

# Limited Asset Market Participation, Sticky Wages and Monetary Policy\*

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## Abstract

A small amount of nominal wage stickiness makes Limited Asset Market Participation (LAMP) irrelevant for the design of monetary policy. Recent research argues that LAMP could invert the slope of the IS curve in otherwise standard New Keynesian models. This, in turn, implies that optimal monetary policy rules should be passive. We show that the so called Inverted Aggregate Demand Logic (IADL) relies on nominal wage flexibility. Outside of extreme parameterizations, wage stickiness prevents the inversion of the slope of the IS curve. Hence, LAMP does not generally alter the trade-offs faced by a welfare maximizing Central Bank, and for this reason it does not fundamentally affect the design of optimal simple rules and optimal monetary policy.

Keywords: optimal monetary policy, sticky wages, non-Ricardian household, determinacy, Taylor principle, optimal simple rules.

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# 1 Introduction

This paper studies the implications of limited asset market participation (LAMP henceforth) for the design of monetary policy. We consider an economy characterized by staggered wage and price contracts together with LAMP. Wage and price stickiness arises from the Calvo-type mechanism. As in Galí et al. (2004, 2007), Bilbiie (2008) and in a number of recent studies, we model LAMP assuming that a portion of agents face a liquidity constraint such that they spend their current labor income in each period. The remaining households hold assets and smooth consumption. This heterogeneity between households breaks the Ricardian Equivalence. For this reason in the remainder of the paper we refer to liquidity constrained agents as to non-Ricardian consumers and symmetrically we define other agents as Ricardian consumers.<sup>1</sup>

The resulting framework nests two popular environments in the optimal monetary policy literature: Bilbiie (2008) and Erceg et al. (2000). The former studies determinacy properties of simple interest rate rules and optimal monetary policy in a NK economy with LAMP and a frictionless labor market. The latter develop a full participation NK model characterized by both staggered prices and wages which features an endogenous trade-off between the stabilization of the output gap, price inflation and wage inflation. Hence, Bilbiie (2008) features sticky prices and LAMP, but not sticky wages; Erceg et al. (2000), instead, features sticky prices and wages, but not LAMP.

Our key finding is that once wage stickiness is taken into account LAMP does not substantially affect the design of monetary policy. In other words the results in Erceg et al. (2000) are robust to the introduction of LAMP, while Bilbiie's (2008) findings are sensitive to the introduction of wage stickiness.

In the presence of LAMP variations in the real wage lead to variations in profits and hence in the dividend income of Ricardian agents. This has wealth effects that can overturn the standard impact of the real interest rate on aggregate demand. Specifically, Bilbiie (2008) finds that, when LAMP is beyond a certain threshold, the slope of the IS curve may turn positive leading to what he calls and Inverted Aggregate Demand Logic (IADL). In the parameter space where the IADL holds, aggregate demand increases with the real interest rate. Importantly, the inversion of the slope of the IS curve requires a passive policy rule.

We prove that this result relies on nominal wage flexibility. Even a small amount of nominal wage rigidity severely restricts the parameter space where the IADL holds. The intuition for this result is the following. Wage stickiness dampens the changes in the real wage, and thus in

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<sup>1</sup>This modelling choice was originally adopted by Mankiw (2000) to account for the empirical relationship between consumption and disposable income, which seems to be stronger than suggested by the permanent income hypothesis.

profits, in response to variations in economic conditions. This prevents the reversal of the slope of the IS curve occurring under wage flexibility, thus restoring standard policy prescriptions for the monetary authority. Next, we study optimal monetary policy and optimal simple rules. To this end, we derive analytically the Central Bank welfare-loss function by taking a second order approximation to a weighted average of households' lifetime utilities and study the design of optimal simple rules and optimal monetary policy. However, in our model LAMP affects uniquely the demand side of the economy, while the trade-off faced by monetary policy when trying to minimize its welfare loss originates entirely from the supply side. Thus, the optimal response of welfare relevant variables to a shock is just marginally affected by LAMP when wages are sticky. What LAMP does affect, through the IS curve, is the path of the nominal interest rate required to implement the optimal path of welfare-relevant variables.

Contrary to Bilbiie (2008), we find that optimal inflation targeting rules (both contemporaneous and forward looking) are restored to be strongly active if wages are sticky, as in the standard NK model. Finally, as in Erceg et al. (2000), price inflation targeting may cause relevant welfare costs and rules should also target wage inflation, the more so, the more wages are sticky. Strict price inflation targeting leads to higher welfare with respect to strict wage inflation targeting just in the case in which asset market participation is restricted to an implausible extent.

Importantly, our results do not depend on the modeling of the labor market. In the main text we assume that labor market unions pool the income of both agents who, as a result, work for the same amount of time. In the on-line Appendix associated to the paper we study an alternative labor market framework, where wage setting decisions depend uniquely on the preferences of asset holders and agents are free to work for different amounts of hours. Since changes in the interest rate and dividend income affect the willingness to supply labor by Ricardian consumers, this modelling device reinforces the link between the asset market and the labor market, which is at the heart of Bilbiie's result. In this case we find that our results are reinforced. Namely, for any degrees of wage stickiness a larger share of non Ricardian consumers is needed to invert the slope of the IS curve with respect to that required in our baseline setting. Thus, while the modelling of the labor market in the main text is more rigorous from a microeconomic point of view with respect to the alternative one, it is actually the less favorable one for the message of the paper.

Several authors analyze the implications of LAMP for monetary policy in NK models. A paper closely related to ours is Colciago (2011). In particular, Colciago (2011) studies determinacy properties of the model and shows numerically that wage stickiness helps restoring the standard Taylor Principle as a necessary condition for determinacy in the presence of LAMP.<sup>2</sup>

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<sup>2</sup>Ascari et al. (2016) provides a proof of this result and analytical conditions for the Taylor principle to hold in a model with sticky wages and LAMP.

Further, he focuses on fiscal policy issues, studying the response of private consumption to a government spending shock in the presence of LAMP and nominal rigidities. Differently from Colciago (2011), we show analytically how the degree of wage stickiness affects the slope of the IS curve, provide a microfounded welfare loss function for the Central Bank and analyse the implications of LAMP for the conduct of monetary policy in a NK model with price and wage stickiness. Galì et al. (2004) study determinacy properties of interest rate rules in a sticky-price economy with a fraction of non-Ricardian consumers and capital accumulation. They show that if the share of non-Ricardian agents is sufficiently large and prices are sticky enough, determinacy of the REE requires that the central bank adopts a Reinforced Taylor Principle, whereby the inflation coefficient response is considerably larger than unity. Amato and Laubach (2003) model non-Ricardian behavior as a consumption habit and show that the optimal interest rate becomes more inertial as the fraction of non-Ricardian consumers increases. Di Bartolomeo and Rossi (2007) show that monetary policy effectiveness increases with the degree of LAMP.

Most of the works mentioned so far are characterized by a frictionless labor market.<sup>3</sup> The few papers which consider the interactions between a non-Walrasian labor market and LAMP focus on fiscal policy issues. This is motivated by recent VAR evidence suggesting that an innovation in government spending causes a persistent rise in private consumption. This evidence cannot be easily addressed resorting to fully Ricardian business cycle models. For this reason, Galì et al. (2007) study the effect of government spending shocks in a model with LAMP. They show that an imperfectly competitive labor market is a fundamental ingredient to obtain the crowding-in of consumption in response to an expansionary government spending shock identified, *inter alia*, by Blanchard and Perotti (2002) and Fatàs and Mihov (2001).

This paper bridges these strands of the literature by providing an exhaustive analysis of the implications of LAMP for the design of monetary policy in a NK model with price and wage stickiness. The remainder of the paper is organized as follows. Section 2 spells out the model economy; Section 3 studies the effects of LAMP and nominal rigidities on the IS curve; Section 4 provides the welfare loss function and optimal monetary policy analysis; Section 5 concludes.

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<sup>3</sup>Sveen and Weinke (2007) find that in the presence of firms specific capital a NK model with both staggered price and wages may generate multiple equilibria. Flaschel et al. (2008) analytically studies the determinacy properties of the model in the Erceg et al. (2000). However these papers consider a model with full asset market participation.

## 2 The Model

Appendix A.1 describes in details the model that is based on Colciago (2011). There is a continuum of households indexed by  $i \in [0, 1]$ . Households in the interval  $[0, \lambda]$  consume their available labor income in each period and do not hold assets. Households in the interval  $(\lambda, 1]$  hold assets and smooth consumption. The period utility function is common across households and equals to:  $\frac{\Psi_t C_{i,t}^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\phi}}{1+\phi}$  for  $i = S, H$ , where  $\sigma$  is the relative risk aversion (and the inverse intertemporal elasticity of substitution), while  $\phi$  is the elasticity of marginal disutility of labor. As in Schmitt-Grohe and Uribe (2005), agent  $i$  supplies each possible type of labor input. Wage-setting decisions are made by labor type specific unions. Given the wage fixed by the union, agents stand ready to supply as many hours as demanded by firms in the labor market. Agents are distributed uniformly across unions; hence aggregate demand for labor type  $j$  is spread uniformly across the households.<sup>4</sup> It follows that the individual quantity of hours worked is common across households. The labor market structure rules out differences in labor income between households without the need to resort to contingent markets for hours.<sup>5</sup> Notice that each union pools the labor income of agents, leading Ricardian and non-Ricardian households to work for the same amount of time. This implies that under flexible wages the model does not fully nest Bilbiie (2008), where Ricardian and non-Ricardian agents are free to make different labor choices. In the on-line Appendix we investigate an alternative labor market arrangement where the wage depends solely on the preferences of Ricardian households, and agents are not forced to work for the same amount of time. In that case the model fully nests Bilbiie (2008), but our results are not affected, and, if anything, strengthened. So our findings do not depend on the chosen structure of the labor market.<sup>6</sup>

Nominal wage rigidities are modeled according to the Calvo (1983) mechanism. In each period a union faces a constant probability  $1 - \xi_w$  of being able to reoptimize the nominal wage. As in Colciago (2011) the nominal wage newly reset at  $t$  is chosen to maximize a weighted average of agents' lifetime utilities. The weights attached to the utilities of Ricardian and non-Ricardian agents are  $(1 - \lambda)$  and  $\lambda$ , respectively.

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<sup>4</sup>Thus a share  $\lambda$  of the members of each union are non-Ricardian consumers, while the remaining portion is composed of Ricardian agents.

<sup>5</sup>Our assumption is similar to Woodford (2003) among others, but different from the one in Erceg et al. (2000). As in most of the literature on sticky wages, Erceg et al. (2000) assume that each agent is the monopolistic supplier of a single labor input. In this case, only households providing the same labor type will exhibit the same labor income. However, the assumption of complete markets and full insurance against the risk associated to labor income fluctuations, rule out differences in income between households. In our model this framework would imply a tractability problem, because non-Ricardian agents do not participate in the asset market, and thus cannot share the risk associated to labor income fluctuations.

<sup>6</sup>The on-line Appendix is available at the web page of the authors. We take the framework spelled out in the text as the baseline because we regard it as a more rigorous microfoundation.

In each period  $t$ , perfectly competitive firms combine a continuum of intermediate inputs according to the standard *CES* production function to produce the final good. Hence, the firms producing intermediate inputs enjoy market power. Their production technology is simply linear in labor and subject to an aggregate technology shock. Intermediate producers set prices according to the same mechanism assumed for wage setting. Firms in each period have a fixed chance  $1 - \xi_p$  to re-optimize their price.

For comparability with Bilbiie (2008) and Erceg et al. (2000), we follow the bulk of the literature (see Woodford, 2003) and impose an efficient steady state. To induce equality between the steady state marginal product of labor and the steady state marginal rate of transformation we assume that the Government subsidizes firms by means of a constant employment subsidy. Firms are also taxed through a constant lump-sum tax which leads to zero steady state profits. Next, we define the equilibrium of the model under flexible prices and wages. Appendix A.1.6 shows that the log-deviations of the efficient output, the efficient real wage and the efficient real rate of interest from their efficient steady state values.

## 2.1 The Log-linear model

The following equations summarize log-linear equilibrium dynamics for price inflation,  $\pi$ , wage inflation,  $\pi^w$ , the real wage gap,  $\tilde{\omega}$ , and the output gap,  $x$ :

$$\begin{aligned}
(M1) \quad \pi_t &= \beta E_t \pi_{t+1} + \kappa_p \tilde{\omega}_t && \text{NKPC} \\
(M2) \quad \pi_t^w &= \beta E_t \pi_{t+1}^w + \kappa_w [(\sigma + \phi)x_t - \tilde{\omega}_t] && \text{Wage Inflation Curve} \\
(M3) \quad \tilde{\omega}_t &= \tilde{\omega}_{t-1} + \pi_t^w - \pi_t - \Delta \omega_t^{Eff} && \text{Real Wage Gap} \\
(M4) \quad x_t &= E_t x_{t+1} - \frac{1}{\sigma} E_t \left( i_t - \pi_{t+1} - r_t^{Eff} \right) - \frac{\lambda}{(1-\lambda)} E_t \Delta \tilde{\omega}_{t+1} && \text{IS curve}
\end{aligned}$$

Equation (M1) is the NKPC obtained from the firms' price setting problem. The variable  $\tilde{\omega}_t = \omega_t - \omega_t^{Eff}$  represents the *real wage gap*, which is defined as the gap between the current and the efficient equilibrium real wage. Given that the production function is linear in labor, it follows that  $mc_t = \omega_t - y_t + l_t = \omega_t - a_t = \tilde{\omega}_t$ , i.e. the real wage gap is equal to the log-deviations of the real marginal cost from the efficient steady state. For this reason  $\tilde{\omega}_t$  appears on the RHS of equation (M1). The *real wage gap* in the NKPC identifies a *labor demand gap* being equal to the difference between the current wage and the marginal productivity of labor. The parameter  $\kappa_p = \frac{(1-\beta\xi_p)(1-\xi_p)}{\xi_p}$  is the slope of the NKPC and  $\beta$  is the subjective discount factor. Equation (M2) is a wage inflation curve, similar to that in Erceg et al. (2000) with slope  $\kappa_w = \frac{(1-\beta\xi_w)(1-\xi_w)}{\xi_w}$ . Symmetrically to the NKPC, the term  $[(\sigma + \phi)x_t - \tilde{\omega}_t]$  in (M2) identifies a *labor supply gap* being equal to the difference between the average (across agent types) marginal rate of substitution between labor and consumption and the real wage. Given the period utility, the production function, the market clearing and the definition of efficient

output, it follows that:

$$\begin{aligned} & (1 - \lambda) mrs_{S,t} + \lambda mrs_{H,t} - \omega_t \\ &= [(\sigma + \phi) y_t - \phi a_t - \psi_t] - \omega_t = (\sigma + \phi) x_t - \tilde{\omega}_t, \end{aligned} \quad (1)$$

where  $x_t = y_t - y_t^{Eff}$  denotes the *output gap*, i.e. the gap between actual output and the efficient output. Equation (M3) simply provides the definition of the real wage gap in terms of wage and price inflation and  $\Delta \omega_t^{Eff} = \omega_t^{Eff} - \omega_{t-1}^{Eff}$ .

Equations (M1) – (M3) are identical to those which would characterize a fully Ricardian NK model with price and wage stickiness, as in Erceg et al. (2000).<sup>7</sup> Notice that the heterogeneity between households does not affect wage inflation dynamics.<sup>8</sup>

Aggregating the Euler equation of Ricardian agents with the budget constraint of non-Ricardian agents delivers the IS curve, equation (M4).<sup>9</sup> The latter differs from a standard IS equation because of the extra term  $\frac{\lambda}{1-\lambda} E_t \Delta \tilde{\omega}_{t+1}$ , which represents the expected growth of the real wage gap. The wage gap affects aggregate demand relative to the efficient allocation through the consumption of non-Ricardian consumers and for this reason appears in the IS curve.

Note that our framework encompasses the models in Erceg et al. (2000) and Bilbiie (2008). Indeed, the extra term in the IS curve disappears if the model is fully Ricardian (i.e. if  $\lambda = 0$ ) as in Erceg et al. (2000). Further, under nominal wage flexibility the labor supply gap is nil and equation (1) implies a strict proportionality between the wage gap and the output gap given by:

$$\tilde{\omega}_t - (\sigma + \phi) x_t = 0. \quad (2)$$

By substituting the latter into equation M4 the IS curve can be rewritten solely in terms of the output gap, as in Bilbiie (2008).

It is worth stressing that the supply side of the model, constituted by equations (M1) – (M3), is isomorphic to that of a fully Ricardian economy with sticky prices and wages. On the contrary the demand side of the model, represented by equation (M4), is affected by the degree of asset market participation and hence characterizes a LAMP economy with sticky wages and prices.

To close the model the behavior of the nominal interest rate needs to be specified. To this end we will consider both interest rate rules and a welfare maximizing policy. We will show that, in both cases, the presence of non-Ricardian agents does not fundamentally alter the design of monetary policy once nominal wage stickiness is considered.

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<sup>7</sup>The only minor difference with Erceg et al (2000) is in the expression for  $\kappa_w$ . This is due to the different assumption regarding the labor market explained in footnote 5.

<sup>8</sup>As emphasized in Colciago (2011), this is due to the fact that the union maximizes a weighted average of agents utilities.

<sup>9</sup>Please see Appendix A.2 for analytical details

### 3 Wage rigidity and the slope of the IS curve

In this section we explore the role played by nominal wage stickiness for the dynamics of the model. We will compare our results to those in Bilbiie (2008), who considers a model with flexible wages. Bilbiie (2008) shows that, when asset market participation is restricted beyond a certain threshold, the slope of the IS curve may turn positive leading to what he calls the *Inverted Aggregate Demand Logic* (IADL). In the parameter space where the IADL holds, aggregate demand increases with the real interest rate. In the remainder of this section, we show that wage stickiness confines the IADL to extreme parameterizations.

To make our point clear we compare the slope of the IS curve obtained in the case of flexible wages to that obtained under wage stickiness. In the remainder we denote the value of the slope of the IS curve with  $(-\delta^i)$ , where  $i = fw$  in the case of flexible wages and  $i = sw$  in the case of sticky wages. Appendix A.2.1 shows that in the case of flexible wages the IS equation reads as:

$$x_t = E_t x_{t+1} - \delta^{fw} E_t (i_t - \pi_{t+1} - r_t^{Eff}), \quad (3)$$

where  $\delta^{fw} = \frac{1}{\sigma} \left[ 1 - \frac{\lambda(\sigma+\phi)}{1-\lambda} \right]^{-1}$ . The coefficient  $(-\delta^{fw})$  represents the elasticity of aggregate demand with respect to the real interest rate, which amounts to the slope of the IS curve.<sup>10</sup> There exists a threshold value of the parameter  $\lambda$  beyond which the parameter  $\delta^{fw} < 0$ , thus changing the sign of the slope of the IS with respect to that in a conventional full participation model. This threshold value is  $\bar{\lambda}^{fw} = \frac{1}{1+\sigma+\phi}$ . When asset market participation is restricted to an extent that  $\lambda > \bar{\lambda}^{fw}$  we are in the IADL region, where an increase in the real interest rate leads to an increase in aggregate demand.

In the case of sticky wages, the counterpart of equation (3) is:

$$x_t = E_t x_{t+1} - \delta^{sw} E_t (i_t - \pi_{t+1} - r_t^{Eff}) + \frac{\lambda}{1-\lambda} \frac{\sigma \delta^{sw}}{1+\beta+\kappa_w} \Theta_t, \quad (4)$$

where  $\delta^{sw} = \frac{1}{\sigma} \left[ 1 - \frac{\lambda(\sigma+\phi)}{1-\lambda} \frac{\kappa_w}{1+\beta+\kappa_w} \right]^{-1}$  and  $\Theta_t = E_t [\Delta \pi_{t+1}^w - \Delta \tilde{\omega}_{t+1} - \beta (\Delta \tilde{\omega}_{t+1} + \Delta \pi_{t+2}^w)]$ . Under flexible wages, i.e.  $\xi_w = 0$ ,  $\kappa_w \rightarrow \infty$  and  $\delta^{sw} \rightarrow \delta^{fw}$ , so that equation (4) collapses to (3). As in the flexible wages case there exists a threshold value of  $\lambda$  such that we can define a region where the IADL holds. Under sticky wages, the slope of the IS curve turns positive if  $\lambda > \bar{\lambda}^{sw} = \frac{1}{1+(\sigma+\phi) \frac{\kappa_w}{1+\beta+\kappa_w}}$ . Clearly

$$\bar{\lambda}^{sw} > \bar{\lambda}^{fw}.$$

The latter states that under sticky wages a higher fraction of non-Ricardian consumers is required for the slope of the IS curve to turn positive with respect to the case of flexible

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<sup>10</sup>The expression is slightly different from Bilbiie (2008) again because of our assumption on the labor market.



wages. Equality holds in the case of flexible wages, i.e. when  $\xi_w = 0$ . In this case  $\kappa_w \rightarrow \infty$ , and  $\lambda^{sw} \rightarrow \lambda^{fw}$ . We collect the main findings of this section in Proposition 1.

**Proposition 1. Wage stickiness and the inversion of the slope of the IS curve.** When nominal wages are sticky the slope of the IS curve turns positive iff:

$$\lambda > \bar{\lambda}^{sw} = \frac{1}{1 + (\sigma + \phi) \frac{\kappa_w}{1 + \beta + \kappa_w}}. \quad (5)$$

- (i) The threshold value  $\bar{\lambda}^{sw} = f(\xi_w)$  is a monotonically increasing function of the degree of wage stickiness for  $\xi_w \in (0, 1]$  assuming values  $\lambda \in (\frac{1}{1 + \sigma + \phi}, 1]$ ;
- (ii) For any given value of the degree of asset market participation,  $\lambda \in (\frac{1}{1 + \sigma + \phi}, 1]$ , there exists a threshold level of wage stickiness  $\bar{\xi}_w = f^{-1}(\lambda)$  such that the slope of the IS curve is negative for any  $\xi_w > \bar{\xi}_w$ . For values  $\lambda \leq \frac{1}{1 + \sigma + \phi}$ , the slope of the IS curve is negative for any value of  $\xi_w \in [0, 1]$ .

**Proof.** See Appendix A.3.

Proposition 1 leads to the following corollary.

**Corollary 1. The IADL region.** Nominal wage stickiness severely restricts the IADL region, and confines it to extreme parameterizations.

Our baseline calibration (see Section 4.2) implies a threshold value  $\bar{\lambda}^{sw} = 0.83$ . The IADL holds if the share of non-Ricardian agents is larger than 83%. This value seems implausibly large, when compared to the empirical evidence by Campbell and Mankiw that places this at around 40–50% for the US economy for data running up to the mid eighties, or to data from the 1989 Survey of Consumer Finances which shows that 59% of US population had no interest-bearing financial assets.<sup>11</sup> Notice that under flexible wages  $\bar{\lambda}^{fw} = 0.17$ , i.e. almost 5 times smaller.

Finally we can state another corollary of Proposition 1 to group some further results on the slope of the IS (see Appendix A.3).

**Corollary 2. The slope of the IS curve.** The slope of the IS curve under sticky wages,  $(-\delta^{sw})$ , is : (i) an increasing function of the degree of wage stickiness (apart in the discontinuity point  $\xi_w = \bar{\xi}_w$  where it is not differentiable); (ii) for flexible wages,  $\xi_w = 0$  :  $(-\delta^{sw}) \rightarrow (-\delta^{fw}) = \frac{-1}{\sigma} \left[ 1 - \frac{\lambda(\sigma + \phi)}{1 - \lambda} \right]^{-1}$ ; (iii) for fixed wages,  $\xi_w = 1$  :  $(-\delta^{sw}) \rightarrow \frac{-1}{\sigma}$  which is independent from the degree of asset market participation,  $\lambda$ .

<sup>11</sup>Note that we are choosing a parameterization against our argument, since we assume high values for  $\sigma = 2$  and  $\phi = 3$ . Assuming an average duration of wage contracts of 3 quarters, rather than 4, yields  $\bar{\lambda}^{sw} = 0.71$ . By choosing a rather standard alternative calibration, as log-utility in consumption and labor, (and keeping an average duration for wage contracts of 4 quarters), return  $\bar{\lambda}^{sw} = 0.92$ .

### 3.1 Intuition: wage stickiness and wage elasticity

The analytics behind the above propositions have a consistent economic intuition that rests on the effect of wage stickiness on the elasticity of the wage schedule of the monopolistic labor union. Appendix A.4 shows that the slope of the wage schedule, i.e., the elasticity of the real wage with respect to hours, in the case of sticky wages is given by

$$\Phi^{sw} = \frac{\kappa_w}{1 + \beta + \kappa_w}(\sigma + \phi), \quad (6)$$

where  $\Phi^{fw} = (\sigma + \phi)$  is the slope of the wage schedule under flexible wages. Figure 1 displays labor demand, together with the wage schedules under sticky ( $WS^{sw}$ ) and flexible wages ( $WS^{fw}$ ) in the space  $(L_t, \omega_t)$ . As shown by (6), wage stickiness dampens the sensitivity of the real wage to changes in hours, so the wage schedule is flatter under wage stickiness.

To see how the interaction between non Ricardian agents and wage stickiness affects the slope of the IS curve consider an increase in the real interest rate, as in Bilbiie (2008). Ricardian agents reduce their demand, while firms that cannot change price reduce labor demand, so that the labor demand curve shifts inward in  $L_2^d$ . Under flexible wages this translates into a large reduction in the real wage and to a modest change in hours, and the more so the higher the elasticity of the marginal disutility of hours,  $\phi$ , and the inverse intertemporal elasticity of substitution in consumption,  $\sigma$ . The decrease in the real wage depresses demand by non-Ricardian agents and reinforces the effects on aggregate demand due to the initial increase in the real interest rate. The sizeable decrease in the real wage, and hence in marginal costs, together with the small change in hours, and hence in output and sales, imply a potential increase in profits. This leads, in turn, to a positive income effect on Ricardian agents. The latter is stronger the larger  $\lambda$ , since Ricardian agents would obtain a higher individual dividend income. If asset market participation is restricted enough ( $\lambda > \bar{\lambda}^{fw}$ ), the positive income effect may counteract the substitution effect induced by the interest rate change and finally lead to an increase in aggregate demand.<sup>12</sup> As a result labor demand would shift rightward, in  $L_3^d$ , leading to an equilibrium with higher-than-initial real wage and output, i.e. where the initial interest rate increase is associated with higher aggregate demand.

Consider now the case of sticky wages. The inward shift in labor demand due to the reduction in consumption by Ricardian agents, results in a large response in hours worked together with a modest reduction in the real wage. The potential income effect is thus less likely and, however, dampened with respect to the case of flexible wages. For this reason, under wage stickiness the inversion of the IS curve requires a much larger share of non Ricardian agents ( $\lambda > \bar{\lambda}^{sw}$ ) to magnify the, eventual, income effect at the individual level for Ricardian agents. The following expression clearly reveals the link between the slope of the wage schedule

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<sup>12</sup>Notice that  $\bar{\lambda}^{fw}$  is lower the steeper the wage schedule, i.e. the higher are  $\sigma$  and  $\phi$ , as emphasized above.

and the slope of the IS curve

$$\underbrace{(-\delta^i)}_{\text{Slope of IS Curve}} = -\frac{1}{\sigma} \left[ 1 - \frac{\lambda}{(1-\lambda)} \times \underbrace{\Phi^i}_{\text{Slope of wage schedule}} \right]^{-1} \text{ for } i = fw, sw. \quad (7)$$

Since  $\Phi^{fw} > \Phi^{sw}$ , the inversion of the slope of the IS curve becomes more likely as wages become more flexible for any given share of non Ricardian agents.<sup>13</sup>

## 4 Optimal Monetary Policy

In this section we look at the optimal policy problem, cast in the standard linear quadratic framework (see Woodford, 2003). First, we derive the welfare loss function and describe the relevant trade-offs faced by the monetary authority. Next, we characterize optimal monetary policy under full commitment, which we take as a benchmark for the remainder of the analysis. Next we consider optimal simple interest rate rules *a la* Schmitt-Grohé and Uribe (2007) and compare their performance in terms of welfare with respect to the case of full commitment.

### 4.1 The Welfare Loss Function

We assume that the central bank maximizes a convex combination of the utilities of two types of households, as in Bilbiie (2008). Weights correspond to the relative importance of agents' groups in the economy. In this case the period welfare function is given by:

$$W_t = \Psi_t [\lambda u(C_{H,t}) + (1-\lambda) u(C_{S,t})] - v(L_t). \quad (8)$$

**Proposition 2. The aggregate welfare loss function.** *The aggregate welfare loss function approximated at second-order around the efficient steady state is given by:*

$$L = -\frac{1}{2} \sum_{t=0}^{\infty} \beta^t \left( \frac{(\sigma-1)\lambda}{1-\lambda} \tilde{\omega}_t^2 + (\sigma+\phi) x_t^2 + \frac{\theta_w}{\kappa_w} (\pi_t^w)^2 + \frac{\theta_p}{\kappa_p} \pi_t^2 \right). \quad (9)$$

**Proof.** See Appendix A.5.

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<sup>13</sup>Our results do not depend on having a union which prevents Ricardian agents from substituting labor intertemporally. As mentioned earlier, in the on-line Appendix we propose an alternative labor market structure where the real wage depends solely on the preferences of asset holders and agents are free to make different labor choices. In this case changes in the interest rate or in dividend income affect the willingness to supply labor by Ricardian consumers, reinforcing the link between the asset and the labor market. Nevertheless, we show that the area where the IADL holds is further restricted with respect to that we obtain under the baseline design of the labor market.

The interaction between nominal wage stickiness and non-Ricardian agents implies that the loss function is characterized by the additional term  $\frac{(\sigma-1)\lambda}{1-\lambda}\tilde{\omega}_t^2$  with respect to the loss function of a fully Ricardian model. The wage gap enters the loss function for the same reasons it appears into the IS equation (4): deviations of the real wage from its efficient counterpart lead to deviations of aggregate demand from the efficient level.<sup>14</sup> Note that when  $\lambda = 0$  the welfare loss function reduces to that in Erceg et al. (2000).

When wages are flexible, wage inflation does not affect welfare. Moreover, the *labor supply gap* is nil, because the real wage equals the average marginal rate of substitution between consumption and labor. In this case equation (2) holds and by closing the output gap the central bank automatically closes the wage gap. Further note that substituting (2) into (9), the loss function reduces to (see Appendix A.5.1 for details)

$$L = -\frac{1}{2} \sum_{t=0}^{\infty} \beta^t \left( (\sigma + \phi) \left( 1 + \frac{(\sigma - 1)(\phi + \sigma)\lambda}{1 - \lambda} \right) x_t^2 + \frac{\theta_p}{\kappa_p} \pi_t^2 \right), \quad (10)$$

which has a form similar to that in Bilbiie (2008), and collapses to the standard text-book welfare-loss for  $\lambda = 0$ .

How monetary policy should be conducted in the LAMP economy with price and wage stickiness? Let us consider the trade-offs faced by monetary policy in the aftermath of a technology shock. We consider technology shocks since preference shocks do not imply any trade-off for the monetary authority. Price-wage stickiness induces an endogenous inflation-output trade-off for monetary policy. Given (M1) and (M2) monetary policy should contemporaneously close the wage and the output gap to fully stabilize wage and price inflation. However this is unfeasible since after a technology shock, that affects  $\Delta\omega_t^{Eff}$ , price and wage inflation should jointly move according to (M3). The intuition is also straightforward: in the social optimum the real wage follows one-to-one the marginal productivity of labor ( $a_t$ ), but this is simply not possible if the variance of both price and wage inflation is stabilized. Importantly, this trade-off originates entirely from the supply side of the model and therefore it is not affected by LAMP. As a result LAMP does not change the trade-offs faced by the monetary authority. However, LAMP alters the IS curve and the welfare loss function, thus it may affect the optimal response to shocks. Nevertheless, in the next section we show that, once nominal wage stickiness is brought into the picture, LAMP has only marginal quantitative effects on the optimal path of the main macro-variables in response to a technology shock.

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<sup>14</sup>The wage gap terms disappear from the loss function also when  $\sigma = 1$ . This is for purely technical reasons. The term  $(\sigma - 1)$  is due to two different approximations applied to  $U(C)$ : 1)  $\sigma$  derives from the second-order approximation of the utility function; 2) 1 is instead the curvature of the logarithmic function used to transform  $C$  into log deviations from steady state.

## 4.2 Commitment

**Model Calibration.** Given that our results are partly numerical, we detail the baseline calibration of the model. Time is measured in quarters. The discount factor  $\beta$  is set to 0.99, so that the annual interest rate amounts to 4%. The utility parameters  $\sigma$  and  $\phi$  are equal to 2 and 3, respectively. According to the estimates in Basu and Fernald (1997) the value added mark-up of prices over marginal cost is around 20%, for this reason we set  $\theta_p$  to 6. We assign an identical value to the elasticity of substitution between labor inputs,  $\theta_w$ . We set  $\xi_p = \xi_w = 0.75$ , which implies an average duration of price and wage contracts of one year, a value which is in compatible with most available empirical estimates (see for example Smets and Wouters 2003 and Levine et al. 2005). However, we evaluate the dependence of our results on the average duration of wage contracts which is a fundamental magnitude in our analysis.

We draw the autoregressive coefficient and the standard deviation of the technology shock from Schmitt-Grohé and Uribe (2007), while for what concerns the preference shock we refer to the estimates by Galí and Rabanal (2004). Selected values are  $\rho_a = 0.855$ ,  $\sigma_a = 0.0064$ ,  $\rho_\psi = 0.93$  and  $\sigma_\psi = 0.025$ . Notice that we assume that the technology and the preference shock are independent from each other.

**Optimal Monetary policy in response to technology shocks.** In the presence of a credible commitment, the central bank minimizes the welfare loss function (9) subject to (M1) – (M3), taking  $\tilde{\omega}_{t-1}$  as given. Then, the IS curve determines the optimal path of the nominal interest rate, while the resource constraint of non-Ricardian agents and the definition of aggregate consumption determine the sharing of resources between agents. Figure 2 depicts the optimal deviations from the efficient steady state of the main macroeconomic variables in response to a persistent technology shock. We consider alternative degrees of asset market participation. Consider the fully Ricardian case ( $\lambda = 0$ ). Since the monetary policy is endowed with a single instrument, it must trade-off between the competing distortions due to sticky prices and sticky wages. The resulting optimal dynamics feature a persistent reduction in inflation and a prolonged adjustment of the output gap. Remarkably, in response to an increase in productivity, hours worked fall. The contraction in hours following a positive productivity shock is in line with recent U. S. evidence (see, for example, Galí and Rabanal, 2004).

Restricting asset market participation has just quantitative implications on the optimal IRFs. This does not come as a surprise since, as discussed above, LAMP does not affect the trade-offs faced by the Central Bank in response to a technology shock. Specifically, restricting asset market participation (i.e. higher  $\lambda$ ) amplifies the propagation of the technology shock to the economy. The intuition for this outcome is as follows. The rise in technology leads to lower

marginal costs and higher output which translate into an increase in total profits. This has a positive income effect on Ricardian households. The latter gets stronger as the portion of non-Ricardian agents enlarges, resulting into a more pronounced reaction of Ricardian agents' consumption to the shock. To support such an outcome the Euler equation requires lower asset market participation to be associated with more aggressive cuts of the nominal interest rate. Because of price stickiness firms satisfy higher demand of the final good via an increase in labor demand. This ultimately affects the real wage and hours worked and thus consumption of non-Ricardian agents.

The main point, however, is that the effect of LAMP on welfare relevant variables such as gaps and inflation rates are minor also from a quantitative point of view. In other words, the optimal IRFs under commitment are *only marginally* affected by LAMP.<sup>15</sup>

Moreover, when  $\sigma = 1$ , the LAMP hypothesis has no effect at all on the optimal monetary policy response. In this case, neither the objective function (9) nor the constraints, (M1) – (M3), depend on the share of non-Ricardian agents. Thus, in response to shocks, the optimal policy implements the same equilibrium path for the welfare relevant variables as in a full participation economy. In this case, society welfare will not be affected by the presence of non-Ricardian agents and just the interest rate will be affected by LAMP assumption through the IS curve.

To conclude this section we report in Table 1 the unconditional welfare loss under full commitment as a function of the share of non-Ricardian agents and the average durations of wage contracts (i.e.,  $(1 - \xi_w)^{-1}$ ).<sup>16</sup> The unconditional welfare loss is expressed as a percentage of aggregate consumption at the efficient steady state. As well known, in the case of flexible wages (i.e.,  $\xi_w = 0 \Rightarrow (1 - \xi_w)^{-1} = 1$ ) the monetary authority faces no trade-off at stabilizing welfare relevant variables in response to a technology shock, for this reason the welfare loss is nil. As expected, the welfare loss increases with the magnitude of the two distortions considered.

### 4.3 Optimal simple rules

In this section we evaluate how the interaction between LAMP and wage stickiness affects the design of optimal simple Taylor-type interest rate rules. Motivated by the analysis in Bilbiie (2008) we initially consider two pure inflation targeting rules, where the interest rate responds solely to current and expected inflation, respectively. Then, as in Erceg et al. (2000),

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<sup>15</sup>The response of the efficient level of output is somewhat in between the responses in the top left panel of Figure 2. Hence the output gap switches sign from negative to positive as  $\lambda$  changes, but this effect is quantitatively negligible.

<sup>16</sup>To facilitate understanding we report in the Tables below the average duration of wage contracts:  $(1 - \xi_w)^{-1}$ . The latter is expressed in quarters.

we consider a hybrid rule where the interest rate reacts to current price inflation and to the deviations of output from the steady state. Finally, we consider a hybrid rule in which the interest rate is a function of current price and wage inflation. Following Schmitt-Grohé and Uribe (2007), we require the simple rules described above to be implementable and optimal. The implementability condition requires policies to deliver local uniqueness of the REE. Optimality requires, instead, selecting policy coefficients in order to minimize the unconditional expectation of the welfare loss function (9). We search for optimal policy coefficients numerically. In doing this we limit attention to the interval  $[-10, 10]$  for each coefficient. Notice that larger coefficients response would fall out of any plausible estimate and would have little credibility. We evaluate the performance of each rule for a range of values of the two relevant parameters:  $\lambda$  and  $\xi_w$ .

In the remainder we state two main results. Result 1 refers to pure inflation targeting rules, while Result 2 to hybrid rules.

**Result 1. Pure inflation targeting rules.** *In the case of pure inflation targeting rules the optimal rule calls for a strong response of monetary policy. LAMP makes the optimal rule highly passive if wages are flexible. However, if wages are sticky, the optimal rule is restored to be highly active, as in the standard NK model.*

Table 2 reports optimal policy coefficients and the associated welfare loss for the contemporaneous and forward-looking inflation targeting rules. Consider the current pure inflation targeting rule (Panel A). In a fully Ricardian economy ( $\lambda = 0$ ) with flexible wages ( $(1 - \xi_w)^{-1} = 1$ ) the optimal response coefficient implies a strong anti-inflationary stance. The reason is that in the absence of a trade-off between inflation and the output gap, stabilizing inflation also results in output stabilization.

In our exercise, thus, the inflation coefficient hits the upper bound (i.e.  $\phi_\pi = 10$ ). Removing the upper bound on policy parameters would result in an unbounded inflation coefficient response and zero welfare loss. The optimal rule is extremely effective, as it delivers a welfare loss equal to 0.002 % of steady state consumption. These results resembles those in other studies such as Schmitt-Grohé and Uribe (2007).

Introducing LAMP in this environment has dramatic consequences for the design of optimal interest rate rules. The optimal contemporaneous rule turns passive and features a strongly negative inflation response, indeed  $\phi_\pi$  hits the lower bound equal to -10. We are in the IADL region implying that the relationship between aggregate demand and the real interest rate is reversed with respect to the standard case. It is worth emphasizing that the negative inflation coefficient obtained under LAMP and flexible wages does not merely serve the purpose of ensuring the uniqueness of the REE. In Ascari, Colciago and Rossi (2016) we show that under a contemporaneous rule also a very strong increase in the real interest rate in response to

a positive change in inflation would, in fact, guarantee determinacy in the LAMP economy. However, it would deliver a lower welfare with respect to the passive rule considered here.

Even a very low, and below estimates, degree of wage stickiness restores the optimality of an active rule for any empirically plausible share of non-Ricardian agents. Moreover, when the degree of wage stickiness assumes values compatible with the empirical evidence, the optimal policy is highly active no matter the extent to which we limit asset market participation. Again, wage stickiness limits the likelihood of a reversal in the slope of the IS curve and it restores standard policy prescriptions. In other words, once wage stickiness is considered, LAMP has just minor quantitative implications for the design of optimal simple rules. In particular, the optimal policy calls for a stronger reaction to inflation as the share of non-Ricardian agents increases.

Similar considerations extend to the forward looking inflation targeting rule in Table 2 (Panel B). As in a standard economy, the simple rules considered here perform quite well in terms of welfare even in the presence of non-Ricardian agents. The welfare loss gets large just in the case where wage stickiness is coupled with an implausibly large share of non-Ricardian consumers. However, this is partly due to the fact that we restrict the interval of admissible values for  $\phi_\pi$ . We next turn to the second result, concerning hybrid rules.

**Result 2. Hybrid Rules.** *In the case of hybrid rules (i) Result 1 is confirmed: nominal wage stickiness makes the optimal rule active; (ii) a rule targeting both price and wage inflation delivers the best performance in terms of welfare; (iii) responding to output only marginally improves the performance of a pure inflation targeting rule.*

Table 3 reports the performance of the hybrid rules we consider. Results 1 is confirmed: nominal wage stickiness makes the optimal policy strongly active, unless the degree of LAMP assumes implausibly large values. In line with Erceg et al. (2000), a rule responding to both price and wage inflation substantially reduces the welfare loss with respect to a pure price inflation targeting rule.

The relative magnitude of the optimal coefficients on price and wage inflation depends on the relative degree of stickiness between prices and wages. The larger between the two coefficients is the one multiplying the inflation of the stickier variable. Further, both coefficients are increasing in the degree of LAMP and are generally very large (possibly unbounded in the case of wage inflation targeting for high degree of wage stickiness). It follows that for realistic values of the degree of wage stickiness, this rule calls for complete wage stabilization.



## 5 Strict targeting rules

To conclude our analysis we consider policy rules aimed at fully stabilizing, at each date and state, one of the welfare relevant variables, that is either one between  $\tilde{\omega}_t, \pi_t, \pi_t^w$ , or  $x_t$ . These rules are often defined as strict targeting rules. The next proposition provides a general result concerning LAMP and strict targeting policies.

**Proposition 3. LAMP and strict targeting rules.** *Under a strict targeting rule (whatever the target among  $(\tilde{\omega}_t, \pi_t, \pi_t^w, x_t)$ ) the path  $\{\tilde{\omega}_t, \pi_t, \pi_t^w, x_t\}_{t=0}^{\infty}$  is not affected by LAMP. As a consequence the unconditional variances of welfare relevant variables do not depend on  $\lambda$ . The path of the instrument,  $\{i_t\}_{t=0}^{\infty}$ , required to implement the allocation depends, instead, on the degree of asset market participation.*

**Proof.** This follows from the fact that the supply side of the model does not depend on the degree of asset market participation,  $\lambda$ . Once either one between  $\tilde{\omega}_t, \pi_t, \pi_t^w, x_t$  is set equal to zero, equations (M1) – (M3) are sufficient to generate the path of the other three variables. Since  $\lambda$  enters only in the IS equation, its value only matters for the behavior of  $i_t$ , but not for the allocation of welfare relevant variables.

We can further specialize the previous proposition showing that strict price inflation targeting and strict wage gap targeting amount to the same policy.

**Proposition 4. LAMP, strict price inflation and real wage-gap targeting.** *Strict price inflation targeting and strict real wage gap targeting are implemented by the same path of the policy instrument  $\{i_t\}_{t=0}^{\infty}$ . They also deliver the same welfare loss given by  $W = \frac{\sigma_a^2}{2\kappa_w^2(\sigma+\phi)} \left[ \frac{1}{1-\rho_a^2} ((\rho_a - 1)(1 - \beta\rho_a))^2 + (1 - \beta(\rho_a - 1))^2 \right] + \frac{\theta_w}{\kappa_w(1+\rho_a)} \sigma_a^2$  which: (i) is independent of the degree of asset market participation, (ii) tends to zero in the case of flexible wages and (iii) increases with the average duration of wage contracts.*

**Proof.** See Appendix A.6

The intuition for this result is straightforward. The NKPC implies that whenever  $\pi_t = 0$  it has to be the case that  $\tilde{\omega}_t = 0$  and vice-versa. In this case the extra term in the IS curve vanishes and the path of the interest rate needed to implement the allocation is the same, and it is independent of the share of non-Ricardian agents. Since both policies lead to the same path for welfare relevant variables, and in particular imply that  $\tilde{\omega}_t = 0$  at all  $t$ , the welfare loss is also independent of  $\lambda$ . Price inflation targeting gets more costly as the mean duration of wage contracts gets longer. Finally, we consider the case of strict wage inflation targeting.

**Proposition 5. LAMP and strict wage inflation targeting.** *Under strict wage inflation targeting the wage gap is proportional to the output gap. The path  $\{\pi_t, \tilde{\omega}_t\}_{t=0}^{\infty}$  is independent of the degree of asset market participation, while the path of the instrument needed*

to implement the equilibrium does depend on it. The unconditional welfare loss increases with the degree of LAMP.

**Proof.** Equation (M2) implies that  $(\sigma + \phi)x_t = \tilde{\omega}_t$ . In this case equations (M1) and (M3) suffice to determine the path  $\{\pi_t, \tilde{\omega}_t\}_{t=0}^{\infty}$ . The latter is independent of the degree of asset market participation. Equation (M4) suggests, instead, that the path of the instrument required to implement this policy depends on  $\lambda$ . Since the coefficient on the wage gap variable,  $\frac{(\sigma-1)\lambda}{1-\lambda}$ , in the welfare loss function (9) is increasing in the share of non-Ricardian agent, society's welfare loss get larger as asset market participation becomes more restricted.

Finally, we compare the welfare performance of strict targeting rules. As a Corollary to Proposition 4 and Proposition 5 we can state the following.

**Corollary.** *Under nominal wage stickiness, there exist a threshold value  $\tilde{\lambda}$ , such that for  $\lambda > \tilde{\lambda}$  wage inflation targeting delivers a higher society's welfare loss with respect to price inflation targeting.*

Therefore, LAMP could overturn the optimality of strict wage inflation targeting over strict price inflation targeting emphasized by Erceg et al. (2000) in a full participation framework. For any empirically relevant degree of asset market participation, however, the Erceg et al. (2000) result holds. This is evident from Figure 3 that depicts welfare losses under strict wage inflation targeting and strict price inflation (or wage gap) targeting. The latter is shown for two alternative mean durations of wage contracts.

## 6 Conclusions

We design a model to study monetary policy in an economy characterized by staggered wage and price contracts and by an arbitrary degree of asset market participation. Our model nests two widely used framework for the analysis of monetary policy. The LAMP model by Bilbiie (2008) and the sticky prices-sticky wages model by Erceg et al. (2000).

Our main finding is that once nominal wage stickiness is taken into account LAMP does not substantially affect the design of monetary policy. The reason is that wage stickiness prevents the inversion of the sign of the elasticity of aggregate demand with respect to the real interest rate identified by Bilbiie (2008) in the presence of LAMP.

In other words the results in Erceg et al. (2000) are robust to the introduction of LAMP, while Bilbiie's (2008) findings are sensitive to the introduction of wage stickiness.

For realistic values of nominal wage stickiness, the welfare properties of simple interest rules and the design of optimal monetary policy differ from those observed in a full partici-

pation model just in the case in which asset market participation is limited to an empirically implausible extent. For values of the share of non-Ricardian agents consistent with the empirical estimates, monetary policy prescriptions are isomorphic to those which characterize a standard NK model with no LAMP.

This suggests that reappraisals of the conduct of monetary policy in specific past periods, such as that of the Great Inflation, based on the presence of non-Ricardian agents cannot neglect nominal wage stickiness.

Our analysis is conducted in the context of a highly stylized economy. For instance, as in Bilbiie (2008), we assume that the government has access to a subsidy, financed with lump-sum taxes, which offset the distortions introduced by imperfect competition in the product and factor markets. Also we neglect the role of capital accumulation. These assumptions allow to obtain many of our results analytically, but they are empirically unrealistic. An extension of our analysis would be that of considering a larger scale business cycle model similarly to those in Christiano et al. (2005) or Smets and Wouters (2003). While this would add in terms of realism, we believe that it would not alter the main message of this paper.

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## A Technical Appendix

### A.1 The Model

#### A.1.1 Households

There is a continuum of households indexed by  $i \in [0, 1]$ . Households in the interval  $[0, \lambda]$  consume their available labor income in each period and do not hold assets. Households in the interval  $(\lambda, 1]$  hold assets and smooth consumption. The period utility function is common across households and it has the following separable form:

$$U_t = \Psi_t u[C_t(i)] - v[L_t(i)], \quad (11)$$

where  $C_t(i)$  is agent  $i$ 's consumption and  $L_t(i)$  are hours worked. The functions  $u$  and  $v$  satisfy the usual properties,<sup>17</sup> while  $\Psi_t$  is a taste shock. We assume a continuum of differentiated labor inputs indexed by  $j \in [0, 1]$ . As in Schmitt-Grohe and Uribe (2005), agent  $i$  supplies each possible type of labor input. Wage-setting decisions are made by labor type specific unions indexed by  $j \in [0, 1]$ . Given the wage  $W_t^j$  fixed by union  $j$ , agents stand ready to supply as many hours to the labor market  $j$  as required by firms, that is:  $L_t^j = \left(\frac{W_t^j}{W_t}\right)^{-\theta_w} L_t^d$ , where  $\theta_w$  is the elasticity of substitution between labor inputs. Here  $L_t^d$  is aggregate labor demand and  $W_t$  is an index of the wages prevailing in the economy at time  $t$ . Formal definitions of labor demand and of the wage index can be found in the section devoted to firms. Agents are distributed uniformly across unions; hence aggregate demand for labor type  $j$  is spread uniformly across the households.<sup>18</sup> It follows that the individual quantity of hours worked,  $L_t(i)$ , is common across households, and we denote it as  $L_t$ . This must satisfy the time resource constraint  $L_t = \int_0^1 L_t^j dj$ . Combining the latter with labor demand we obtain  $L_t = L_t^d \int_0^1 \left(\frac{W_t^j}{W_t}\right)^{-\theta_w} dj$ . The labor market structure rules out differences in labor income between households without the need to resort to contingent markets for hours. The common labor income is given by  $L_t^d \int_0^1 W_t^j \left(\frac{W_t^j}{W_t}\right)^{-\theta_w} dj$ . Notice that each union pools the labor income of agents, leading Ricardian and non-Ricardian households to work for the same amount of time.

**Ricardian Households** Ricardian agents face the following flow budget constraint in nominal terms:

$$E_t \Lambda_{t,t+1} X_{t+1} + \Omega_{S,t+1} V_t \leq X_t + L_t^d \int_0^1 W_t^j \left(\frac{W_t^j}{W_t}\right)^{-\theta_w} dj + \Omega_{S,t} (V_t + P_t D_t) - P_t C_{S,t}. \quad (12)$$

In each period  $t$ , Ricardian agents (indicated with the subscript S) can purchase any desired state-contingent nominal payment  $X_{t+1}$  in period  $t+1$  at the dollar cost  $E_t \Lambda_{t,t+1} X_{t+1}$ . The

<sup>17</sup>The function  $u$  is increasing and concave and the function  $v$  is increasing and convex.

<sup>18</sup>Thus a share  $\lambda$  of the members of each union are non-Ricardian consumers, while the remaining portion is composed of Ricardian agents.

variable  $\Lambda_{t,t+1}$  denotes the stochastic discount factor between period  $t+1$  and  $t$ . A Ricardian agent has labor income  $L_t^d \int_0^1 W_t^j \left( \frac{W_t^j}{\bar{W}_t} \right)^{-\theta_w} dj$  and holds a share  $\Omega_{S,t}$  of the stock market value,  $V_t$ , of firms producing intermediate goods. Nominal dividends received for the ownership of firms are denoted by  $P_t D_t$ . Combining the FOCs with respect to  $C_{S,t}$ ,  $\Omega_{S,t}$  and  $X_{t+1}$  together with the no-arbitrage condition on asset markets, i.e.  $E_t \Lambda_{t,t+1} \equiv (1+i_t)^{-1}$  we recover the Euler equation for Ricardian agents:

$$\frac{1}{1+i_t} = E_t \left\{ \beta \frac{\Psi_{t+1} u_c(C_{S,t+1})}{\Psi_t u_c(C_{S,t})} \frac{P_t}{P_{t+1}} \right\}. \quad (13)$$

**Non-Ricardian Households** Non-Ricardian agents (indicated with the subscript H) do not enjoy firms' profits in the form of dividend income and cannot trade in the financial markets. The nominal budget constraint of a typical non-Ricardian household is thus simply given by:

$$P_t C_{H,t} = L_t^d \int_0^1 W_t^j \left( \frac{W_t^j}{\bar{W}_t} \right)^{-\theta_w} dj. \quad (14)$$

Agents belonging to this group consume disposable income in each period and delegate wage decisions to unions. For these reasons there are no first order conditions with respect to consumption and labor supply.

### A.1.2 Wage Setting

Nominal wage rigidities are modeled according to the Calvo (1983) mechanism. In each period a union faces a constant probability  $1 - \xi_w$  of being able to reoptimize the nominal wage. As in Colciago (2011) the nominal wage newly reset at  $t$ ,  $\widetilde{W}_t$ , is chosen to maximize a weighted average of agents' lifetime utilities. The weights attached to the utilities of Ricardian and non-Ricardian agents are  $(1 - \lambda)$  and  $\lambda$ , respectively. The union problem is

$$\max_{\widetilde{W}_t} E_t \sum_{k=0}^{\infty} (\xi_w \beta)^k \{ [(1 - \lambda) u(C_{S,t+k}) + \lambda u(C_{H,t+k})] - v(L_{t+k}) \},$$

subject to  $L_t = \int_0^1 L_t^j dj$ , (12) and (14). The FOC with respect to  $\widetilde{W}_t$  is

$$E_t \sum_{s=0}^{\infty} (\beta \lambda_w)^{t+s} \Phi_{t,t+s} \left\{ \left[ \lambda \frac{1}{MRS_{H,t+s}} + (1 - \lambda) \frac{1}{MRS_{S,t+s}} \right] \frac{\widetilde{W}_t}{P_{t+s}} - \mu^w \right\} = 0, \quad (15)$$

where  $\Phi_{t,t+s} = v_L(L_{t+s}) L_{t+s}^d W_{t+s}^{\theta_w}$  and  $\mu^w = \frac{\theta_w}{(\theta_w - 1)}$  is the, constant, wage mark-up in the case of wage flexibility. The variables  $MRS_{H,t}$  and  $MRS_{S,t}$  denote the marginal rates of substitution between labor and consumption of non-Ricardian and Ricardian agents respectively.

### A.1.3 Firms

In each period  $t$ , a final good  $Y_t$  is produced by perfectly competitive firms combining a continuum of intermediate inputs  $Y_t(z)$  according to the following standard CES production function:  $Y_t = \left( \int_0^1 Y_t(z)^{\frac{\theta_p-1}{\theta_p}} dz \right)^{\frac{\theta_p}{\theta_p-1}}$ , with  $\theta_p > 1$ . The competitive final good producers' demand of the intermediate good  $z$  and the price of the final good are thus equal to:  $Y_t(z) = \left( \frac{P_t(z)}{P_t} \right)^{-\theta_p} Y_t$  and  $P_t = \left[ \int_0^1 P_t(z)^{1-\theta_p} dz \right]^{\frac{1}{1-\theta_p}}$ .

Intermediate inputs are produced by a continuum of monopolistic firms indexed by  $z \in [0, 1]$ . The production technology is simply linear in labor services,  $L_t(z)$ :

$$Y_t(z) = A_t L_t(z), \quad (16)$$

where  $A_t$  represents, exogenous, technology.

The labor input is defined as  $L_t(z) = \left( \int_0^1 \left( L_t^j(z) \right)^{\frac{\theta_w-1}{\theta_w}} dj \right)^{\frac{\theta_w}{\theta_w-1}}$ . Firm's  $z$  demand for labor type  $j$  and the aggregate wage index are then respectively:  $L_t^j(z) = \left( \frac{W_t^j}{W_t} \right)^{-\theta_w} L_t(z)$  and  $W_t = \left( \int_0^1 \left( W_t^j \right)^{1-\theta_w} dj \right)^{1/(1-\theta_w)}$ . Finally, given that the production function has constant return to scale, the nominal marginal cost,  $MC_t$ , is common across producers.

### A.1.4 Price Setting

Intermediate producers set prices according to the same mechanism assumed for wage setting. Firms in each period have a fixed chance  $1 - \xi_p$  to re-optimize their price. A price setter takes into account that the choice of its time  $t$  nominal price,  $\tilde{P}_t$ , might affect not only current but also future profits. The FOC for price setting is:

$$E_t \sum_{k=0}^{\infty} (\beta \xi_p)^k \gamma_{t+k} P_{t+k}^{\theta_p} Y_{t+k} \left[ \tilde{P}_t - (1 + \mu^p) MC_{t+k} \right] = 0, \quad (17)$$

which has the usual interpretation. The variable  $\gamma_t$  is the Lagrange multiplier on Ricardian households nominal flow budget constraint. Thus,  $\gamma_t$  represents the value of an additional dollar for Ricardian households, who own the firm shares. Notice that  $\mu^p = (\theta_p - 1)^{-1}$  represents the net markup over the price which would prevail in the absence of nominal rigidities.

### A.1.5 Aggregation and Market Clearing

Aggregate consumption is given by

$$C_t = \lambda C_{H,t} + (1 - \lambda) C_{S,t}. \quad (18)$$

The variable  $\Omega_t = (1 - \lambda) \Omega_{S,t}$  represents aggregate asset holdings. In equilibrium  $\Omega_t = 1$ , thus each Ricardian agent has asset holdings equal to  $\frac{1}{1-\lambda}$ . The clearing of good and labor



markets requires:

$$Y_t(z) = \left( \frac{P_t(z)}{P_t} \right)^{-\theta_p} Y_t^d \quad \forall z \quad Y_t^d = Y_t, \quad (19)$$

$$L_t^j = \left( \frac{W_t^j}{W_t} \right)^{-\theta_w} L_t^d \quad \forall j \quad L_t = \int_0^1 L_t^j dj, \quad (20)$$

where  $Y_t^d = C_t$  represents aggregate demand,  $L_t^j = \int_0^1 L_t^j(z) dz$  is total aggregate demand of labor input  $j$  and  $L_t^d = \int_0^1 L_t(z) dz$  denotes firms' aggregate demand of the composite labor input  $L_t$ .

### A.1.6 The Efficient Steady State and the Efficient Equilibrium Output

Following the literature (see Woodford, 2003) and as in Bilbiie (2008) and Erceg et al. (2000), society's welfare loss will be represented by a second order approximation to a weighted average of households lifetime utilities, where weights are given by the relative importance of agents's groups in the economy. In order to study the welfare properties of the economy without resorting to a full second order approximation to the model equations, we assume an efficient steady state of the economy. More precisely, we assume that the government imposes a lump sum tax,  $T$ , on firms such that steady state profits are zero. The tax proceeding are then used by the government to subsidize steady state firms' labor demand at the constant rate  $\tau$ .<sup>19</sup> In this case steady state profits read as

$$D = Y - \frac{(1 - \tau)W}{P}L - T, \quad (21)$$

where  $T = \tau \frac{W}{P}L$ . Profit maximization implies

$$\frac{W}{P} = \frac{1}{(1 + \mu_p)(1 - \tau)} MPL,$$

where  $MPL$  is the steady state marginal product of labor. Given steady state profits are zero it follows that  $C_S = C_L = C$  and, thus, that agents have a common marginal rate of substitution between labor and consumption, denoted by  $MRS$ . As a consequence the steady state wage set by unions reads as

$$\frac{W}{P} = (1 + \mu^w) MRS.$$

The steady state labor market equilibrium implies

$$\frac{1}{(1 + \mu_p)(1 - \tau)} MPL = (1 + \mu^w) MRS. \quad (22)$$

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<sup>19</sup>Out of steady state taxes are zero:  $\tau = T = 0$ . This allows to preserve inequality between agents out of the steady state and at the same time delivers steady state equality. Since the focus of the paper is not on the long-run differences across households, we view this device as innocuous.

Given the selected production function, and normalizing labor productivity to unity, at the efficient steady state it has to be the case that

$$MPL = MRS = 1, \quad (23)$$

From equation (22), the latter condition is satisfied if

$$\tau = 1 - \frac{1}{(1 + \mu_p)(1 + \mu^w)}. \quad (24)$$

As argued above the implied value of  $\tau$  leads to zero steady state profits

$$D = Y - \frac{(1 - \tau)W}{P}L - T = Y - \frac{Y}{(1 + \mu_p)^2(1 + \mu^w)} - \left(1 - \frac{1}{(1 + \mu_p)^2(1 + \mu^w)}\right)Y = 0.$$

Next, we solve the Social Planner problem (SPP). We assume a period utility of the form  $\frac{\Psi_t C_{i,t}^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\phi}}{1+\phi}$  for  $i = S, H$ , where  $\sigma$  is the relative risk aversion (and the inverse intertemporal elasticity of substitution), while  $\phi$  is the elasticity of marginal disutility of labor. The equilibrium output which solve the SPP corresponds to efficient equilibrium output. The SPP reads as

$$\begin{aligned} \max_{\{C_{H,t}, C_{S,t}, L_t\}} & \lambda \frac{\Psi_t C_{H,t}^{1-\sigma}}{1-\sigma} + (1 - \lambda) \frac{\Psi_t C_{S,t}^{1-\sigma}}{1-\sigma} - \lambda \frac{L_{H,t}^{1+\phi}}{1+\phi} - (1 - \lambda) \frac{L_{S,t}^{1+\phi}}{1+\phi} \\ \text{s.t. } & C_t = Y_t = A_t L_t = \lambda C_{H,t} + (1 - \lambda) C_{S,t} = A_t (\lambda L_{H,t} + (1 - \lambda) L_{S,t}). \end{aligned} \quad (25)$$

Writing the Lagrangian  $\mathcal{L}$ , and taking the first order condition with respect to  $C_{H,t}$ ,  $C_{S,t}$ ,  $L_{H,t}$  and  $L_{S,t}$  we find

$$C_{H,t} = C_{S,t} = C_t, \quad (26)$$

$$L_{H,t} = L_{S,t} = L_t. \quad (27)$$

In short, at the efficient equilibrium the economy behaves as if there was a representative agent with marginal rate of substitution between consumption and hours given by  $\Psi_t^{-1} C_t^\sigma L_t^\phi$ . The social planner sets the latter equal to the marginal product of labor,  $A_t$ , which also represents the equilibrium real wage,  $(W/P)_t^{Eff}$ . Using the relationship just described, imposing the market clearing condition  $Y_t = C_t$  and using the production function, delivers the efficient level of output as

$$Y_t^{Eff} = A_t^{\frac{1+\phi}{\sigma+\phi}} \Psi_t^{\frac{1}{\sigma+\phi}}. \quad (28)$$

Log-linearizing and considering that  $\Psi = 1$  delivers the log-deviations of the efficient output, the efficient real wage and the efficient real rate of interest from their efficient steady state values

$$y_t^{Eff} = \frac{1 + \phi}{\sigma + \phi} a_t + \frac{1}{(\sigma + \phi)} \psi_t, \quad (29)$$

$$\omega_t^{Eff} = a_t, \quad (30)$$

$$r_t^{Eff} = \sigma \left( \frac{1+\phi}{\sigma+\phi} \Delta a_{t+1} - \frac{\phi}{\sigma(\sigma+\phi)} \Delta \psi_{t+1} \right), \quad (31)$$

where we denote log-deviations by lower case letters, and  $\omega$  stands for the log-deviation of the real wage.

Assuming an AR(1) process for the logarithms of the exogenous state variables

$$a_t = \rho^a a_{t-1} + \varepsilon_t^a, \quad (32)$$

$$\psi_t = \rho^\psi a_{t-1} + \varepsilon_t^\psi, \quad (33)$$

fully specifies the dynamics of the log-deviations from the efficient equilibrium.

## A.2 Derivation of the IS curve

Log-linearization of the Euler equation of Ricardian agents leads

$$c_{s,t} = E_t c_{s,t+1} - \frac{1}{\sigma} E_t (i_t - \pi_{t+1}) - \frac{1}{\sigma} \Delta \psi_{t+1}, \quad (34)$$

while from the consumption function of non-Ricardian consumer we get

$$c_{H,t} = l_t + \omega_t. \quad (35)$$

Aggregate consumption is

$$c_t = (1 - \lambda) c_{s,t} + \lambda c_{H,t}, \quad (36)$$

combined with the Euler equation

$$c_t = E_t (c_{t+1} - \lambda \Delta c_{H,t+1}) - \frac{(1 - \lambda)}{\sigma} E_t (i_t - \pi_{t+1}) - \frac{(1 - \lambda)}{\sigma} \Delta \psi_{t+1}. \quad (37)$$

Substituting for  $c_t = y_t$ , for  $E_t \Delta c_{H,t+1} = E_t (\Delta l_{t+1} + \Delta \omega_{t+1})$  and for  $l_t = y_t - a_t$  we get

$$y_t = E_t y_{t+1} + \frac{\lambda}{1 - \lambda} E_t \Delta a_{t+1} - \frac{\lambda}{1 - \lambda} E_t \Delta \omega_{t+1} - \frac{1}{\sigma} E_t (i_t - \pi_{t+1}) - \frac{1}{\sigma} \Delta \psi_{t+1}, \quad (38)$$

rewriting equation (38) in terms of output gap from the efficient equilibrium output ( $x_t = y_t - y_t^{Eff}$ ), considering that  $r_t^{Eff} = \sigma \Delta y_{t+1}^{Eff} - \Delta \psi_{t+1}$  and given the definition of the real wage gap  $\tilde{\omega}_t = \omega_t - \omega_t^{Eff}$ , we can finally write the IS as

$$x_t = E_t x_{t+1} - \frac{1}{\sigma} E_t (i_t - \pi_{t+1} - r_t^{Eff}) - \frac{\lambda}{1 - \lambda} E_t \Delta \tilde{\omega}_{t+1}. \quad (39)$$

### A.2.1 The slope of the IS curve

**Flexible wages** In the case of flexible wages the real wage is given by

$$\omega_t = \sigma c_t + \phi l_t - \psi_t, \quad (40)$$

$$m c_t = \omega_t - (y_t - l_t) = \omega_t - a_t = (\sigma + \phi) x_t. \quad (41)$$

Hence  $\Delta\omega_{t+1} = (\sigma + \phi)\Delta x_{t+1} + \Delta a_{t+1}$ , and thus  $\Delta\omega_{t+1} - \Delta a_{t+1} = \Delta\tilde{\omega}_{t+1} = (\sigma + \phi)\Delta x_{t+1}$ . Substitute  $\Delta\tilde{\omega}_{t+1}$  in (39) to get

$$x_t = E_t x_{t+1} - \delta^{fw} E_t \left( i_t - \pi_{t+1} - r_t^{Eff} \right), \quad (42)$$

where  $\delta^{fw} = \frac{1}{\sigma} \left[ 1 - \frac{\lambda(\sigma+\phi)}{1-\lambda} \right]^{-1}$ .

**Sticky wages** In the case of sticky wages the real wage is given by

$$\omega_t = \frac{1}{1 + \beta + \kappa_w} [w_{t-1} - p_t] + \frac{\beta}{1 + \beta + \kappa_w} E_t (w_{t+1} - p_t) + \frac{\kappa_w}{1 + \beta + \kappa_w} ((\sigma + \phi)x_t + a_t). \quad (43)$$

This is a weighted average between: (i) the past nominal wage at current prices; (ii) the future nominal wage at current prices; (iii) the flexible wage ( $mc_t + a_t$ ). Note that as  $\xi_w \rightarrow 0$ , then  $\kappa_w \rightarrow \infty$ , and this expression collapses to the usual flexible wage case. Then

$$\Delta\omega_{t+1} = F + \frac{\kappa_w}{1 + \beta + \kappa_w} ((\sigma + \phi)\Delta x_{t+1} + \Delta a_{t+1}), \quad (44)$$

where  $F = \frac{1}{1 + \beta + \kappa_w} [\pi_t^w - \pi_{t+1}] + \frac{\beta}{1 + \beta + \kappa_w} E_t (\pi_{t+2}^w - \pi_{t+1})$ .

Substituting (44) into (39), recalling that  $\tilde{\omega}_t = \omega_t - \omega_t^{Eff}$ , we get

$$x_t = E_t x_{t+1} - \delta^{sw} E_t \left( i_t - \pi_{t+1} - r_t^{Eff} \right) + \frac{\lambda}{1 - \lambda} \frac{\sigma \delta^{sw}}{1 + \beta + \kappa_w} [(1 + \beta) E_t \Delta a_{t+1} - E_t (\pi_t^w - \pi_{t+1}) - \beta E_t (\pi_{t+2}^w - \pi_{t+1})], \quad (45)$$

where  $\delta^{sw} = \frac{1}{\sigma} \left[ 1 - \frac{\lambda(\sigma+\phi)}{1-\lambda} \frac{\kappa_w}{1+\beta+\kappa_w} \right]^{-1}$ . This expression is equivalent to (4) in the main text by noting that the last square bracket could be written as  $E_t [\Delta\pi_{t+1}^w - \Delta\tilde{\omega}_{t+1} - \beta E_t (\Delta\tilde{\omega}_{t+1} + \Delta\pi_{t+2}^w)]$ .

Wage flexibility requires  $\xi_w = 0$ . In this case  $\kappa_w \rightarrow \infty$ , and thus  $\delta^{sw} \rightarrow \delta^{fw} = 1 - \frac{\lambda(\sigma+\phi)}{1-\lambda}$ .<sup>20</sup>

### A.3 Proof of Propositions 1: Wage stickiness and the inversion of the slope of the IS curve

The threshold value is  $\bar{\lambda}^{sw} = \frac{1}{1 + (\sigma + \phi) \frac{\kappa_w}{1 + \beta + \kappa_w}}$  because  $\delta^{sw} \leq 0 \Leftrightarrow \lambda \geq \bar{\lambda}^{sw} = \frac{1}{1 + (\sigma + \phi) \frac{\kappa_w}{1 + \beta + \kappa_w}}$ . Then,  $\frac{\partial \bar{\lambda}^{sw}}{\partial \xi_w} = \frac{\partial \bar{\lambda}^{sw}}{\partial \kappa_w} \frac{\partial \kappa_w}{\partial \xi_w} = - \left[ 1 + (\sigma + \phi) \frac{\kappa_w}{1 + \beta + \kappa_w} \right]^{-2} (\sigma + \phi) \frac{1 + \beta}{(1 + \beta + \kappa_w)^2} \frac{\partial \kappa_w}{\partial \xi_w} > 0$ , because  $\frac{\partial \kappa_w}{\partial \xi_w} = \frac{-\beta \xi_w - \xi_w + 2\beta \xi_w^2 - 1 + \beta \xi_w + \xi_w - \beta \xi_w^2}{\xi_w^2} = \frac{\beta \xi_w^2 - 1}{\xi_w^2} < 0$ .

Moreover, note that in the interval  $\xi_w \in (0, 1]$ ,  $\bar{\lambda}^{sw}$  is a continuous and monotonic increasing function of  $\xi_w$  assuming values in the interval  $(\frac{1}{1 + \sigma + \phi}, 1]$ . So we can invert it and define a continuous and monotonically increasing function  $\bar{\xi}_w = f(\lambda)$  that gives me the threshold value (for the inversion of the slope of the IS curve) of wage stickiness for each value of  $\lambda \in (\frac{1}{1 + \sigma + \phi}, 1]$ . For values of  $\lambda \leq \frac{1}{1 + \sigma + \phi}$ , the slope of the IS curve is negative for any value

<sup>20</sup>Notice also that under flexible wages the last term on the RHS of (4) vanishes.

of  $\xi_w \in [0, 1]$ , because also the flexible wage slope of the IS does not invert for values of  $\lambda \leq \frac{1}{1+\sigma+\phi}$ . This completes the proof of Proposition 1.

For Corollary 2, recall that  $\delta^{sw} = \frac{1}{\sigma} \left[ 1 - \frac{\lambda(\sigma+\phi)}{1-\lambda} \frac{\kappa_w}{1+\beta+\kappa_w} \right]^{-1}$  and  $\kappa_w = \frac{(1-\beta\xi_w)(1-\xi_w)}{\xi_w}$ . Then:

(i)  $\frac{\partial \delta^{sw}}{\partial \kappa_w} = \frac{1}{\sigma} \left[ 1 - \frac{\lambda(\sigma+\phi)}{1-\lambda} \frac{\kappa_w}{1+\beta+\kappa_w} \right]^{-2} \frac{\lambda(\sigma+\phi)}{1-\lambda} \frac{1+\beta}{(1+\beta+\kappa_w)^2} > 0$  and since  $\frac{\partial \kappa_w}{\partial \xi_w} < 0$ , it follows that  $\frac{\partial \delta^{sw}}{\partial \xi_w} = \frac{\partial \delta^{sw}}{\partial \kappa_w} \frac{\partial \kappa_w}{\partial \xi_w} < 0$ . So the slope  $(-\delta^{sw})$  is an increasing function of  $\xi_w$ . Note that the derivative is not defined when  $\lambda = \bar{\lambda}^{sw} = \frac{1}{1+(\sigma+\phi)\frac{\kappa_w}{1+\beta+\kappa_w}}$ .

(ii) Wage flexibility requires  $\xi_w = 0$ . In this case  $\kappa_w \rightarrow \infty$ , and thus  $\delta^{sw} \rightarrow \delta^{fw} = \frac{1}{\sigma} \left[ 1 - \frac{\lambda(\sigma+\phi)}{1-\lambda} \right]^{-1}$ .<sup>21</sup>

(iii) **Fixed wages require**  $\xi_w = 1$ . In this case  $\kappa_w \rightarrow 0$ , and thus  $\delta^{sw} \rightarrow \frac{1}{\sigma}$ .

#### A.4 Intuition and wage elasticity

It is easy to rearrange equation (M2) to deliver the wage schedule

$$WS^{sw} : \omega_t = \Phi^{sw} l_t + \Upsilon_t^{sw}, \quad (46)$$

where  $\Phi^{sw} = \frac{\kappa_w}{1+\beta+\kappa_w}(\sigma + \phi)$  denotes the slope of the wage schedule, i.e., the elasticity of the real wage with respect to hours, in the case of sticky wages. For convenience the term  $\Upsilon_t^{sw} = \frac{1}{1+\beta+\kappa_w} [\omega_{t-1} - \pi_t + \beta E_t \omega_{t+1} + \beta E_t \pi_{t+1} + \kappa_w (\sigma a_t - \psi_t)]$  groups together all the other terms in the equation.

Under flexible wages (i.e.,  $\kappa_w \rightarrow \infty$ ) the wage schedule reduces to

$$WS^{fw} : \omega_t = \Phi^{fw} l_t + \Upsilon_t^{fw}, \quad (47)$$

where  $\Phi^{fw} = (\sigma + \phi)$  is the slope of the wage schedule under flexible wages and  $\Upsilon_t^{fw} = (\sigma a_t - \psi_t)$ . It follows that

$$\Phi^{sw} = \frac{\kappa_w}{1+\beta+\kappa_w} \Phi^{fw}. \quad (48)$$

Recall that  $\frac{\kappa_w}{1+\beta+\kappa_w}$  decreases in the degree of wage stickiness,  $\xi_w$ , and it takes values between 0 (when wages are fixed,  $\xi_w = 1$ ) and 1 (when wages are flexible,  $\xi_w = 0$ ).

#### A.5 Proof of Proposition 2: derivation of the aggregate Welfare-based Loss Function

Remember that the steady state of our economy is efficient, therefore:

$$\frac{v_{L,H}}{u_{C,H}} = \frac{v_{L,S}}{u_{C,S}} = \frac{W}{P} = \frac{Y}{L} = 1, \quad (49)$$

where  $L_H = L_S = L = Y$  and  $C_H = C_S = C = Y$ . The last equality in (49) holds since the economy production function is:  $Y_t = L_t A_t$ , where  $A = 1$  in steady state.

<sup>21</sup>Notice also that under flexible wages the last term on the RHS of (4) vanishes.

As in Bilbiie (2008) we assume that the Central Bank maximizes a convex combination of the utilities of two types of households, weighted by the mass of agents of each type, i.e.:

$$W_t = \lambda [u(C_{H,t}) - v(L_{H,t})] + (1 - \lambda) [u(C_{S,t}) - v(L_{S,t})], \quad (50)$$

we know that in our model, because of the presence of the union,  $L_{H,t} = L_{S,t} = L_t$  for each  $t$ , this means that (50) can be rewritten as

$$W_t = \lambda u(C_{H,t}) + (1 - \lambda) u(C_{S,t}) - v(L_t). \quad (51)$$

A second order approximation of  $\lambda u(C_{H,t})$  and  $(1 - \lambda) u(C_{S,t})$  delivers

$$\lambda u(C_{H,t}) - \lambda u(C_H) \simeq \lambda u_{C_H} C_H \left( c_{h,t} + \frac{1}{2} (1 - \sigma) c_{h,t}^2 + c_{h,t} \psi_t \right) + tip \quad (52)$$

$$(1 - \lambda) u(C_{S,t}) - \lambda u(C_S) \simeq (1 - \lambda) u_{C_S} C_S \left( c_{s,t} + \frac{1}{2} (1 - \sigma) c_{s,t}^2 + c_{s,t} \psi_t \right) + tip. \quad (53)$$

Also a second order approximation to  $v(L_t)$  yields:

$$v(L_t) - v(L) \simeq v_L L \left( l_t + \frac{1 + \phi}{2} l_t^2 \right). \quad (54)$$

Summing all the terms and considering steady state consumption levels of the two households are identical

$$\begin{aligned} W_t - W &= \lambda u_C C \left( c_{h,t} + \frac{1}{2} (1 - \sigma) c_{h,t}^2 \right) + u_C C c_t \psi_t \\ &+ (1 - \lambda) u_C C \left( c_{s,t} + \frac{1}{2} (1 - \sigma) c_{s,t}^2 \right) - v_L L \left( l_t + \frac{1 + \phi}{2} l_t^2 \right) + tip. \end{aligned} \quad (55)$$

From the economy production function we know that

$$l_t = y_t + d_{w,t} + d_{p,t} - a_t, \quad (56)$$

where  $d_{w,t} = \log \int_0^1 \left( \frac{W_t^j}{W_t} \right)^{-\theta_w} dj$  is the log of the wage dispersion and  $d_{p,t} = \log \int_0^1 \left( \frac{P_t^i}{P_t} \right)^{-\theta_p} di$  is the log of the price dispersion. Both terms are of second order and therefore they cannot be neglected in a second order approximation. Notice that

$$l_t^2 = (y_t + d_{w,t} + d_{p,t} - a_t)^2 = y_t^2 + a_t^2 - 2y_t a_t, \quad (57)$$

using (56), the efficient steady state condition  $u_C C = v_L L$ , the equilibrium condition  $c_t = y_t$  we get:

$$\begin{aligned} \frac{W_t - W}{u_C C} &= y_t + \frac{(1 - \sigma)}{2} [\lambda c_{h,t}^2 + (1 - \lambda) c_{s,t}^2] + c_t \psi_t + \\ &- \left( y_t + d_{w,t} + d_{p,t} - a_t + \frac{1 + \phi}{2} y_t^2 - (1 + \phi) y_t a_t \right) + tip. \end{aligned} \quad (58)$$

Next notice that  $c_{H,t} = w_t + l_t$ , then

$$\begin{aligned} c_{H,t}^2 &= w_t^2 + l_t^2 + 2w_t l_t \\ &= w_t^2 + y_t^2 + a_t^2 - 2y_t a_t + 2w_t y_t - 2w_t a_t \\ &= (y_t - a_t)^2 + w_t^2 + 2w_t y_t - 2w_t a_t, \end{aligned}$$

and  $c_{S,t} = \frac{1}{1-\lambda} c_t - \frac{\lambda}{1-\lambda} c_{H,t}$ , thus

$$\begin{aligned} c_{S,t}^2 &= \frac{1}{(1-\lambda)^2} c_t^2 + \left( \frac{\lambda}{1-\lambda} \right)^2 c_{H,t}^2 - 2 \left( \frac{1}{1-\lambda} \right) \left( \frac{\lambda}{1-\lambda} \right) c_t c_{H,t} \\ &= \frac{1}{(1-\lambda)^2} c_t^2 + \left( \frac{\lambda}{1-\lambda} \right)^2 (w_t^2 + l_t^2 + 2w_t l_t) - \frac{2\lambda}{(1-\lambda)^2} c_t (w_t + l_t) \\ &= \frac{1}{(1-\lambda)^2} \hat{y}_t^2 + \left( \frac{\lambda}{1-\lambda} \right)^2 (w_t^2 + y_t^2 + a_t^2 - 2y_t a_t + 2w_t y_t - 2w_t a_t) \\ &\quad - \frac{2\lambda}{(1-\lambda)^2} (y_t w_t + y_t^2 - y_t a_t), \end{aligned}$$

then

$$\begin{aligned} &(\lambda c_{H,t}^2 + (1-\lambda) c_{S,t}^2) \\ &= \lambda (y_t^2 + a_t^2 - 2y_t a_t + w_t^2 + 2w_t y_t - 2w_t a_t) + \\ &\quad \frac{1}{(1-\lambda)} y_t^2 + \frac{\lambda^2}{(1-\lambda)} (w_t^2 + y_t^2 + a_t^2 - 2y_t a_t + 2w_t y_t - 2w_t a_t) - \frac{2\lambda}{(1-\lambda)} (y_t w_t + y_t^2 - y_t a_t), \end{aligned}$$

collecting terms and simplifying

$$(\lambda c_{H,t}^2 + (1-\lambda) c_{S,t}^2) = \left( \frac{\lambda}{(1-\lambda)} \right) w_t^2 + y_t^2 + \frac{\lambda}{(1-\lambda)} a_t^2 - 2 \left( \frac{\lambda}{(1-\lambda)} \right) w_t a_t.$$

Using this results and considering that  $a_t$  is independent of policy the welfare function can be rewritten as

$$\begin{aligned} \frac{W_t - W}{u_C C} &= \frac{1}{2} \left[ \frac{(1-\sigma)\lambda}{(1-\lambda)} w_t^2 - (\sigma + \phi) y_t^2 - 2 \frac{(1-\sigma)\lambda}{(1-\lambda)} w_t a_t + 2y_t \psi_t + 2(1+\phi) y_t a_t \right] \\ &\quad - (d_{w,t} + d_{p,t}) + tip. \end{aligned}$$

Next we have to rewrite some terms. Recall that  $(\sigma + \phi) y_t^{Eff} = (1 + \phi) a_t + \psi_t$ , thus

$$(\sigma + \phi) y_t y_t^{Eff} = (1 + \phi) y_t a_t + y_t \psi_t,$$

and

$$\begin{aligned} (\sigma + \phi) (y_t - y_t^{Eff})^2 &= (\sigma + \phi) \left( y_t^2 + (y_t^{Eff})^2 - 2y_t y_t^{Eff} \right) \\ &= (\sigma + \phi) \left( y_t^2 + (y_t^{Eff})^2 \right) - 2(\sigma + \phi) y_t y_t^{Eff}, \end{aligned}$$

substituting for the previous result

$$(\sigma + \phi) (y_t - y_t^{Eff})^2 = (\sigma + \phi) \left( y_t^2 + (y_t^{Eff})^2 \right) - 2(1 + \phi) y_t a_t - 2y_t \psi_t.$$

In this case

$$\frac{W_t - W}{u_C C} = \frac{1}{2} \left[ \frac{(1 - \sigma) \lambda}{(1 - \lambda)} (w_t^2 - 2w_t a_t) - (\sigma + \phi) x_t^2 \right] - (d_{w,t} + d_{p,t}) + tip,$$

where  $x_t = (y_t - y_t^{Eff})$  and given that  $y_t^{Eff}$  is independent of policy. Also notice that  $w_t^{eff} = a_t$ , which is a term independent of policy. Multiplying  $w_t^{Eff}$  by  $w_t$  we get:  $w_t w_t^{eff} = w_t a_t$ , and therefore

$$(w_t - w_t^{eff})^2 = w_t^2 + (w_t^{eff})^2 - 2w_t w_t^{eff} = w_t^2 - 2w_t a_t + (w_t^{eff})^2,$$

which implies

$$w_t^2 - 2w_t a_t = (w_t - w_t^{eff})^2 - (w_t^{eff})^2 = \tilde{\omega}_t^2 - (w_t^{eff})^2.$$

Substituting the latter into the welfare loss function and considering that  $w_t^{eff}$  is a term independent of policy, we get

$$\frac{W_t - W}{u_C C} = \frac{1}{2} \left[ \frac{(1 - \sigma) \lambda}{(1 - \lambda)} \tilde{\omega}_t^2 - (\sigma + \phi) x_t^2 \right] - (d_{w,t} + d_{p,t}) + tip.$$

Using Woodford Lemma 1 and Lemma 2, we can finally write the present discounted value of the Central Bank loss function as

$$L = -\frac{1}{2} \sum_{t=0}^{\infty} \beta^t \left( \frac{(\sigma - 1) \lambda}{(1 - \lambda)} \tilde{\omega}_t^2 + (\sigma + \phi) x_t^2 + \frac{\theta_w}{\kappa_w} (\pi_t^w)^2 + \frac{\theta_p}{\kappa_p} \pi_t^2 \right) + tip.$$

Notice that if  $\sigma < 1$  deviation of the real wage from its efficient level leads to a lower society's loss.

#### A.5.1 Derivation of the welfare function under flexible wages

Remember that in the case in which wages are fully flexible, the labor supply is:

$$\omega_t = \sigma c_t + \phi l_t - \psi_t = (\sigma + \phi) y_t - \phi a_t - \psi_t - \phi d_{p,t}, \quad (59)$$

hence, subtracting the efficient equilibrium to the LHS and the RHS of the previous equation

$$\tilde{\omega}_t = (\sigma + \phi) x_t - \phi d_{p,t}, \quad (60)$$

where we use the fact that  $d_{p,t} - d_{p,t}^{Eff} = d_{p,t}$  (given that  $d_{p,t}^{Eff} = 0$ ). Moreover, we know  $a_t = a_t^{Eff}$  and that  $\psi_t = \psi_t^{Eff}$  and terms multiplied by  $-\phi d_{p,t}$  are terms higher than second order. Then

$$\tilde{\omega}_t^2 = (\sigma + \phi)^2 x_t^2,$$

this means that the welfare-loss can be re-written as follows:

$$L = -\frac{1}{2} \sum_{t=0}^{\infty} \beta^t \left( (\sigma + \phi) \left[ 1 + (\sigma - 1) (\sigma + \phi) \frac{\lambda}{1 - \lambda} \right] x_t^2 + \frac{\theta_p}{\kappa_p} \pi_t^2 \right).$$



Notwithstanding wage flexibility there is an additional term with respect to a fully Ricardian framework, given by  $\frac{(\sigma+\phi)(\sigma-1)\lambda}{1-\lambda}x_t^2$ . Two conditions are necessary for the presence of this additional term. Once again this is due to the presence of rot agents and similarly it disappears when  $\sigma = 1$ . Also, when  $\sigma < 1$ , the identified additional term leads to a reduction in society's welfare loss.

#### A.6 Proofs of Proposition 4: LAMP, strict price inflation and real wage-gap targeting

Given (M1) it follows immediately that strict price inflation targeting and strict wage gap targeting are equivalent. Indeed,  $\pi_t = 0, \forall t \Leftrightarrow \tilde{\omega}_t = 0, \forall t$ . In this case the model reduces to

$$(M2) \quad \pi_t^w = \beta E_t \pi_{t+1}^w + \kappa_w(\sigma + \phi)x_t$$

$$(M3) \quad \pi_t^w = \Delta\omega_t^{Eff}$$

$$(M4) \quad x_t = E_t x_{t+1} - \frac{1}{\sigma} E_t \left( i_t - r_t^{Eff} \right)$$

from which we can determine the path  $\{\pi_t, \pi_t^w, x_t\}_{t=0}^{\infty}$  independently of  $\lambda$ . The loss function also does not depend on  $\lambda$ . From (M3) and Given  $a_t = \rho_a a_{t-1} + \varepsilon_t^a$ , then  $\pi_t^w = \Delta\omega_t^{Eff} = \Delta a_t = (\rho_a - 1)a_{t-1} + \varepsilon_t^a$ . For  $\rho_a < 1$

$$Var(\pi^w) = Var(\Delta a_t) = (\rho_a - 1)^2 Var(a_t) + \sigma_a^2 = \frac{2}{1 + \rho_a} \sigma_a^2.$$

Then substituting (M3) into (M2) :

$$\begin{aligned} \pi_t^w &= \beta E_t \pi_{t+1}^w + \kappa_w(\sigma + \phi)x_t, \\ \Delta\omega_{tt}^{Eff} &= \beta E_t \Delta\omega_{t+1}^{Eff} + \kappa_w(\sigma + \phi)x_t, \end{aligned}$$

then assuming that  $a_t$  is known at  $t$  it follows that

$$x_t = \frac{1}{\kappa_w(\sigma + \phi)} [\Delta a_t - \beta E_t \Delta a_{t+1}] = \frac{1}{\kappa_w(\sigma + \phi)} [(\rho_a - 1)(1 - \beta\rho_a)a_{t-1} + (1 - \beta(\rho_a - 1))\varepsilon_t^a],$$

One can find a value for the variance of the output gap as

$$Var(x_t) = \left( \frac{(\rho_a - 1)(1 - \beta\rho_a)}{\kappa_w(\sigma + \phi)} \right)^2 \frac{\sigma_a^2}{1 - \rho_a^2} + \left( \frac{1 - \beta(\rho_a - 1)}{\kappa_w(\sigma + \phi)} \right)^2 \sigma_a^2.$$

Substitute the unconditional variances in unconditional expectation of the loss function to get unconditional society's loss.

## B Figures

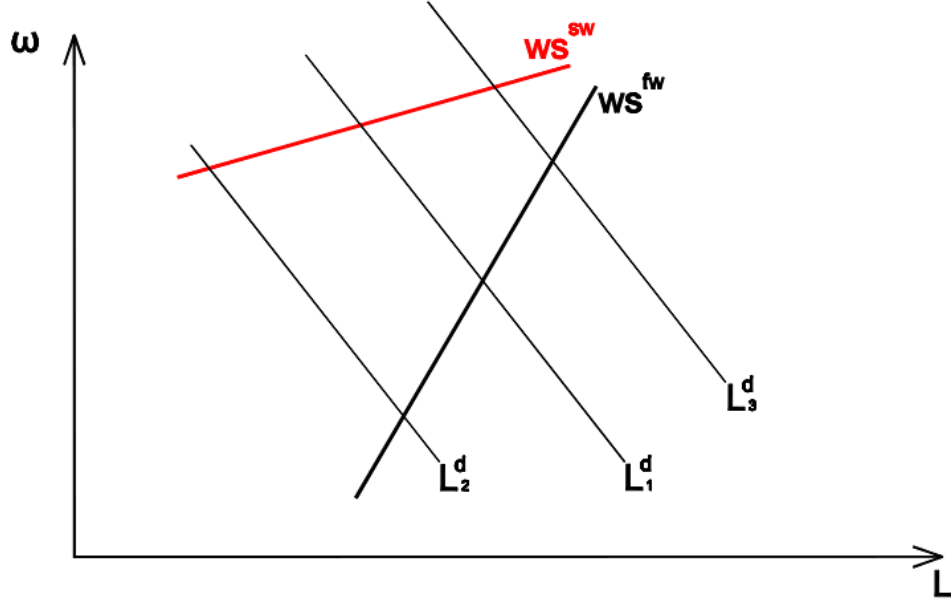


Figure 1: The wage schedule under sticky wages ( $WS^{sw}$ ) and flexible wages ( $WS^{fw}$ ) and the equilibrium in the labor market.

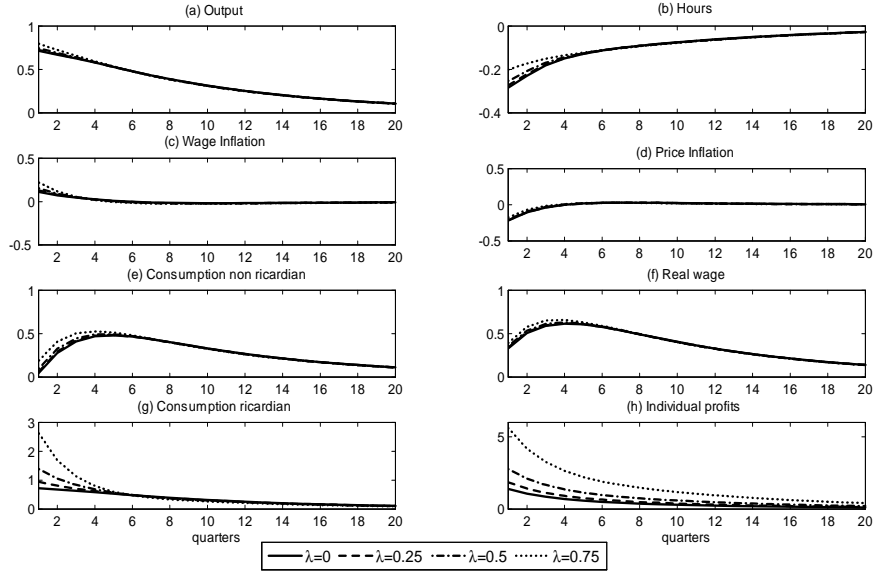


Figure 2. Impulse response function to a technology shock under full commitment for alternative values of the share of non-Ricardian agents ( $\lambda$ )

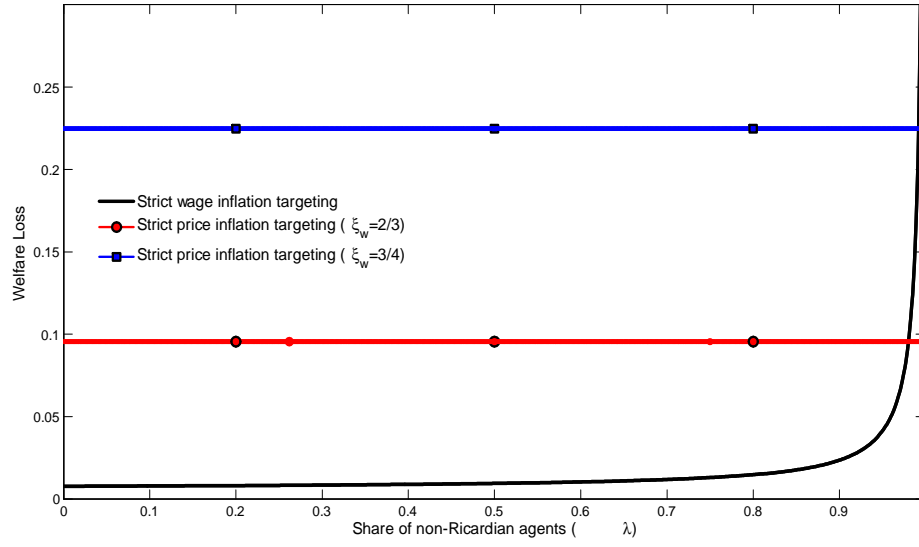


Figure 3. Unconditional welfare loss under strict wage inflation targeting and strict price inflation targeting. The latter is reported for two alternative average durations of wage contracts: 3 quarters ( $\xi_w = 2/3$ ) and 4 quarters ( $\xi_w = 3/4$ ).

## C Tables

Average duration of wage contracts $(1-\xi_w)^{-1}$	$\lambda = 0$	$\lambda = 0.25$	$\lambda = 0.5$	$\lambda = 0.75$
	<i>Full Commitment</i>			
1	0	0	0	0
2	0.0046	0.0054	0.007	0.0108
3	0.0059	0.0066	0.008	0.0125
4	0.0066	0.0071	0.0084	0.0125
5	0.0069	0.0075	0.0086	0.0124

Table 1: Unconditional welfare loss under full commitment. We consider alternative parameterizations for the share of non-Ricardian consumers and alternative average duration of wage contracts. The welfare loss is expressed as a percentage of the efficient steady state level of consumption, while the average duration of wage contracts is expressed in quarters.

<i>Average duration of wage contracts</i> $(1-\xi_w)^{-1}$	$\lambda = 0$	$\lambda = 0.25$	$\lambda = 0.5$	$\lambda = 0.75$
	A) $i_t = \phi_\pi \pi_t$			
1	10,0.03	-10,0.02	-10,0.02	-10,0.02
2	5,1.3	5.1,1.1	6.1,0.9	-10,0.48
3	4.3,2.1	4.5,1.9	5.4,1.6	10,1.4
4	4.3,2.8	4.6,2.5	5.4,2.1	9.6,1.9
5	4.4,3.5	4.8,3.2	5.6,2.8	9.4,2.4
	B) $i_t = \phi_\pi E_t \pi_{t+1}$			
1	10,0.06	-5.2,0.1	-10,0.06	-10,0.06
2	7.8,1	8.4,0.9	10,0.8	-10,0.6
3	6.5,1.6	7.1,1.4	9.4,1.3	10,2.2
4	6.4,2.2	7.1,2	9,1.8	10,2.7
5	6.7,2.8	7.3,2.6	9.1,2.3	10,3.4

Table 2: Panel A: Optimal contemporaneous inflation response coefficient (left), welfare loss (right). Panel B: Optimal expected inflation response coefficient (left), welfare loss (right). The welfare loss is expressed as a fraction of the efficient steady state consumption multiplied by one hundred. The average duration of wage contracts is expressed in quarters

<i>Average duration of wage contracts</i> $(1-\xi_w)^{-1}$	$\lambda = 0$	$\lambda = 0.25$	$\lambda = 0.5$	$\lambda = 0.75$
A) $i_t = \phi_\pi \pi_t + \phi_y y_t$				
1	10,0.05,0.04	-10,0.04,0.03	-10,0.05,0.03	-10,0.05,0.03
2	5.5,0.2,1.2	5.6,0.16,1.1	6.45,0.08,0.9	-10,-1.3,0.34
3	4.42,0.15,1.9	4.7,0.12,1.8	5.59,0.07,1.5	10,-0.07,1.4
4	4.8,0.2,2	5.04,0.17,1.8	5.8,0.1,1.5	9.5,-0.04,1.8
5	5.05,0.2,3.2	5.37,0.18,3	6.5,0.13,2.7	9.4,-0.01,2.4
B) $i_t = \phi_\pi \pi_t + \phi_\pi \pi_t^w$				
1	10,-0.006,0.04	-10,-0.13,0.02	-10,-0.11,0.03	-9.2,0.5,0.04
2	10,7.24,0.4	10,6.13,0.5	10,4.18,0.6	-10,-10,0.7
3	6.75,10,0.6	7.9,10,0.7	10,10,0.8	10,7.8,1.2
4	4.33,10,0.7	5.2,10,0.8	7.2,10,0.9	10,10,1.2
5	3.3,10,0.8	4.12,10,0.8	5.82,10,0.9	10,10,1.3

Table 3: Panel A: Optimal inflation response coefficient (left), optimal output response coefficient (center), welfare loss (right). Panel B: Optimal inflation response coefficient (left), optimal wage inflation response coefficient (center), welfare loss (right). The welfare loss is expressed as a fraction of the efficient steady state consumption multiplied by one hundred. The average duration of wage contracts is expressed in quarters