L & \widehat{w}_t^L & \widehat{i}_t \end{bmatrix}'$, $\varepsilon_t = e_t$, $v_t = \begin{bmatrix} e_t & v_t^\pi & v_t^u & v_t^{mc} & v_t^n & v_t^c \end{bmatrix}'$,with $x_t^q = E_t q_{t+1}$, the v_t^q denoting the belief shock associated with the forecast of the t+1 value of variable q and $\widehat{mc}_t' = \lambda mc_t$. Furthermore, $\Gamma_0 = [\Gamma_0^1 \; \Gamma_0^2]$ and

$$\Gamma_0^1 = \begin{pmatrix} \beta & 0 & 0 & 0 & 0 & 0 \\ 0 & -\kappa_F^* & h_c & 0 & 0 & \lambda\left(p_0 + \rho_a p_1\right) \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ -1 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & \kappa_F^* & 0 & -\lambda\left(p_0 + \rho_a p_1\right) \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$
\Gamma_0^2 = \begin{pmatrix}
-1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & \kappa_0^* & 1 & 0 & 0 & a^* & -w^* & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & c_0^* & 0 & 0 & 1 & -c_L & 0 & 0 \\
(1-\rho)\,\phi_\pi & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\
0 & 0 & 0 & -\kappa_0^* & 0 & -a^* & w^* & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0
\end{pmatrix}
$$

$$
\Gamma_1 = \begin{pmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \kappa_{L1}^{*} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-(1-x)(1-\beta_s)}{u(1-u)} & 0 & 0 & 0 & (1-x)\,\beta_s & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-(1-x)\left(1-\beta_s^{1-\gamma}\right)}{u(1-u)} & 0 & 0 & 0 & 0 & (1-x)\,\beta_s^{1-\gamma} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -c_1^{*} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\rho \\
0 & 0 & 0 & 0 & 0 & \rho_a & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -\kappa_{L1}^{*} & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{pmatrix}
$$

$$\Psi = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad \Pi = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

E Derivation of the Laws of Motion of $\widehat{a}_t^L$ and $\widehat{w}_t^L$

A log linear approximation to the skill level A_t^L is given by

$$\widehat{a}_t^L = \frac{\sum_{i=0}^{\infty} ds_t^i \beta_s^i}{A^L} \tag{19}$$

The shares of the various groups of the unemployed are given by

$$s_t^i = \frac{\delta N_{t-1-i} \prod_{j=1}^{i} (1 - x_{t-j})}{U_t}$$

This can be log-linearised as

$$ds_t^i = s^i \left[\widehat{n}_{t-1-i} - \widehat{U}_t + \sum_{j=1}^{i} \frac{-x}{1-x} \widehat{x}_{t-j} \right]$$

Log linear approximations to x_t and U_t are given by $\widehat{x}_{t-j} = \frac{\widehat{n}_{t-j} - (1-\delta)(1-x)\widehat{n}_{t-1-j}}{\delta}$ and $\widehat{U}_t =$

$-\frac{(1-\delta)x}{\delta}\widehat{n}_t$. Substituting these yields

$$\begin{aligned}
ds_t^i &= s^i\left[\widehat{n}_{t-1-i}+\frac{1-\delta}{\delta}x\widehat{n}_{t-1}-\sum_{j=1}^{i}\frac{-x}{1-x}\frac{\widehat{n}_{t-j}-(1-\delta)(1-x)\widehat{n}_{t-1-j}}{\delta}\right]\\
&= s^i\left[\widehat{n}_{t-1-i}+\frac{1-\delta}{\delta}x\widehat{n}_{t-1}-\frac{x}{1-x}\left[\sum_{j=1}^{i}\frac{\widehat{n}_{t-j}}{\delta}-\frac{(1-\delta)(1-x)}{\delta}\sum_{j=1}^{i}\frac{\widehat{n}_{t-j-1}}{\delta}\right]\right]\\
&= s^i\left[\widehat{n}_{t-1-i}+\frac{1-\delta}{\delta}x\widehat{n}_{t-1}-\frac{x}{1-x}\left[\begin{array}{c}\sum_{j=2}^{i}\frac{\widehat{n}_{t-j}}{\delta}+\frac{\widehat{n}_{t-1}}{\delta}\\ -\frac{(1-\delta)(1-x)}{\delta}\sum_{j=2}^{i}\frac{\widehat{n}_{t-j}}{\delta}-\frac{(1-\delta)(1-x)}{\delta}\widehat{n}_{t-j-1}\end{array}\right]\right]\\
&= s^i\left[\begin{array}{c}\widehat{n}_{t-1-i}\left[1+\frac{x(1-\delta)}{\delta}\right]+\frac{1-\delta}{\delta}x\widehat{n}_{t-1}-\frac{x}{1-x}\frac{\widehat{n}_{t-1}}{\delta}\\ -\frac{x}{1-x}\left(\frac{1}{\delta}-\frac{(1-\delta)(1-x)}{\delta}\right)\sum_{j=2}^{i}\frac{\widehat{n}_{t-j}}{\delta}\end{array}\right]\\
&= s^i\left[\begin{array}{c}\widehat{n}_{t-1-i}\left[1+\frac{x(1-\delta)}{\delta}\right]-\frac{x}{1-x}\left(\frac{1}{\delta}-\frac{(1-\delta)(1-x)}{\delta}\right)\widehat{n}_{t-1}\\ -\frac{x}{1-x}\left(\frac{1}{\delta}-\frac{(1-\delta)(1-x)}{\delta}\right)\sum_{j=2}^{i}\frac{\widehat{n}_{t-j}}{\delta}\end{array}\right]\\
&= s^i\left[\widehat{n}_{t-1-i}\left[1+\frac{x(1-\delta)}{\delta}\right]-\left(\frac{x^2}{\delta(1-x)}+x\right)\sum_{j=1}^{i}\frac{\widehat{n}_{t-j}}{\delta}\right]
\end{aligned}$$

We now use $\delta=\frac{ux}{(1-x)(1-u)}$ and $(1-\delta)=\frac{1-u-x}{(1-x)(1-u)}$ to eliminate δ in the $1+\frac{(1-\delta)x}{\delta}$ and $\frac{x^2}{\delta(1-x)}+x$ terms. This yields

$$\begin{aligned}
1+x\frac{(1-\delta)}{\delta} &= 1+x\frac{(1-u-x)}{(1-x)(1-u)}\frac{(1-x)(1-u)}{ux}=1+\frac{1-u-x}{u}=\frac{1-x}{u}\\
\frac{x^2}{\delta(1-x)}+x &= \frac{x^2}{\frac{ux}{(1-x)(1-u)}(1-x)}+x=\frac{x}{u}(1-u)+x=\frac{x}{u}
\end{aligned}$$

Hence we can write

$$ds_t^i=s^i\left[-\frac{x}{u}\sum_{j=1}^{i}\widehat{n}_{t-j}+\frac{1-x}{u}\widehat{n}_{t-1-i}\right] \tag{20}$$

Substituting this into (19) yields

$$
\begin{aligned}
\widehat{a}_t^L &= \frac{\sum\limits_{i=0}^{\infty}\beta_s^i s^i \left[-\frac{x}{u}\sum\limits_{j=1}^{i}\widehat{n}_{t-j} + \frac{1-x}{u}\widehat{n}_{t-1-i}\right]}{A^L} \\
&= \frac{1}{A^L}\left[\frac{1-x}{u}\sum_{i=0}^{\infty}\beta_s^i s^i \widehat{n}_{t-1-i} - \frac{x}{u}\sum_{i=0}^{\infty}\sum_{j=1}^{i}\beta_s^i s^i \widehat{n}_{t-j}\right] \\
&= \frac{1}{A^L}\left[\frac{1-x}{u}\sum_{i=0}^{\infty}\beta_s^i s^i \widehat{n}_{t-1-i} - \frac{x}{u}\sum_{q=1}^{\infty}\beta_s^q s^q \sum_{j=1}^{q}\widehat{n}_{t-j}\right] \\
&= \frac{1}{A^L}\left[\frac{1-x}{u}\sum_{i=0}^{\infty}\beta_s^i s^i \widehat{n}_{t-1-i} - \frac{x}{u}\sum_{q=1}^{\infty}\beta_s^q s^q \left(\widehat{n}_{t-1} + \widehat{n}_{t-2} + \widehat{n}_{t-3}\ldots + \widehat{n}_{t-q}\right)\right] \\
&= \frac{1}{A^L}\left[\begin{array}{c}
\frac{1-x}{u}\sum\limits_{i=0}^{\infty}\beta_s^i s^i \widehat{n}_{t-1-i} \\
-\frac{x}{u}\left[\beta_s^1 s^1 \widehat{n}_{t-1} + \beta_s^2 s^2\left(\widehat{n}_{t-1} + \widehat{n}_{t-2}\right) + \beta_s^3 s^3\left(\widehat{n}_{t-1} + \widehat{n}_{t-2} + \widehat{n}_{t-3}\right)\ldots\ldots\right]
\end{array}\right] \\
&= \frac{1}{A^L}\left[\begin{array}{c}
\left[\frac{1-x}{u}\sum\limits_{i=0}^{\infty}\beta_s^i s^i \widehat{n}_{t-1-i}\right] \\
-\frac{x}{u}\left[\begin{array}{c}
\left(\sum\limits_{q=1}^{\infty}\beta_s^q s^q\right)\widehat{n}_{t-1} + \left(\sum\limits_{q=2}^{\infty}\beta_s^q s^q\right)\widehat{n}_{t-2} \\
+\left(\sum\limits_{q=3}^{\infty}\beta_s^q s^q\right)\widehat{n}_{t-3} + \left(\sum\limits_{q=4}^{\infty}\beta_s^q s^q\right)\widehat{n}_{t-4}\ldots
\end{array}\right]
\end{array}\right] \\
&= \frac{1}{A^L}\left[\begin{array}{c}
\frac{1-x}{u}\left[s^0 \widehat{n}_{t-1} + \beta_s^1 s^1 \widehat{n}_{t-2} + \beta_s^2 s^2 \widehat{n}_{t-3} + \beta_s^3 s^3 \widehat{n}_{t-4}\ldots\ldots\right] \\
-\frac{x}{u}\left[\begin{array}{c}
\left(\sum\limits_{q=1}^{\infty}\beta_s^q s^q\right)\widehat{n}_{t-1} + \left(\sum\limits_{q=2}^{\infty}\beta_s^q s^q\right)\widehat{n}_{t-2} \\
+\left(\sum\limits_{q=3}^{\infty}\beta_s^q s^q\right)\widehat{n}_{t-3} + \left(\sum\limits_{q=4}^{\infty}\beta_s^q s^q\right)\widehat{n}_{t-4}\ldots
\end{array}\right]
\end{array}\right] \\
&= \frac{1}{A^L}\left[\begin{array}{c}
\left[s^0\frac{1-x}{u} - \frac{x}{u}\left(\sum\limits_{q=1}^{\infty}\beta_s^q s^q\right)\right]\widehat{n}_{t-1} + \left[s^1\frac{1-x}{u} - \frac{x}{u}\left(\sum\limits_{q=2}^{\infty}\beta_s^q s^q\right)\right]\widehat{n}_{t-2} \\
+\left[s^2\frac{1-x}{u} - \frac{x}{u}\left(\sum\limits_{q=3}^{\infty}\beta_s^q s^q\right)\right]\widehat{n}_{t-3} + \left[s^3\frac{1-x}{u} - \frac{x}{u}\left(\sum\limits_{q=4}^{\infty}\beta_s^q s^q\right)\right]\widehat{n}_{t-4}\ldots
\end{array}\right] \\
&= \frac{1}{A^L}\sum_{i=1}^{\infty}\left[\left[\beta_s^{i-1}s^{i-1}\frac{1-x}{u} - \frac{x}{u}\left(\sum_{q=i}^{\infty}\beta_s^q s^q\right)\right]\widehat{n}_{t-i}\right]
\end{aligned}
$$

Using $A^L = \sum_{i=0}^{\infty} s^i \beta_s^i = \frac{x}{1-(1-x)\beta_s}$ and $s^i = x(1-x)^i$ we can write $\left(\sum_{q=i}^{\infty} \beta_s^q s^q\right) = x \sum_{q=i}^{\infty} \beta_s^q (1-x)^q = \beta_s^i (1-x)^i x \sum_{q=0}^{\infty} \beta_s^q (1-x)^q = \beta_s^i (1-x)^i A^L$ and thus arrive at

$$\widehat{a}_t^L = \frac{x}{u} \sum_{i=1}^{\infty} \left[\left[\frac{\beta_s^{i-1} (1-x)^i}{A^L} - \beta_s^i (1-x)^i \right] \widehat{n}_{t-i} \right]$$

Using $A^L = \frac{x}{1-(1-x)\beta_s}$, this can be rewritten as

$$\begin{aligned} \widehat{a}_t^L &= \sum_{i=1}^{\infty} \frac{1}{u} (1-x)^i \left(\beta_s^{i-1} - \beta_s^i\right) \widehat{n}_{t-i} \\ &= \sum_{i=1}^{\infty} a_i^n \widehat{n}_{t-i}, \;\; a_i^n = \frac{1}{u} (1-x)^i \left(\beta_s^{i-1} - \beta_s^i\right) \end{aligned}$$

or, if we substitute $\widehat{u}_t = -\frac{\widehat{n}_t}{1-u}$, as

$$\widehat{a}_t^L = -\sum_{i=1}^{\infty} a_i^u \widehat{n}_{t-i}, \;\; a_i^u = \frac{1}{u(1-u)} (1-x)^i \left(\beta_s^{i-1} - \beta_s^i\right)$$

To express the component of the real wage depending on the skill of the worker as a function of past employment rates, we follow an analogous process. A log linear approximation to W_t^L is given by

$$\widehat{w}_t^L = \frac{\sum_{i=0}^{\infty} ds_t^i \beta_s^{i(1-\gamma)}}{W^L}$$

Note that the only difference to (19) is that β_s and A^L are replaced by $\beta_s^{(1-\gamma)}$ and W^L, respectively. Substituting (20) and going through exactly the same process as before thus yields

$$\begin{aligned}\widehat{w}_t^L &= \sum_{i=1}^{\infty} w_i^n \widehat{n}_{t-i},\ w_i^n = \frac{1}{u}(1-x)^i \left(\beta_s^{(1-\gamma)(i-1)} - \beta_s^{(1-\gamma)i}\right) \\ &= -\sum_{i=1}^{\infty} w_i^u \widehat{n}_{t-i},\ w_i^u = \frac{1}{u(1-u)}(1-x)^i \left(\beta_s^{(1-\gamma)(i-1)} - \beta_s^{(1-\gamma)i}\right)\end{aligned}$$

We now turn to express $\widehat{a}_t^L$ and $\widehat{w}_t^L$ as a function of their $t-1$ values and past employment. For $\widehat{a}_t^L$ we have

$$\begin{aligned}\widehat{a}_t^L &= \frac{1}{u}(1-x)(1-\beta_s)\widehat{n}_{t-1} + \frac{1}{u}\sum_{i=2}^{\infty}(1-x)^i\left(\beta_s^{i-1} - \beta_s^i\right)\widehat{n}_{t-i} \\ &= \frac{1}{u}(1-x)(1-\beta_s)\widehat{n}_{t-1} + \frac{1}{u}\sum_{i=1}^{\infty}(1-x)^{i+1}\left(\beta_s^{i} - \beta_s^{i+1}\right)\widehat{n}_{t-i} \\ &= \frac{1}{u}(1-x)(1-\beta_s)\widehat{n}_{t-1} + \beta_s(1-x)\frac{1}{u}\sum_{i=1}^{\infty}(1-x)^i\left(\beta_s^{i-1} - \beta_s^i\right)\widehat{n}_{t-i}\end{aligned}$$

and thus

$$\widehat{a}_t^L = (1-x)\left(\frac{1}{u}(1-\beta_s)\widehat{n}_{t-1} + \beta_s\widehat{a}_{t-1}^L\right) \tag{21}$$

Correspondingly for $\widehat{w}_t^L$ we have

$$\widehat{w}_t^L = (1-x)\left(\frac{1}{u}\left(1-\beta_s^{1-\gamma}\right)\widehat{n}_{t-1} + \beta_s^{1-\gamma}\widehat{w}_{t-1}^L\right) \tag{22}$$

F Derivation of the marginal Cost Equation and the Output Equation in the Model with Skill Loss

This appendix derives equations (14), ($M2$) and the linearised net and gross output equations. Linearising equation (10) yields

$$
\begin{aligned}
\widehat{mc}_t = &- (1 - Mg)\,\widehat{a}_t^P \\
&- (1 - Mg)\,\widehat{a}_t^L + \frac{M}{A^L} W \widehat{w}_t + M\alpha g \widehat{x}_t \\
&- (1-\delta)\,\beta E_t \left[\begin{array}{c} X\left(\widehat{c}_t - \widehat{c}_{t+1}\right) + \left(\frac{1-A^L}{A^L}\right)\widehat{mc}_{t+1} + \left[\left(\frac{1-A^L}{A^L}\right) - \frac{(1-\gamma)\Theta M}{A^L} + Mg\right]\widehat{a}_{t+1}^P \\ - (1-Mg)\,\widehat{a}_{t+1}^L + \frac{M}{A^L} W \widehat{w}_{t+1} + M\alpha g \widehat{x}_{t+1} \end{array} \right]
\end{aligned}
\tag{23}
$$

with $X = gM + \frac{1-A^L-M(\Theta'-W)}{A^L}$ and $g = B'x^{\alpha}$. From (8) and (9), we see that the average wage can be written up to first order as

$$
\widehat{w}_t = (1 - \gamma_P)\,\widehat{a}_t^P + \widehat{w}_t^L \tag{24}
$$

Using (24) on (23) gives

$$\widehat{mc}_t = -(1-Mg)\left(\widehat{a}_t^L - \beta(1-\delta)E_t\widehat{a}_{t+1}^L\right) \tag{25}$$

$$+\frac{M}{A^L}W\left[\widehat{w}_t^L - (1-\delta)\beta E_t\widehat{w}_{t+1}^L\right] \tag{26}$$

$$-\Phi'\widehat{a}_t^P - \beta(1-\delta)\left[\frac{1-(1-\gamma)\Theta' M}{A^L} - \Phi'\right]E_t\widehat{a}_{t+1}^P + M\alpha g\widehat{x}_t$$

$$-\beta(1-\delta)E_t\left[X(\widehat{c}_t - \widehat{c}_{t+1}) + \left(\frac{1-A^L}{A^L}\right)\widehat{mc}_{t+1} + M\alpha g\widehat{x}_{t+1}\right]$$

$$\Phi' = 1 - gM - (1-\gamma_P)\frac{M}{A^L}W$$

Linearising (13) yields

$$\widehat{c}_t = \frac{A^A}{A^A - A^L g\delta}\widehat{a}_t^A - \frac{Ag\delta}{A^A - A^L g\delta}\left(\widehat{a}_t^L + \widehat{a}_t^P\right) + \xi_0'\widehat{n}_t + \xi_1'\widehat{n}_{t-1} \tag{27}$$

with $\xi_0' = \frac{A^L(1-g(1+\alpha))}{A^A - Ag\delta}$ and $\xi_1' = \frac{(1-\delta)\left((1+\alpha(1-x))A^L g + \left(1-A^L\right)\right)}{A^A - A^L g\delta}$. Linearising (12), (13) and combining the two yields

$$\widehat{a}_t^A = \frac{A^L\delta}{A^A}\widehat{a}_t^L + \widehat{a}_t^P - \frac{\left(1-A^L\right)(1-\delta)}{A^A}\left(\widehat{n}_t - \widehat{n}_{t-1}\right) \tag{28}$$

Substituting this into (27) yields

$$\widehat{c}_t = \widehat{a}_t^P + c^L\widehat{a}_t^L + \xi_0'\widehat{n}_t + \xi_1'\widehat{n}_{t-1} \tag{29}$$

$$c^L = \frac{A^L\delta(1-g)}{A^A - A^L g\delta}$$

Substituting (29) into (25) yields

$$
\begin{aligned}
\widehat{mc}_t &= a_1^L \widehat{a}_t^L + a_2^L E_t \widehat{a}_{t+1}^L + \frac{M}{A^L} W \left[\widehat{w}_t^L - \beta (1-\delta) E_t \widehat{w}_{t+1}^L \right] \\
&\quad - p_0 \widehat{a}_t^P - p_1 E_t \widehat{a}_{t+1}^P + M \alpha g \widehat{x}_t \\
&\quad + \beta (1-\delta) \left[\begin{array}{c} X \left(\xi_0' - \xi_1' \right) \widehat{n}_t + X \xi_0' E_t \widehat{n}_{t+1} \\ - \beta (1-\delta) \xi_1' \widehat{n}_{t-1} - \left(\frac{1-A^L}{A^L} \right) \widehat{mc}_{t+1} - M \alpha g \widehat{x}_{t+1} \end{array} \right] \\
a_1^L &= 1 - gM + \beta (1-\delta) \frac{A^L \delta (1-g)}{A^A - A g \delta} X \\
a_2^L &= \beta (1-\delta) \left[1 - gM + \frac{A^L \delta (1-g)}{A^A - A g \delta} X \right] \\
p_0 &= \Phi' + \beta (1-\delta) X, \;\; p_1 = \beta (1-\delta) \frac{\gamma M (\Theta' - W)}{A^L}
\end{aligned}
$$

Using $\widehat{x}_t = \frac{\widehat{n}_t - (1-\delta)(1-x)\widehat{n}_{t-1}}{\delta}$ then yields

$$
\begin{aligned}
\widehat{mc}_t &= -a_1^L \widehat{a}_t^L + a_2^L E_t \widehat{a}_{t+1}^L + w_1^L \widehat{w}_t^L - w_2^L E_t \widehat{w}_{t+1}^L - p_0 \widehat{a}_t^P - p_1 E_t \widehat{a}_{t+1}^P \\
&\quad + h_0' \widehat{n}_t + h_L' \widehat{n}_{t-1} + h_F' E_t \widehat{n}_{t+1} - h_c E_t \widehat{mc}_{t+1}
\end{aligned} \tag{30}
$$

Using $\widehat{n}_t = \frac{-\widehat{u}_t}{1-u}$ then yields equation (14). We now substitute (21) and (22) into (30) which, after rearranging, yields

$$
\begin{aligned}
\widehat{mc}_t &= -\left(a_1^L - a_2^L (1-x) \beta_s \right) \widehat{a}_t^L + \left(w_1^L - w_2^L (1-x) \beta_s^{1-\gamma} \right) \widehat{w}_t^L \\
&\quad - \left[h_0' + (1-x) \left(a_2^L \frac{(1-\beta_s)}{u} - w_2^L \frac{\left(1-\beta_s^{1-\gamma}\right)}{u} \right) \right] \widehat{n}_t \\
&\quad + h_L' \widehat{n}_{t-1} + h_F' E_t \widehat{n}_{t+1} - h_c E_t \widehat{mc}_{t+1} - p_0 \widehat{a}_t^P - p_1 E_t \widehat{a}_{t+1}^P
\end{aligned}
$$

Using $\widehat{n}_t = \frac{-\widehat{u}_t}{1-u}$ then yields equation $(M2)$:

$$
\begin{aligned}
\lambda\widehat{mc}_t &= -a^*\widehat{a}_t^L + w^*\widehat{w}_t^L - \kappa_0^*\widehat{u}_t + \kappa_L^*\widehat{u}_{t-1} + \kappa_F^* E_t\widehat{u}_{t+1} - \lambda h_c E_t\widehat{mc}_{t+1} - \lambda\left(p_0 + \rho_a p_1\right)\widehat{a}_t^P \\
a^* &= \lambda\left(a_1^L - a_2^L\left(1-x\right)\beta_s\right) \\
w^* &= \lambda\left(w_1^L - w_2^L\left(1-x\right)\beta_s^{1-\gamma}\right) \\
\kappa_0^* &= \frac{\lambda}{1-u}\left[h_0^{'} + \left(1-x\right)\left(a_2^L\frac{\left(1-\beta_s\right)}{u} - w_2^L\frac{\left(1-\beta_s^{1-\gamma}\right)}{u}\right)\right] \\
\kappa_L^* &= \frac{-\lambda h_L^{'}}{1-u}, \kappa_F^* = \frac{-\lambda h_F^{'}}{1-u}
\end{aligned}
$$

The equation for output including hiring costs is derived as follows. We have $Y_t = A_t^A N_t$. Linearising gives $\widehat{y}_t = \widehat{a}_t^A + \widehat{n}_t$ which, using (28) can be written as

$$
\begin{aligned}
\widehat{y}_t &= \widehat{a}_t^P + \frac{1}{A^A}\left[A^L\delta\widehat{a}_t^L + A^L\widehat{n}_t + \left(1-A^L\right)\left(1-\delta\right)\widehat{n}_{t-1}\right] \\
&= \widehat{y}_t = \widehat{a}_t^P + y^L\widehat{a}_t^L - y_0\widehat{u}_t - y_1\widehat{u}_{t-1}
\end{aligned}
$$

with $y^L = \frac{A^L\delta}{A^A}$, $y_0 = \frac{A^L}{A^A(1-u)}$ and $y_1 = \frac{\left(1-A^L\right)(1-\delta)}{A^A(1-u)}$.

G Tables

$h_c = \beta(1-\delta)\frac{(1-A^L)}{A^L}$	$a_i^n = \frac{1}{u(1-u)}(1-x)^i\left(\beta_s^{i-1} - \beta_s^i\right)$
$h_F' = -\beta(1-\delta)\left(\frac{\alpha g M}{\delta} - \xi_0' X\right)$	$w_i^n = \frac{1}{u(1-u)}(1-x)^i\left(\beta_s^{(1-\gamma)(i-1)} - \beta_s^{(1-\gamma)i}\right)$
$h_0' = \left(\frac{\alpha g M}{\delta}\right)\left(1+\beta(1-\delta)^2(1-x)\right) + \beta(1-\delta)\left(\xi_1' - \xi_0'\right)X$	
$h_L' = -\left(\frac{\alpha g M}{\delta}\right)(1-\delta)(1-x) - \beta(1-\delta)\xi_1' X$	
$a_1^L = 1 - gM + \beta(1-\delta)\frac{A^L\delta(1-g)}{A^A - Ag\delta}X$	$\kappa_0^* = \frac{\lambda}{1-u}\left[h_0' + (1-x)\left(a_2^L\frac{(1-\beta_s)}{u} - w_2^L\frac{\left(1-\beta_s^{1-\gamma}\right)}{u}\right)\right]$
$a_2^L = \beta(1-\delta)\left[1 - gM + \frac{A^L\delta(1-g)}{A^A - Ag\delta}X\right]$	$\kappa_L^* = \frac{-\lambda h_L'}{1-u}$, $\kappa_F^* = \frac{-\lambda h_F'}{1-u}$
$w_1^L = \frac{M}{A^L}W$, $w_2^L = \beta(1-\delta)\frac{M}{A^L}W$	$a^* = \lambda\left(a_1^L - a_2^L(1-x)\beta_s\right)$
$p_1 = \beta(1-\delta)\frac{\gamma M(\Theta' - W)}{A^L}$	$w^* = \lambda\left(w_1^L - w_2^L(1-x)\beta_s^{1-\gamma}\right)$
$p_0 = \Phi' + \beta(1-\delta)X$	$c^L = \frac{A^L\delta(1-g)}{A^A - A^L g\delta}$
$X = gM + \frac{1-A^L-M(\Theta'-W)}{A^L}$	$y^L = \frac{A^L\delta}{A^A}$
$g = B'x^\alpha$	$y_0 = \frac{A^L}{A^A(1-u)}$
$\Phi' = 1 - gM - (1-\gamma_P)\frac{M}{A^L}W$	$y_1 = \frac{\left(1-A^L\right)(1-\delta)}{A^A(1-u)}$

Table 1: Reduced Form Coefficients

Parameter	"American"	"European"
β	0.99	0.99
λ	0.08	0.08
θ	6	6
M	1.2	1.2
α	1	1
x	**0.9**	**0.2**
u	**0.05**	**0.1**
$\boldsymbol{\delta}$	**0.47**	**0.03**
B'	0.12	0.12
γ	$[0,1]$	$[0,1]$

Table 2: Calibration

		γ									
		0, 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
$\boldsymbol{\delta}_s$	0	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$
	0.005	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$2.9 > \phi_\pi > 1$
	0.01	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$2.4 > \phi_\pi > 1$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$
	0.015	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$2.9 > \phi_\pi > 1$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$
	0.02	$\phi_\pi > 1$	$\phi_\pi > 1$	$\phi_\pi > 1$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$
	0.025	$\phi_\pi > 1$	$\phi_\pi > 1$	$2.6 > \phi_\pi > 1$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$
	0.03	$\phi_\pi > 1$	$\phi_\pi > 1$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$
	0.035	$\phi_\pi > 1$	$\phi_\pi > 1$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$
	0.04	$\phi_\pi > 1$	$\phi_\pi > 1$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$
	0.045	$\phi_\pi > 1$	$\phi_\pi > 1$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$
	0.05	$\phi_\pi > 1$	$\phi_\pi > 1$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$
	0.055	$\phi_\pi > 1$	$3 > \phi_\pi > 1$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$
	0.06	$\phi_\pi > 1$	$2.9 > \phi_\pi > 1$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$
	0.065	$\phi_\pi > 1$	$2.8 > \phi_\pi > 1$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$
	0.07	$\phi_\pi > 1$	$2.8 > \phi_\pi > 1$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$	$\boldsymbol{\phi_\pi < 1}$

Table 3: European Calibration (x=0.2): Determinacy Requirement on the Coefficient on Inflation

γ	**Critical value of δ_s**	**Implied Annual Skill Loss**
0.3	0.03	11.5%
0.4	0.02	7.8%
0.5-0.6	0.015	5.9%
0.7-1	0.01	3.9%

Table 4: Critical values of Skill Decay for the European Calibration

<table>
<tr><td></td><td colspan="7">γ</td><td></td></tr>
<tr><td rowspan="11">δ_s</td><td></td><td>0-0.4</td><td>0.5</td><td>0.6</td><td>0.7</td><td>0.8</td><td>0.9</td><td>1</td></tr>
<tr><td>0-0.015</td><td rowspan="10">0.1</td><td rowspan="7">0.1</td><td rowspan="4">0.1</td><td rowspan="2">0.1</td><td rowspan="2">0.1</td><td>0.1</td><td>0.1</td></tr>
<tr><td>0.02</td><td>0.2</td><td>0.2</td></tr>
<tr><td>0.025</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.2</td></tr>
<tr><td>0.03</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.3</td></tr>
<tr><td>0.035</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.3</td><td>0.3</td></tr>
<tr><td>0.04</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.3</td><td>0.4</td></tr>
<tr><td>0.045</td><td>0.2</td><td>0.2</td><td>0.3</td><td>0.3</td><td>0.4</td></tr>
<tr><td>0.05</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.3</td><td>0.4</td><td>0.4</td></tr>
<tr><td>0.055</td><td>0.2</td><td>0.2</td><td>0.3</td><td>0.3</td><td>0.4</td><td>0.4</td></tr>
<tr><td>0.06-0.07</td><td>0.2</td><td>0.2</td><td>0.3</td><td>0.3</td><td>0.4</td><td>0.5</td></tr>
</table>

Table 5: Outputgap Coefficient sufficient to guarantee Determinacy for phipi<2.1

	γ								
		0-0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	0-0.01				0.1	0.1	0.1	0.1	0.1
	0.015			0.1			0.2	0.2	0.2
	0.02					0.2	0.2	0.3	0.3
	0.025				0.2	0.2	0.3	0.3	0.4
	0.03		0.1	0.2	0.2	0.3	0.3	0.4	0.5
$\boldsymbol{\delta}_s$	0.035			0.2	0.2	0.3	0.4	0.5	0.5
	0.04	0.1		0.2	0.3	0.4	0.4	0.5	0.6
	0.045			0.2	0.3	0.4	0.5	0.6	0.7
	0.05			0.2	0.3	0.4	0.5	0.6	0.7
	0.055		0.2	0.3	0.3	0.4	0.5	0.6	0.8
	0.06		0.2	0.3	0.4	0.5	0.6	0.7	0.8
	0.065		0.2	0.3	0.4	0.5	0.6	0.7	0.9
	0.07		0.2	0.3	0.4	0.5	0.6	0.7	0.9

Table 6: Outputgap Coefficient sufficient to guarantee Determinacy for full Interval of phipi

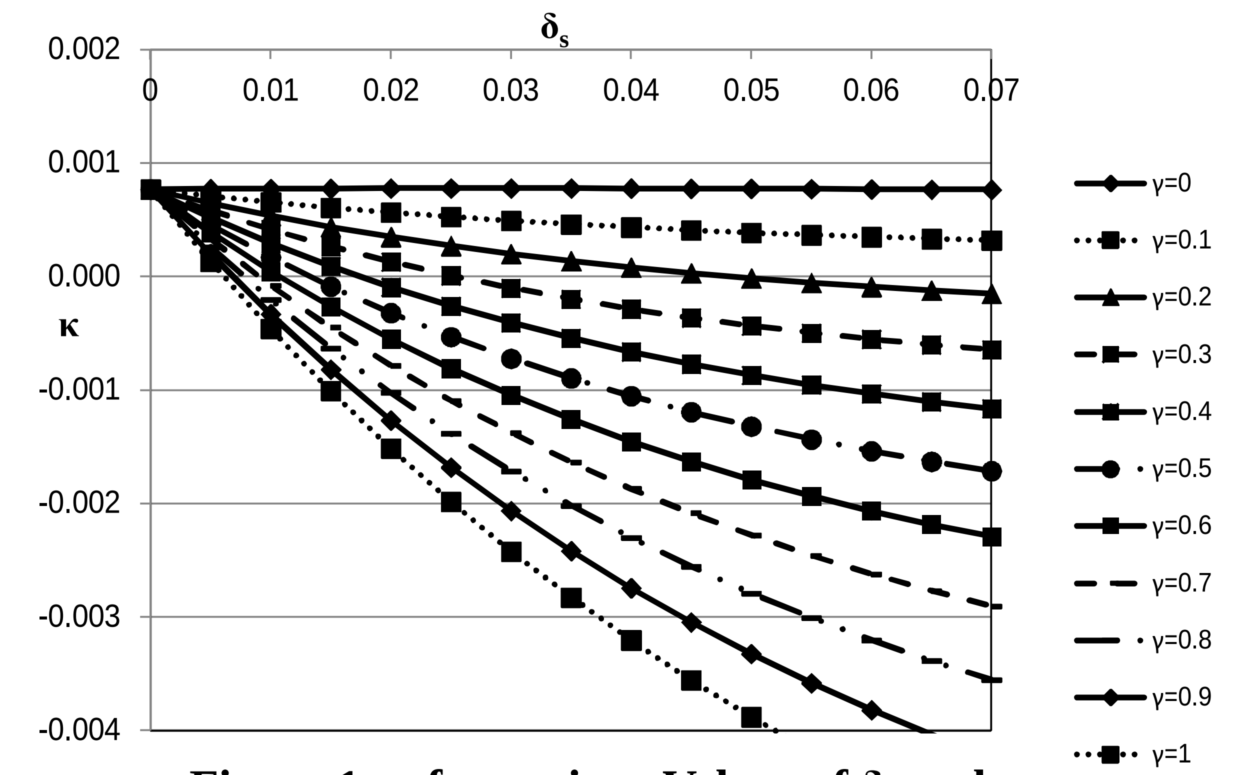

Figure 1: κ for various Values of δ_s and γ

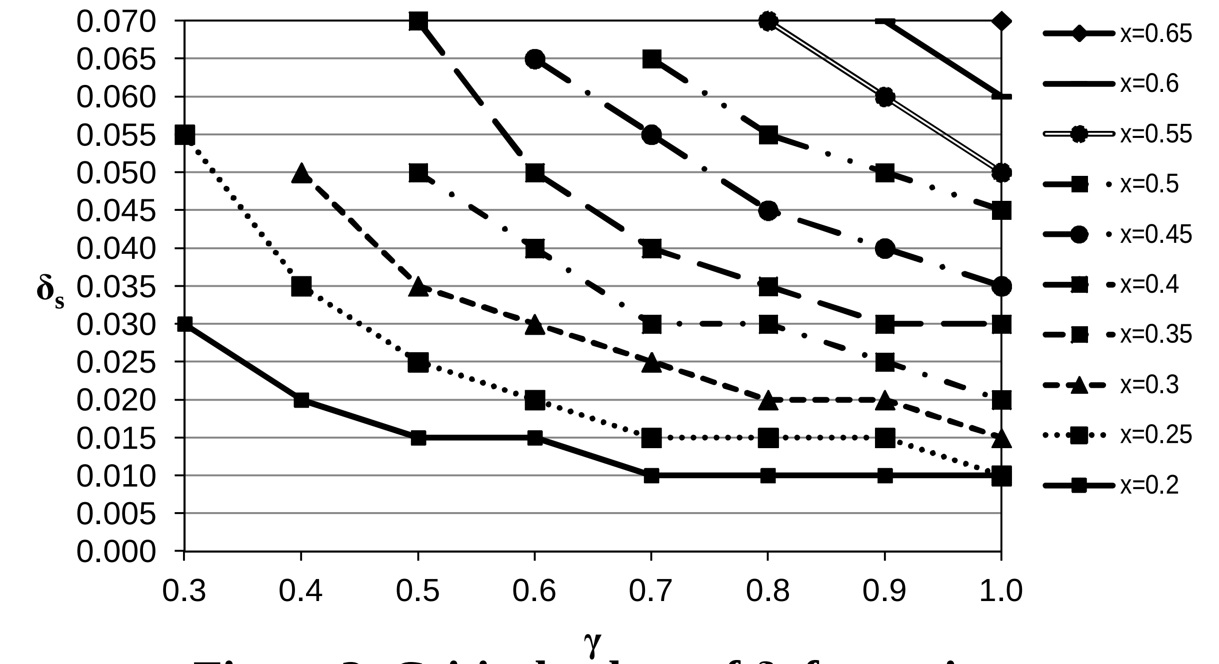

Figure 2: Critical values of δ_s for various Values of x and γ

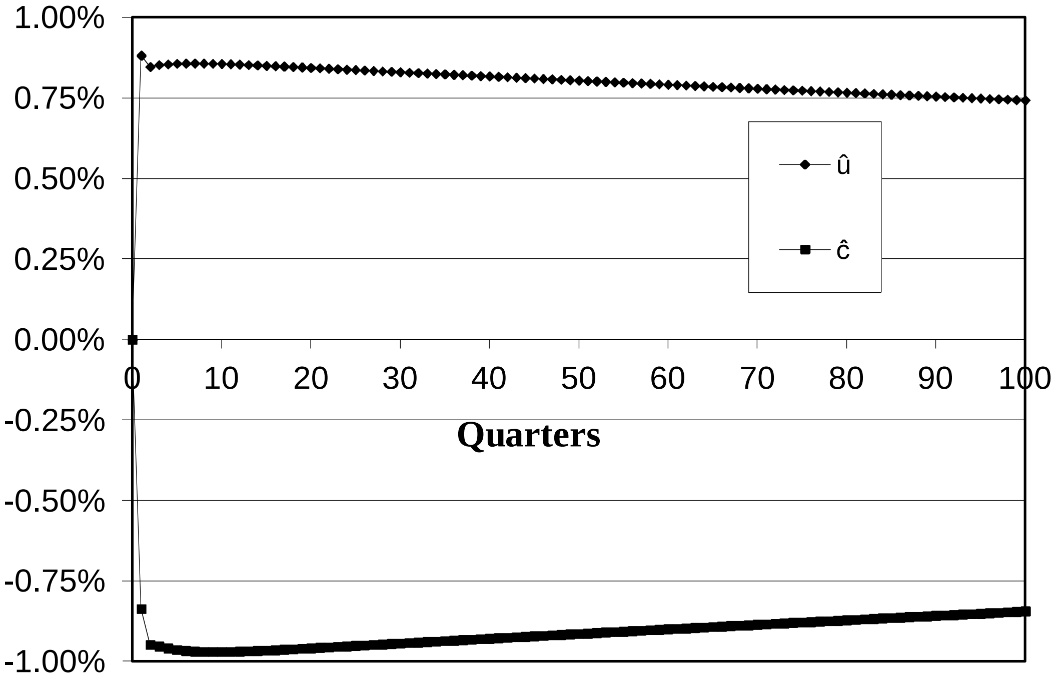

Figure 3: European Calibration, -2% Consumption Belief Shock, û and ĉ

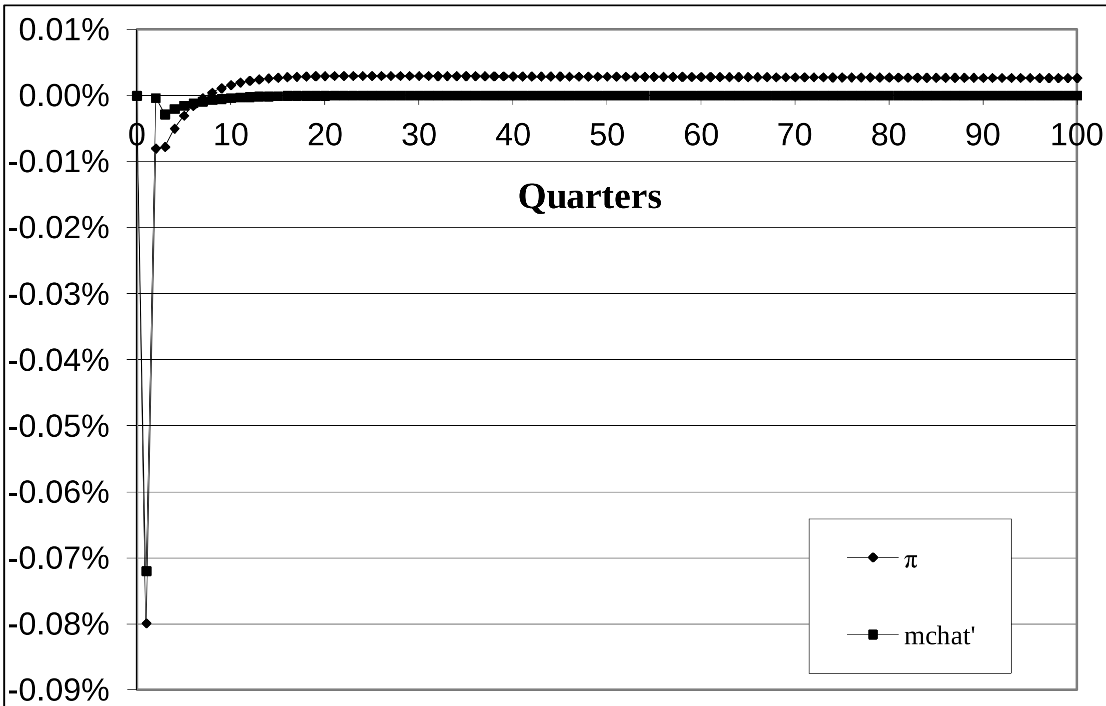

Figure 4: European Calibration, -2% Consumption Belief Shock - π and mchat'

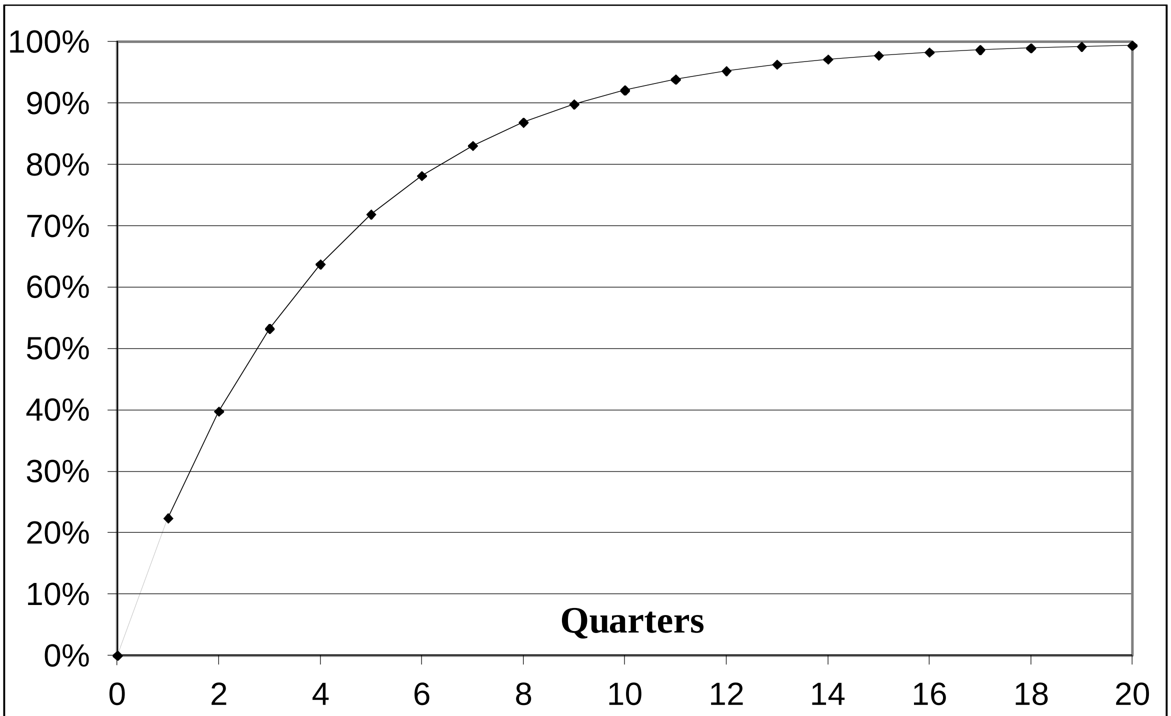

Figure 5: Skill Decline following a permanent Unemployment Increase - Percentage of total Drop

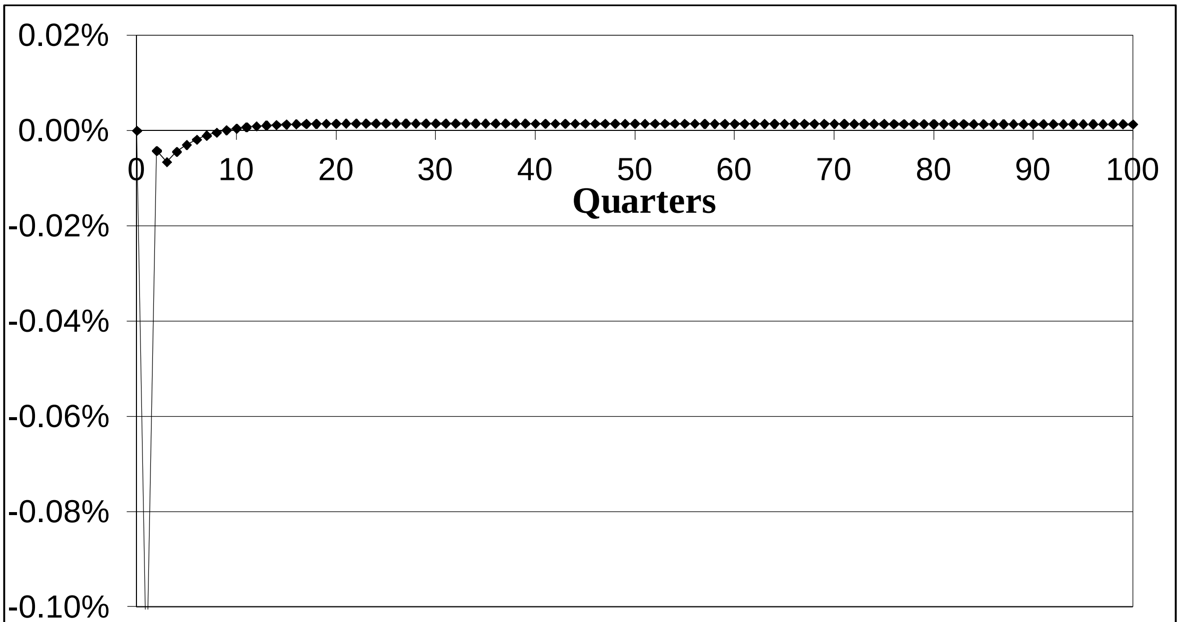

Figure 6: European Calibration, Consumption Belief Shock: Ex-ante real Interest Rate

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