Labor Market Frictions and Optimal Steady-State Inflation*

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February 26, 2014

Abstract

In central theories of monetary non-neutrality, the Ramsey optimal steady-state inflation rate varies between the negative of the real interest rate and zero. This paper explores how the interaction of nominal wage and search and matching frictions affect the policy prescription. The mechanism we have in mind arises in a model with search frictions when nominal wages are not continuously rebargained and some newly hired workers enter into an existing wage structure. We show that adding the combination of such frictions to the canonical monetary model can generate an optimal inflation rate that is significantly positive. Specifically, for a standard U.S. calibration, we find a Ramsey optimal inflation rate of 1.15 percent per year, as compared to a rate of −0.76 percent when wages for new hires are fully flexible.

Keywords: Optimal Monetary Policy, Inflation, Labor Market Frictions.

JEL classification: E52, H21, J60.

*We are grateful to the editor Antonella Triagari, an anonymous referee, Roberto Billi, Tore Ellingsen, Michael Krause, Per Krusell, Lars E.O. Svensson, Karl Walentin and participants at the Greater Stockholm Macro Group, JLS Seminar Series, Frankfurt, and the EEA Congress in Oslo, 2011, for useful comments and discussions. The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Executive Board of Sveriges Riksbank.

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1 Introduction

In leading theories of monetary non-neutrality, the policy prescription for the optimal steady-state inflation rate varies between the negative of the real interest rate (the Friedman rule) and zero (price stability); see Schmitt-Grohe Uribe, 2010, for an overview. In this paper we explore a new channel where the interaction of nominal wage and labor market search and matching frictions affects the planner's trade-off between the welfare costs and benefits of inflation. We show that the combination of such frictions can in fact generate a Ramsey optimal inflation rate that is significantly positive. Importantly, this is the case even in the presence of a monetary friction, which drives the optimal inflation rate towards the Friedman rule of deflation.

The mechanism we have in mind arises in a model with search frictions when nominal wages are not continuously rebargained and some newly hired workers enter into an existing wage structure.[1] In this case, we show in a stylized model that inflation not only affects real-wage profiles over a contract spell, but also redistributes surplus between workers and firms, since incumbent workers impose an externality on new hires through the entry wage. Specifically, this affects the wage-bargaining outcome through the workers' outside option and hence the expected present value of total labor costs for a match as well as firms' incentives for vacancy creation. We derive a Hosios condition for the stylized model and show that the Ramsey planner has incentives to increase inflation if employment and vacancy creation are inefficiently low in order to push the economy towards the efficient allocation. Thus, in an efficient allocation, as in Thomas (2008), this incentive vanishes (and the reverse occurs when employment is inefficiently high). Also, the Ramsey planner loses the ability to affect real-wage costs via inflation if all new workers get to rebargain their wage. In this case, the full effect of inflation on entry wages is internalized in the wage bargain, and firm and worker surpluses, as well as real wage costs, become neutral to inflation. This is also the case if search frictions vanish since the Ramsey planner loses any leverage over vacancy/job creation. Thus, models without an extensive margin on the labor market lack the mechanism described here (as e.g. in Erceg, Henderson and Levin, 2000).

Overall, the key insight from the stylized model is that if both search and wage-setting externalities are present, there is an incentive for the Ramsey planner to vary the inflation rate to increase welfare through its effect on job creation and unemployment.

To quantitatively evaluate the relative strength of this mechanism, we introduce it into a full-fledged

[1] Data supports that a non-negligible share of newly hired workers enter into an existing wage structure. First, micro-data evidence on wages does not indicate that wages are more sensitive to labor market conditions at the beginning than later in the span of a match (once the variation in the composition of firms and match quality over the cycle is controlled for); see Gertler and Trigari (2009). Secondly, survey evidence, like Bewley (1999), Bewley (2007) for the U.S. and the study performed within the Eurosystem Wage Dynamics Network (WDN), reported by Galuscak, Keeney, Nicolitsas, Smets, Strzelecki, and Vodopivec (2012), present strong evidence that the wages of new hires are tightly linked to those of incumbents.

model encompassing leading theories of monetary non-neutrality. The model we outline features a non-Walrasian labor market with search frictions as in Mortensen and Pissarides (1994), Trigari (2009) and Christoffel, Kuester, and Linzert (2009). Moreover, there are impediments to continuous resetting of nominal prices and wages modeled along the lines of Dotsey, King, and Wolman (1999), where adjustment probabilities are endogenous. Finally, the model features a role for money as a medium of exchange, as in Khan, King, and Wolman (2003) and Lie (2010).

In the quantitative model, variation in the average inflation rate will have several effects on welfare. First, inflation will affect the opportunity cost of holding money, pushing the optimal inflation rate towards the Friedman rule. Second, because of monopolistic competition and nominal frictions, inflation causes relative price distortions, which drive the optimal inflation rate towards zero. Finally, we introduce the mechanism presented above, i.e., search frictions combined with new hires entering into an existing wage structure, where the inflation rate affects equilibrium real-wage costs and, in turn, job creation.

In a standard U.S. calibration of the model, implying that employment is 1.87 percentage points lower than in the efficient allocation, we find that the Ramsey optimal inflation rate is 1.15 percent per year. Moreover, varying the share of new hires receiving rebargained wages has a substantial effect on the optimal inflation rate. If all newly hired workers receive rebargained wages, thus shutting down the interaction effect between nominal wage frictions and search and matching frictions, the optimal inflation rate is -0.76 percent.[2] When none [50 percent, the baseline] (all, as in Gertler and Trigari (2009)), of the newly hired workers enter into an existing wage structure, the optimal inflation rate is -0.76 [1.15] (1.35) percent. Thus, only a moderate share of new workers entering into an existing wage structure is needed to obtain a significantly positive optimal inflation rate.

When shutting down the monetary distortion and looking at the cashless economy, as analyzed in Woodford (2003), we find that the Ramsey optimal inflation rate increases to 1.52 percent. Thus, the monetary distortion has a moderately negative effect on the optimal policy prescription.

The results reported above are conditional on agents optimally choosing when to change prices and wages. It is then interesting to study the effect of shutting down the endogenous response of the adjustment probabilities to variations in inflation and let the agents face a fixed adjustment hazard. In contrast to Lie (2010), we find that endogenizing adjustment probabilities matters for the quantitative analysis. Specifically, exogenous price and wage adjustment hazards give a Ramsey optimal inflation rate of 2.95 percent, thus an increase of almost two percentage points relative to the

[2] This is the same rate as if we let all wage contracts be continuously rebargained in the model (not only those of the new hires). These cases are the same due to the fact that wages are not allocative in the search-matching framework we rely on, or more specifically, a relative-wage dispersion across firms does not give rise to a dispersion of labor supply across individuals working at different firms.

case with endogenous adjustment hazards.

All in all, we find that the combination of search and wage-setting externalities within the canonical monetary model introduces an important link between inflation and welfare and hence potentially a large difference in prescribed policy.

For clarity, the quantitative model outlined in this paper does not encompass all mechanisms that can affect the Ramsey optimal steady-state inflation rate. Papers studying the effect of other mechanisms on the Ramsey optimal steady-state inflation are Schmitt-Grohé and Uribe (2010) using inflation as an indirect tax to address tax evasion, Schmitt-Grohé and Uribe (2012a) analyzing foreign demand of domestic currency, Schmitt-Grohé and Uribe (2012b) studying quality bias, Adam and Billi (2006) and Billi (2011) looking into the effect of the zero lower bound, and Kim and Ruge-Murcia (2011) addressing downward nominal wage rigidity.[3] Of these, only a substantial foreign demand of domestic currency and a planner that only cares about the well-being of the home country may lead to a significantly positive inflation rate. Moreover, all of these features are, if anything, likely to drive up the Ramsey optimal steady-state inflation rate. Thus, in this sense the results presented here can be viewed as a lower bound.

This paper is outlined as follows: In section 2 we present the basic mechanism we have in mind, in section 3, we outline the framework for the quantitative evaluation, including a description of the optimal Ramsey policy, in section 4 the calibration and the quantitative results are presented. Finally, section 5 concludes.

2 The Mechanism

To set ideas, it is helpful to first focus on a stylized stationary equilibrium model of the labor market featuring the interaction mechanism we have in mind.[4] Let firms and workers sign contracts with a fixed (nominal) wage, W, that with certainty lasts for two periods. Letting P denote the price level in the first period of the contract and π the gross inflation rate, the real wage in the first and second periods of the contract, respectively, are then $w = \frac{W}{P}$ and $w' = \frac{W}{\pi P} = \frac{w}{\pi}$. This captures the first component we need, i.e. nominal wage frictions. We restrict attention to the case where gross inflation is positive, i.e., $\pi > 0$. Secondly, we assume that there are search and matching frictions captured by a constant returns matching function, giving rise to a surplus to be bargained over. Specifically, we assume that the number of matches, μ, is given by the constant-returns matching function in

[3] There is also a literature focusing on the dynamic effects of labor market frictions under the Ramsey optimal policy; see Faia (2008, 2009) and Faia and Rossi (2013).

[4] We are grateful to Antonella Trigari for suggesting how to substantially improve this section.

Den Haan, Ramey, and Watson (2000);

$$\mu = \frac{u\nu}{(u^{\sigma_a} + \nu^{\sigma_a})^{\frac{1}{\sigma_a}}}. \tag{1}$$

where u is unemployment and ν vacancies. The probability that a worker is matched to a firm is

$$s = \frac{\mu}{u}, \tag{2}$$

and the probability that a vacancy is filled is

$$q = \frac{\mu}{\nu}. \tag{3}$$

We denote the surplus of the firm (worker) J^i (H^i) with $i \in \{0, 1\}$ where $i = 0$ denotes that the wage is rebargained and $i = 1$ that the wage is not rebargained. The surplus for the firm in a period when wages are rebargained is then

$$J^0 = p^w - w + \beta\rho J^1, \tag{4}$$

where p^w is the (real) marginal revenue for the firm, β is the discount factor and ρ is the fixed probability that the match survives into the next period. Moreover, in a period when the wage is not rebargained the, surplus is

$$J^1 = p^w - \frac{w}{\pi} + \beta\rho J^0. \tag{5}$$

Similarly, the surpluses for the worker are

$$H^0 = w - b_r + \beta \left[\rho H^1 - sH_x\right] \tag{6}$$

$$H^1 = \frac{w}{\pi} - b_r + \beta \left[\rho H^0 - sH_x\right], \tag{7}$$

where b_r is (real) income received when unemployed, financed via lump-sum taxes, s the probability of finding a job and H_x the average value of being employed across all firms in the economy. Note that variations in H_x affect the workers' outside option in the bargain. All renegotiating firms set the same wage w and the wage path for a rebargaining firm is

$$\{w, \frac{w}{\pi}, w, \frac{w}{\pi}, \ldots\}, \tag{8}$$

and for a non-rebargaining firm, the wage path is

$$\{\frac{w}{\pi}, w, \frac{w}{\pi}, w, \ldots\}. \tag{9}$$

The output, denoted by x^w, is sold at price p^w and is used as input by final-good firms that produce using a constant returns technology $Y = x^w$, facing CES demand with elasticity σ as in equation (41) below. This implies that p^w is the marginal cost of final-goods firms which in equilibrium is $p^w = \frac{\sigma-1}{\sigma} < 1$. Note, however, that the social value of an additional employed worker is equal to unity due to the constant returns technology. The planner solution can be described by[5]

$$1-\eta\left(\theta\right)=\frac{\kappa+q\eta\left(\theta\right)\kappa\theta-\kappa\beta\rho}{q}, \tag{12}$$

where κ is the vacancy posting cost, q is the probability of filling a vacancy, $\theta = \frac{\nu}{u}$ is tightness and $\eta\left(\theta\right) = -\frac{\partial q}{\partial \theta}\frac{\theta}{q}$, i.e. the elasticity of the job-finding probability w.r.t. to tightness, together with the unemployment transition equation.[6]

Case 1: Flexible Wages

In a competitive equilibrium, labor market variables are determined by job creation and bargaining. Firm and worker values are

$$\begin{aligned} J^0 &= p^w - w + \beta\rho J^0 \qquad (13) \\ H^0 &= w - b_r + \beta\left[\rho H^0 - sH_x\right], \end{aligned}$$

where $H_x = H^0$ in this case. From job creation, we have

$$\kappa = q\beta J^0, \tag{14}$$

where

$$J^0 = \frac{p^w - w}{1-\beta\rho}. \tag{15}$$

From wage setting, via Nash bargaining, we have

$$\left(1-\varphi\right)H^0 = \varphi J^0, \tag{16}$$

[5] This follows from solving the planner problem as in Pissarides (2000) p. 184-185 for a discrete economy. Formally, social welfare is

$$\sum_{t=0}^{\infty}\beta^t\left(1\left(1-u_t\right)-\kappa\theta_t u_t\right) \tag{10}$$

and unemployment evolves according to

$$1-u_t = \rho\left(1-u_{t-1}\right)+q_{t-1}\theta_{t-1}u_{t-1}. \tag{11}$$

Solving the optimization problem then gives expression (12) in steady state.

[6] Note that if the matching function is Cobb-Douglas, $\eta(\theta)$ is a constant and equal to the elasticity of the matching function w.r.t. unemployment.

where φ is the workers bargaining power, implying that the flexible wage, denoted by w_F, is given by

$$w_F = \frac{\varphi\left(1-\beta\left(\rho-s\right)\right)p^w + \left(1-\varphi\right)\left(1-\beta\rho\right)b_r}{1-\beta\left(\rho-\left(1-\left(1-\varphi\right)\right)s\right)}. \tag{17}$$

Using the solution for the wage in job creation condition (14) implies that the Hosios (1990) condition is

$$1-\varphi = \frac{1-\eta\left(\theta\right)}{p^w-b_r} + \frac{\left(\varphi-\eta\left(\theta\right)\right)\kappa\theta}{p^w-b_r}. \tag{18}$$

In the competitive economy, there is an externality imposed in job creation, due to the fact that the individual firm does not take into account that an increase in vacancies affects the aggregate probability that a vacancy is filled. This implies that if the firms were to obtain the entire surplus, too many vacancies would be posted in this economy (as long as φ in equation (18) is interior). The bargaining power as defined in equation (18), is the bargaining power that ensures that the firms' job creation incentives lead to the planner allocation as described in equation (12). Let $\varphi_{H,F}$ denote the value of bargaining power satisfying the Hosios condition (18) under flexible wages. Note that this differs from the standard Hosios condition due to the fact that the firm revenues differ from the social value of an employee (p^w vs. unity) and also because workers get an unemployment benefit, b_r, which would be zero in the standard approach outlined in Pissarides (2000); see equations (8.5) - (8.7). Specifically, the reason why b_r enters the Hosios condition is that a change in b_r affects the competitive equilibrium through wages (see equation (17)), but does not affect the planner solution since it is just a transfer.

We can also think about the Hosios condition in terms of the wage. In particular, from expression (17), the wage is a function of bargaining power and thus the wage at bargaining power $\varphi = \varphi_{H,F}$, denoted by $w_{H,F}$, implies that the Hosios condition must be satisfied.

Case 2: Sticky wages

For simplicity, this section focuses on the two boundary cases where $H_x = H^0$ or $H_x = H^1$. Thus, either new hires get rebargained wages or they enter into the second period of the wage contract. Note that by solving the system of equations (4) and (5), we can rewrite firm values as

$$J^0 = \frac{1}{1-\beta\rho}\left[p^w - \underbrace{\frac{w+\beta\rho\frac{w}{\pi}}{1+\beta\rho}}_{\equiv\tilde{w}^0}\right] \tag{19}$$

and

$$J^1 = \frac{1}{1-\beta\rho}\left[p^w - \underbrace{\frac{\frac{w}{\pi}+\beta\rho w}{1+\beta\rho}}_{\equiv\tilde{w}^1}\right]. \tag{20}$$

Similarly, from the system of equations (6) and (7),

$$H^0 = \frac{1}{1-\beta\rho}\left[\tilde{w}^0 - (b_r + \beta s H_x)\right], \tag{21}$$

$$H^1 = \frac{1}{1-\beta\rho}\left[\tilde{w}^1 - (b_r + \beta s H_x)\right]. \tag{22}$$

Nash bargaining (16) implies that, when renegotiating, the parties share the surplus so that the present value of the wage sequence shares the present value of surpluses according to the bargaining power φ and we get

$$\tilde{w}_i^0 = \varphi p^w + (1-\varphi)(b_r + \beta s H_x), \tag{23}$$

where superscript $i = \{b, nb\}$ denotes when $H_x = H^0$ and $H_x = H^1$, respectively. That is $\tilde{w}_b^0$ is the wage when all new hires get a rebargained wage and $\tilde{w}_{nb}^0$ is the wage when all new hires enter into an old contract. In the latter case, the present value of the wage sequence is lower when $\pi > 1$, since the worker first gets the deflated wage and then the rebargained wage w. Furthermore, the higher the inflation rate, the lower the present value of wages when new hires enter into an existing contract relative to in a renegotiated match. We denote this ratio by

$$\delta(\pi) \equiv \frac{\tilde{w}_i^1}{\tilde{w}_i^0} = \frac{\frac{1}{\pi} + \beta\rho}{1 + \beta\rho\frac{1}{\pi}} \tag{24}$$

for $i = \{b, nb\}$. Note also that $\delta'(\pi) < 0$, $\lim_{\pi\to 0}\delta(\pi) = 1/\beta\rho$, $\delta(1) = 1$ and $\lim_{\pi\to\infty}\delta(\pi) = \beta\rho$.

Using (6), (7) and (23) gives

$$\tilde{w}_b^0 = \frac{1-\beta(\rho - s)}{1-\beta(\rho - (1-(1-\varphi))s)}\left[\varphi p^w + (1-\varphi)\frac{1-\beta\rho}{1-\beta(\rho-s)}b_r\right] \tag{25}$$

and

$$\tilde{w}_{nb}^0 = \frac{1-\beta(\rho - s)}{1-\beta(\rho - (1-(1-\varphi)\delta(\pi))s)}\left[\varphi p^w + (1-\varphi)\frac{1-\beta\rho}{1-\beta(\rho-s)}b_r\right]. \tag{26}$$

Note that whenever $\pi > 1$ and hence $\delta(\pi) < 1$ the wage when new hires get rebargained wages is higher than when new hires enter into an existing wage structure, i.e. $\tilde{w}_b^0 > \tilde{w}_{nb}^0$. The reason for this is that employed workers take into account that an increase in inflation affect the wage profile for their own contract and hence adjust w accordingly, but they do not take into consideration the effect the wage profile has on the entry wages of new hires, i.e. w/π. Thus, incumbent (bargaining) workers impose an externality on the entry wage of new hires. This, in turn, leads to a lowering of the present value of the wage sequence for new hires (see equation (9)), and in turn to a worsening of the outside option for workers when bargaining and a reduction in the equilibrium wage. Relying on the same notation, note also that job creation is

$$\kappa = \beta q J_b^0 \tag{27}$$

when $H_x = H^0$ and

$$\kappa = \beta q J_{nb}^1 \tag{28}$$

when $H_x = H^1$. Thus, it is the wages of newly hired workers ($\tilde{w}_b^0$ and $\tilde{w}_{nb}^1$) that matters for equilibrium outcomes (echoing Pissarides, 2009).

Now consider the relationship to the flexible wage economy and the Hosios condition. First, when $H_x = H^0$, note that $\tilde{w}_b^0 = w_F$. Hence, the firm surplus J_b^0 in equation (27) is the same as in the economy with flexible wages (see equation (15)). This in turn implies that job creation, employment and unemployment are the same and $\varphi_{H,b} = \varphi_{H,F}$. Moreover, the Hosios condition is again described as in equation (18).

Second, if $H_x = H^1$ when $\pi > 1$ we have $\tilde{w}_{nb}^0 < \tilde{w}_b^0$ since $\delta < 1$ and when $\pi < 1$ we have $\tilde{w}_{nb}^0 > \tilde{w}_b^0$. Focusing on the case where $\pi > 1$, the equilibrium present value of wages in a non-renegotiating match $\tilde{w}_{nb}^1$ does not share the surplus according to the bargaining power φ, but instead gives the firm a higher share of the surplus than what would be implied by its bargaining power. Also, from (19) - (21) the total surplus for new matches is

$$\frac{1}{1-\beta\rho}\left[p^w - \left(b_r + \beta s H_b^0\right)\right] \tag{29}$$

when $H_x = H^0$ and

$$\frac{1}{1-\beta\rho}\left[p^w - \left(b_r + \beta s H_{nb}^1\right)\right] \tag{30}$$

when $H_x = H^1$. Since $H_b^0 = \frac{\tilde{w}^0 - b_r}{1-\beta(\rho-s)} > H_{nb}^1 = \frac{\delta(\pi)\tilde{w}^1 - b_r}{1-\beta(\rho-s)}$, the total surplus for new matches is larger when $H_x = H^1$ than when $H_x = H^0$. Thus, when new hires get non-renegotiated wages, the firm gets a *larger share* of a *larger surplus*, both of which increase the firm value of a new hire. Formally,

$$J_{nb}^1 = \frac{p^w - \delta(\pi)\,\tilde{w}_{nb}^0}{1-\beta\rho} > J_b^0 = \frac{p^w - \tilde{w}_b^0}{1-\beta\rho}, \tag{31}$$

implying that firms will post more vacancies than in the case where new workers get rebargained wages. Hence, employment will be higher and unemployment lower. Furthermore, by subtracting and adding $\tilde{w}_b^0$ in the numerator for the value of J_{nb}^1 in equation (31), using $\tilde{w}_b^0 = w_F$ and proceeding as in the flexible wage case, the Hosios condition is

$$1-\varphi = \frac{1-\eta(\theta)}{p^w - b_r} - \frac{\eta(\theta)-\varphi}{p^w - b_r}\kappa\theta - \frac{1-\beta\rho+\varphi\beta\theta q}{(1-\beta\rho)(p^w - b_r)}\left(\tilde{w}_b^0 - \delta(\pi)\,\tilde{w}_{nb}^0\right), \tag{32}$$

where the first two terms on the right-hand side are as in equation (18), but the last term is new and is due to the fact that the wage paid to new hires is different from the wage in equation (25) (and thus the wage in equation (17)). Let $\varphi_{H,nb}$ denote the value of φ satisfying the above equation.

Note that equation (32) depends on δ. Then, in contrast to the flexible wage case and the case where new hires get new wages, there are several values of φ for which the planner solution can be implemented by an appropriate choice of δ. To see this, first note that, using $\tilde{w}^0_{nb}$ in (28) and that q and s are functions of θ (using the CRS property of the matching function), the job creation condition (28) implicitly determines equilibrium tightness θ as a function of δ and φ. Denote this function by $\theta = \theta_{nb}(\delta, \varphi)$, which is decreasing in δ.[7] The equilibrium wage costs ($\tilde{w}^1$ in equation (20)) paid by hiring firms is

$$
\begin{aligned}
\hat{w}^1_{nb}(\delta, \varphi) \quad = \quad & \delta \frac{1 - \beta\left(\rho - s\left(\theta_{nb}(\delta, \varphi)\right)\right)}{1 - \beta\left(\rho - \left(1 - (1-\varphi)\delta\right) s\left(\theta_{nb}(\delta, \varphi)\right)\right)} \\
& \times \left[\varphi p^w + (1-\varphi) \frac{1 - \beta\rho}{1 - \beta\left(\rho - s\left(\theta_{nb}(\delta, \varphi)\right)\right)} b_r\right],
\end{aligned}
\tag{33}
$$

which is increasing in δ, again by using (28). Since δ is in the open set $(\beta\rho, 1/\beta\rho)$ and since $\hat{w}^1_{nb}(\delta, \varphi)$ is increasing in δ, the set of feasible wages, $W_{nb} \equiv (\underline{w}_{nb}, \bar{w}_{nb})$, is open where the lower and upper bounds are $\underline{w}_{nb} \equiv \hat{w}^1_{nb}(\beta\rho, \varphi)$ and $\bar{w}_{nb} \equiv \hat{w}^1_{nb}(1/\beta\rho, \varphi)$, respectively. Furthermore, as $\beta\rho \to 1$ both the upper and lower bounds converge to w_F. Whether $w_{H,F} \in W_{nb}$ or not determines if the planner solution can be achieved. Note first that when $\varphi = \varphi_{H,F}$ the planner solution can be implemented by setting $\pi = 1$, implying $\delta(\pi) = 1$ and hence $\hat{w}^1_{nb}\left(1, \varphi_{H,F}\right) = w_{H,F}$ and $\underline{w}_{nb} < w_{H,F} < \bar{w}_{nb}$. Second, since the bounds are continuous in φ, we have $w_{H,F} \in W_{nb}$ for φ close to $\varphi_{H,F}$ implying that there is a $\pi \in (0, \infty)$ that implements the planner solution.[8] Third, if $w_{H,F} < \underline{w}_{nb}$ or $w_{H,F} > \bar{w}_{nb}$ the planner solution can not be implemented and the policymaker has incentives to either create hyper inflation ($\pi \to \infty$) or hyper deflation ($\pi \to 0$) depending on which boundary is relevant.[9] Thus, there is a set of values for the bargaining power

$$
\Omega = \left\{\varphi \in [0, 1] \mid \exists \delta \in (\beta\rho, 1/\beta\rho) \text{ s.t. } \hat{w}^1_{nb}(\delta, \varphi) = w_{H,F}\right\}, \tag{34}
$$

where the planner solution can be implemented by appropriately choosing π.

Recall that the Ramsey planner chooses inflation subject to the constraints from private sector behavior. Then it follows from above that the Ramsey optimal inflation rate either does not exist

[7] This follows from differentiating (28).

[8] Here we do not consider a subsidy to intermediate goods production or b_r as instruments for the Ramsey policy maker. For a discussion on tax-policy implementation of the first-best allocation in a model with nominal rigidities and labor market frictions see Ravenna and Walsh (2012).

[9] That the planner solution can not be implemented for some parameter values follows from noting that when $\varphi > \varphi_{H,F}$ we have $\hat{w}^1_{nb}(1, \varphi) > w_{H,F}$ and, if we in addition let $\beta\rho \to 1$, we also have $\underline{w}_{nb} > w_{H,F}$.

or is the rate that implements the planner solution in (12). Below we develop a richer model adding additional frictions for the Ramsey planner to consider when designing optimal policy (i.e., price adjustment frictions and money demand). These frictions introduce additional trade-offs that eliminate the nonexistence problems associated with hyper inflation/deflation. Specifically, price adjustment tends to push the Ramsey optimal inflation rate to zero, while the Friedman rule tends to push it towards the negative of the real interest rate.

Note also that, if search frictions vanish, i.e., when the job finding probability $s \rightarrow 1$, due to $\kappa \rightarrow 0$, the competitive equilibrium converges to the planner solution. To see this, note that the planner solution has $q \rightarrow 0$ and $s \rightarrow 1$ when $\kappa \rightarrow 0$.[10] In the competitive economy, the equilibrium also has $q \rightarrow 0$ and $s \rightarrow 1$ in the case where $\kappa \rightarrow 0$.[11] This follows from that the surplus of a match βJ_{nb}^1 is strictly positive and hence we have $q \rightarrow 0$ from equation (28), in turn implying $s \rightarrow 1$.[12] Thus, when search frictions vanish, the competitive equilibrium allocation converges to the planner solution, eliminating any incentives to use the mechanism above.[13]

The key insight here is that if both search and wage-setting externalities are present, this mechanism is active. In this case, a Ramsey planner has incentives to vary the inflation rate in order to increase welfare through its effect on equilibrium wages through δ, in turn affecting job creation and unemployment.

In relation to earlier literature it is first worth noting that this mechanism is not at work in Thomas

[10] To see this, note first that

$$q = \frac{1}{(1+\theta^{\sigma_a})^{\frac{1}{\sigma_a}}} \tag{35}$$

$$s = \frac{1}{\left(1+\theta^{-\sigma_a}\right)^{\frac{1}{\sigma_a}}} \tag{36}$$

and

$$\eta(\theta) = \frac{\theta^{\sigma_a}}{1+\theta^{\sigma_a}}. \tag{37}$$

The planner optimality condition can be written as

$$\kappa(1-\beta\rho) = \frac{1}{(1+\theta^{\sigma_a})^{\frac{1}{\sigma_a}+1}}\left(1-\theta^{\sigma_a+1}\kappa\right). \tag{38}$$

Then, as $\kappa \rightarrow 0$, we have $\theta \rightarrow \infty$ and hence $q \rightarrow 0$ and $s \rightarrow 1$.

[11] As long as there is not too much deflation.

[12] To see this, note first that we can write

$$J_{nb}^1 = \frac{K(\delta,s)}{(1-\beta\rho)(1-\beta(\rho-(1-(1-\varphi)\delta)s))}, \tag{39}$$

where $K > 0$ for $\delta < 1$ and $s \in [0,1]$. Also, for $\delta > 1$, K is decreasing in s. Note also that the denominator is always positive. Consider the equilibrium for diffferent values of δ and let $\bar{\delta}$ be defined by $K\left(\bar{\delta},1\right) = 0$. Then, for all $\delta < \bar{\delta}$, since $K(\delta,s) > 0$ for all $s \in [0,1]$, we have $q \rightarrow 0$ from equation (28) when $\kappa \rightarrow 0$ and in turn $s \rightarrow 1$. For $\delta > \bar{\delta}$ we instead have $s \rightarrow s^{\max}(\delta) < 1$ when $\kappa \rightarrow 0$, where $s^{\max}(\delta)$ is the value of s that solves $K(\delta,s) = 0$. Then equilibrium tightness, denoted by $\theta^{\max}$, is determined by using equation (36). This, in turn, determines q from equation (35).

[13] For the case of too much deflation, the entry wage $\hat{w}_{nb}^1(\delta,\varphi)$ is larger than the gross surplus, for job finding rates close to one. Then the limit equilibrium job finding probability is instead the value of s where $J_{nb}^1 = 0$, leading to an inefficient outcome.

(2008) due to the fact that the calibration implies that the Hosios condition holds and hence that there are no steady-state search externalities. Moreover, the model of Erceg, Henderson, and Levin (2000) does not feature this mechanism either. This is due to the fact that there is no extensive margin on the labor market in that model and hence no room for search frictions. Thus, the Ramsey planner has no leverage on job creation through the channel outlined above. However, and similarly to our model, the Erceg, Henderson, and Levin (2000) model features a markup in wage-setting where the actual markup can be different from the flexible price markup because of Calvo (1983)-style wage stickiness. Thus, in both models the planner has incentives to tilt the real-wage profile in order to lower the actual markup and increase labor input.[14] Note though, since the model lacks a leverage on job creation there is much less of a motive for the planner to use this channel as shown by Amano, Moran, Murchison, and Rennison (2009).[15] The model in Kim and Ruge-Murcia (2011) is similar to Amano, Moran, Murchison, and Rennison (2009), but differs in that it instead relies on wage-setting frictions along the lines of Rotemberg (1982). This, however, does not seem to be important for the Ramsey optimal inflation rate.[16]

3 A Model for Quantitative Evaluation

The next step in our analysis attempts to realistically evaluate the quantitative importance of the mechanism outlined above by embedding it in the canonical monetary model. The basic framework for the quantitative evaluation shares many elements of standard models. There is a monopolistically competitive intermediate goods sector where producers set prices facing a stochastic fixed adjustment cost as in Dotsey, King, and Wolman (1999). The intermediate goods sector buys a homogenous input from the wholesale sector, which, in turn, uses labor in the production of this input. The market for this homogenous input is characterized by perfect competition.

In contrast to previous papers studying the Ramsey optimal steady-state inflation rate, our model features search and matching frictions and staggered wage bargaining. Specifically, the wholesale sector posts vacancies on a search and matching labor market similar to Christoffel, Kuester, and Linzert (2009) and Trigari (2009). Wages are bargained between a representative family and wholesale firms in a setting with stochastic impediments to rebargaining, akin to how price setting is modeled. The representative family construct, composed of many workers as in Merz (1995), is introduced

[14] The average wage markup in an EHL model is computed in equation (16) in Amano, Moran, Murchison, and Rennison (2009).

[15] In Table 1 of Amano, Moran, Murchison, and Rennison (2009), the optimal inflation rate (without productivity growth) is 0.03%. Since only taking into account markup variations across households would imply an optimal inflation rate of zero, the effect of using inflation to affect the average markups in the economy is tiny.

[16] The paper by Kim and Ruge-Murcia (2011) has its focus on downward nominal wage rigidities, which is not the focus here. However, they also look at the case with symmetric wage adjustment frictions and find a deflation rate of about 0.1 percent. Thus, their result is very much in line with Amano, Moran, Murchison, and Rennison (2009).

to ensure complete consumption insurance. The representative family then supplies labor, bargains wages and assures equal consumption across workers within the family. Finally, notation is simplified by assuming a flexible-price retail sector that repacks the intermediate goods in accordance with consumer preferences and sells them to the representative family on a competitive market. We also add a monetary friction along the lines of Dotsey, King, and Wolman (1999).

3.1 Intermediate-Goods Firms

The intermediate-goods firm chooses whether to adjust prices or not. Let the probability of adjusting prices in a given period be denoted by α_t^j, given that the firm last adjusted its price j periods ago. For technical reasons, we assume that there is some $J > 1$ such that $\alpha^{J-1} = 1$. Note that we follow standard notation and label the J cohorts from 0 to $J-1$.

3.1.1 Prices

Given that an intermediate-goods firm last reset prices in period $t-j$, the maximum duration of the price contract is then $J-j$, where J is the maximum price contract duration and α_t^j is the adjustment probability j periods after the price was last reset. The intermediate-goods firms buys a homogeneous input from the wholesale firms at the (real) price p_t^w. As in Khan, King, and Wolman (2003), an intermediate producer chooses the optimal price P_t^0 so that

$$\begin{aligned} v_t^0 \quad = \quad & \max_{P_t^0}\left[\frac{P_t^0}{P_t} - p_t^w\right] Y_t^0 + E_t\Lambda_{t,t+1}\beta\left(\alpha_{t+1}^1 v_{t+1}^0 + \left(1-\alpha_{t+1}^1\right) v_{t+1}^1\left(\frac{P_t^0}{P_{t+1}}\right)\right) \\ & - E_t\Lambda_{t,t+1}\beta p_{t+1}^w \Xi_{1,t+1}, \end{aligned} \tag{40}$$

where

$$Y_t^j = \left(\frac{P_t^j}{P_t}\right)^{-\sigma} Y_t, \tag{41}$$

and where P_t is the aggregate intermediate goods price level and β the discount factor. Moreover, $\Lambda_{t,t+1}$ is the ratio of Lagrange multipliers in the problem of the consumer tomorrow and today. Finally, $\Xi_{1,t+1}$ is the expected adjustment cost. Note that the term within the square brackets is just the firm's per unit profit in period t.

The values v_t^j evolve according to

$$\begin{aligned} v_t^j\left(\frac{P_t^j}{P_t}\right) \quad = \quad & \left[\frac{P_t^j}{P_t} - p_t^w\right] Y_t^j + E_t\Lambda_{t,t+1}\beta\left(\alpha_{t+1}^{j+1} v_{t+1}^0 + \left(1-\alpha_{t+1}^{j+1}\right) v_{t+1}^{j+1}\left(\frac{P_t^j}{P_{t+1}}\right)\right) \\ & - E_t\Lambda_{t,t+1}\beta p_{t+1}^w \Xi_{j+1,t+1}, \\ v_t^{J-1}\left(\frac{P_t^{J-1}}{P_t}\right) \quad = \quad & \left[\frac{P_t^{J-1}}{P_t} - p_t^w\right] Y_t^{J-1} + E_t\Lambda_{t,t+1}\beta v_{t+1}^0 - E_t\Lambda_{t,t+1}\beta p_{t+1}^w \Xi_{J,t+1}. \end{aligned} \tag{42}$$

We model price adjustment probabilities as in Dotsey, King, and Wolman (1999) and others. Thus, adjustment probabilities are chosen endogenously by the firm and are one if $c^j_{p,t} < \frac{v^0_t - v^j_t}{p^w_t}$ and zero if $c^j_{p,t} > \frac{v^0_t - v^j_t}{p^w_t}$. Adjustment costs are drawn from a cumulative distribution function G_P with upper bound Ω_P. The maximal cost $c^{j,\max}_{p,t}$ for a cohort j at time t that induces price changes is then $c^{j,\max}_{p,t} = \frac{v^0_t - v^j_t}{p^w_t}$ and we can thus express the expected adjustment costs as

$$\Xi_{j,t} = \int_0^{c^{j,\max}_{p,t}} c_p dG_P\left(c_p\right). \tag{43}$$

The share of firms among those that last adjusted the price j periods ago that adjusts the price today is then given by

$$\alpha^j_t = G_P\left(c^{j,\max}_{p,t}\right). \tag{44}$$

The first-order condition to problem (40) is

$$\left[(1-\sigma)\frac{P^0_t}{P_t} + \sigma p^w_t\right] Y^0_t \frac{1}{P_t} + E_t \Lambda_{t,t+1}\beta\left(\left(1-\alpha^1_{t+1}\right) D_1 v^1_t\left(\frac{P^0_t}{P_{t+1}}\right)\frac{1}{P_{t+1}}\right) = 0, \tag{45}$$

where, noting that $P^j_{t+j} = P^0_t$, the derivative $D_1 v^1_t$ can be computed by using

$$\begin{aligned} D_1 v^j_t &= \left[(1-\sigma)\frac{P^j_t}{P_t} + \sigma p^w_t\right]\frac{Y^j_t}{P_t} + E_t\Lambda_{t,t+1}\beta\left(\left(1-\alpha^{j+1}_{t+1}\right) D_1 v^{j+1}_{t+1}\left(\frac{P^j_t}{P_{t+1}}\right)\frac{1}{P_{t+1}}\right), \\ D_1 v^{J-1}_t &= \left[(1-\sigma)\frac{P^{J-1}_t}{P_t} + \sigma p^w_t\right]\frac{Y^{J-1}_t}{P_t}. \end{aligned} \tag{46}$$

Thus, optimal pricing behavior is fully characterized by expressions (45) and (46).

The share of firms with duration j since the last price change is denoted by ω^j_t. For $j \geq 1$ the shares evolve as

$$\omega^j_t = \left(1-\alpha^j_t\right)\omega^{j-1}_{t-1}, \tag{47}$$

and, the share of firms with newly set prices (ω^0_t) in period t will be

$$\omega^0_t = \sum_{j=1}^{J-1} \alpha^j_t \omega^{j-1}_{t-1}. \tag{48}$$

3.2 Retailers

The retail firm buys intermediate goods and repackages them as final goods. We follow Erceg, Henderson, and Levin (2000) and Khan, King, and Wolman (2003) and assume a competitive retail sector selling a composite good. The composite good is combined from intermediate goods in the same proportions as families would choose. Given intermediate goods output Y_t^j, produced by intermediate-goods firms in each cohort j, the amount of the composite good Y_t is

$$Y_t = \left[\sum_{j=0}^{J-1} \omega_t^j \left(Y_t^j \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \tag{49}$$

where $\sigma > 1$ and ω_t^j is the share of retail firms producing Y_t^j at price P_t^j.

As in Khan, King, and Wolman (2003), the retailers need to borrow to finance current production and choose $\{Y_t^j\}_{j=0}^J$ to minimize costs for a given amount Y_t of final goods created. Thus, retailers solve

$$\min_{\{Y_t^j\}_{j=0}^J} (1 + R_t) \sum_{j=0}^{J-1} \omega_t^j p_t^j Y_t^j, \tag{50}$$

where $(1 + R_t)$ is the gross nominal interest rate, subject to (49). Cost minimization implies that the intermediate goods price level is given by

$$P_t = \left[\sum_{j=0}^{J-1} \omega_t^j \left(P_t^j \right)^{1-\sigma} df \right]^{\frac{1}{1-\sigma}}. \tag{51}$$

The price level of the retailers is then $\bar{P}_t = (1 + R_t) P_t$ and hence

$$\bar{p}_t = \frac{\bar{P}_t}{P_t} = (1 + R_t). \tag{52}$$

3.3 Families

To introduce a demand for money in the model, we follow Khan, King, and Wolman (2003) and assume that agents use either credit or money to purchase consumption goods. Specifically, families purchase a fraction ξ_t of consumption with credit goods. Using credit requires paying a stochastic fixed time cost, drawn from a cumulative distribution G_c, with upper bound Ω_C, and hence $\xi_t = \int_0^{\bar{c}} dG_c(x)$, where $\bar{c}$ is the maximal credit cost paid by the family for a consumption good (for a detailed discussion see Khan, King and Wolman, 2003). The amount of labor used in obtaining credit is denoted h_t^c. The total time cost of credit for the family is then

$$h_t^c = \int_0^{\bar{c}} x dG_c(x). \tag{53}$$

Families have preferences

$$E_t \sum_{t=t_0}^{\infty} \beta^{t-t_0} \left[u\left(c_t\right) + \sum_{j^w=0}^{J_w-1} n_t^{j_w} \kappa^L \frac{\left(1-\bar{h}-h_t^c\right)^{1-\phi}}{1-\phi} + \left(1-n_t\right) \kappa^L \frac{\left(1-h_t^c\right)^{1-\phi}}{1-\phi} \right], \tag{54}$$

where $\bar{h}$ denotes the workers' hours worked at a wholesale firm, c_t consumption, $n_t^{j_w}$ the number of employees in wage cohort j_w and n_t aggregate employment. Families hold an aliquot share of all firms. The budget constraint of the family is given by

$$M_t + \frac{1}{1+R_t} B_{t+1} \geq B_t - D_t - T_t + \mathcal{W}_t, \tag{55}$$

where P_t is the price level, M_t is money holdings, B_t bonds, D_t credit debt, T_t consists of lump-sum transfers from the government and firm dividends, R_t is the one-period nominal interest rate between period t and $t+1$ and

$$\mathcal{W}_t = \sum_{j^w=0}^{J_w-1} n_t^{j_w} W_t^{j_w} \bar{h} + \left(1-n_t\right) P_t b_r, \tag{56}$$

with $P_t b_r$ being the unemployment benefits. Moreover, $W_t^{j_w}$ denotes the workers' nominal wage in wage cohort j_w and $1-n_t$ is equal to the unemployment rate. In real terms

$$m_t + \frac{1}{1+R_t} b_{t+1} \geq \frac{b_t - d_t}{\pi_t} - \tau_t + \frac{\mathcal{W}_t}{P_t}, \tag{57}$$

where $m_t = \frac{M_t}{P_t}$, $b_{t+1} = \frac{B_{t+1}}{P_t}$, $d_t = \frac{D_t}{P_{t-1}}$, $\tau_t = \frac{T_t}{P_t}$ and $\pi_t = \frac{P_t}{P_{t-1}}$ is the gross inflation rate between period $t-1$ and t. Since agents purchase a fraction $1-\xi_t$ of consumption goods with money, the demand for money is

$$m_t = \left(1-\xi_t\right) \bar{p}_t c_t. \tag{58}$$

Similarly, we have that the real credit debt to be paid in period $t+1$ is $d_{t+1} = \xi_t \bar{p}_t c_t$. Using credit requires paying a stochastic fixed time cost. This cost is realized after the family has decided on the amount of a product to buy but before choosing between credit or money as the mean of payment. Here, credit is defined as a one-period interest rate-free loan that needs to be repaid in full the next period. Families then choose to use credit as long as the gain, $R_t c_t$, is larger than the cost of credit.[17]

[17] That is, the real discounted net gain of placing the transaction amount in a bond for a period and repay the transaction amount the next period. To see this, combine the first-order condition with respect to ξ (59) together with the Euler equation (60), below.

The family's first-order conditions with respect to c_t and ξ_t are, using that $\bar{p}_t = (1 + R_t)$,

$$\begin{aligned} c_t &: \quad u_c(c_t) = \lambda_t (1 + R_t (1 - \xi_t)) \\ \xi_t &: \quad \lambda_t R_t c_t = \left[n_t \kappa^L \left(1 - \bar{h} - h_t^c\right)^\phi + (1 - n_t) \kappa^L (1 - h_t^c)^\phi \right] G_c^{-1}(\xi_t), \end{aligned} \tag{59}$$

where $G_c^{-1}(\xi_t)$ is the realization of the credit cost in terms of time.

Using the envelope theorem and the first-order condition with respect to b_{t+1} we can write the family Euler equation as

$$\frac{\lambda_t}{1 + R_t} = \beta E_t \frac{\lambda_{t+1}}{\pi_{t+1}}. \tag{60}$$

3.4 Search and Matching, the Hiring Decision and Employment Flows

The matching function is as in equation (1) in Section 2 and the job finding and vacancy filling probabilities are given by equations (2) and (3), respectively.

As in Christoffel, Kuester, and Linzert (2009), where firms are modeled as having one employee, new matches may enter into an existing wage structure. Vacancies are determined as usual by the equation of the vacancy cost of an employee and the expected value of the worker to the firm. Thus, hiring is determined by

$$\kappa = q_t \beta E_t \left[(1 - s^{new}) \sum_{j_w=0}^{J_w-1} \varpi_t^{j_w} J_{t+1}^{j_w}\left(w_{t+1}^{j_w}\right) + s^{new} J_{t+1}\left(w_{t+1}^0\right) \right], \tag{61}$$

where κ is the cost of posting a vacancy, s^{new} the share of new hires that receive a rebargained wage, $\varpi_t^{j_w}$ the share of employed workers in cohort j_w and $J_t^{j_w}\left(w_t^{j_w}\right)$ is the value of the firm in cohort j_w, described in detail below. Note that this formulation builds on the assumption that filled vacancies become productive and receive a wage in the next period. Thus, with probability $(1 - s^{new}) \varpi_t^{j_w}$ a firm is randomly assigned to cohort $j_w > 0$ and with probability $(1 - s^{new}) \varpi_t^0 + s^{new}$ to cohort 0.

The employment flow between categories $n_t^{j_w}$ is given by

$$n_t^0 = \sum_{j_w=1}^{J_w-1} \rho \alpha_t^{j_w} n_{t-1}^{j_w-1} + \left(s^{new} + (1 - s^{new}) \varpi_t^0\right) \mu_t, \tag{62}$$

and, for $j > 0$,

$$n_t^{j_w} = \rho \left(1 - \alpha_t^{j_w}\right) n_{t-1}^{j_w-1} + (1 - s^{new}) \varpi_t^{j_w} \mu_t, \tag{63}$$

where $\alpha_t^{j_w}$ is the wage adjustment probability $\alpha_t^{j_w}$ in the j_wth period following the last rebargain. We assume that $\alpha_t^{J_w-1} = 1$ for some $J_w > 1$. Also, $\varpi_t^{j_w}$ is the share of workers in the j_wth cohort.

Aggregate employment is

$$n_t = \sum_{j^w=0}^{J_w-1} n_t^{j_w}, \tag{64}$$

and the number of unemployed workers is

$$u_t = 1 - n_t. \tag{65}$$

3.5 Value Functions

The value in period t for the family of a worker at a wholesale firm where the wage was last rebargained in period $t - j_w$ is[18]

$$\begin{aligned} V_t^{j_w}\left(w_t^{j_w}\right) &= w_t^{j_w}\bar{h} - \kappa^L \frac{\left(1-\bar{h}-h_t^c\right)^{1-\phi}}{(1-\phi)\lambda_t} + \beta E_t \Lambda_{t,t+1}\left(\rho \alpha_{t+1}^{j_w+1} V_{t+1}^0\left(w_{t+1}^0\right)\right) \\ & +\beta E_t \Lambda_{t,t+1}\left(\rho\left(1-\alpha_{t+1}^{j_w+1}\right) V_{t+1}^{j_w+1}\left(w_{t+1}^{j_w+1}\right) + (1-\rho) U_{t+1}\right), \end{aligned} \tag{66}$$

where $w_t^{j_w}$ is the real wage and $h_t^{j_w}$ hours worked. The value when being unemployed is

$$U_t = b_r - \kappa^L \frac{\left(1-h_t^c\right)^{1-\phi}}{(1-\phi)\lambda_t} + \beta E_t \Lambda_{t,t+1}\left(s_t V_{x,t+1} + (1-s_t) U_{t+1}\right), \tag{67}$$

where $V_{x,t}$ is average value of employment across firms. As in the stylized model above in section 2, whether newly hired workers get new rebargained wages or enter into a given wage structure of the firm affects the value of $V_{x,t}$ and hence the family's outside option. We thus have

$$V_{x,t} = s^{new} V_t^0\left(w_t^0\right) + (1-s^{new}) \sum_{j_w=0}^{J_w-1} \varpi_t^{j_w} V_t^{j_w}\left(w_t^{j_w}\right). \tag{68}$$

The expected net surplus for the family to have a worker employed in a wholesale firm that last rebargained wages j_w periods ago is

$$H_t^{j_w}\left(w_t^{j_w}\right) = V_t^{j_w}\left(w_t^{j_w}\right) - U_t, \tag{69}$$

[18] This follows from taking the derivative of the family value in (54) with respect to $n_t^{j_w}$.

and hence, using (66) and (67), the value of an additional employee for the family can then be written as

$$\begin{aligned} H_t^{j_w}\left(w_t^{j_w}\right) &= w_t^{j_w}\bar{h} - b_r - \kappa^L \frac{\left(1-\bar{h}-h_t^c\right)^{1-\phi}}{(1-\phi)\lambda_t} + \kappa^L \frac{\left(1-h_t^c\right)^{1-\phi}}{(1-\phi)\lambda_t} \\ &+ \beta E_t \Lambda_{t,t+1}\left[\rho\alpha_{t+1}^{j_w+1} H_{t+1}^0\left(w_{t+1}^0\right) + \rho\left(1-\alpha_{t+1}^{j_w+1}\right) H_{t+1}^{j_w}\left(w_{t+1}^{j_w+1}\right) - s_t H_{x,t+1}\right], \end{aligned} \tag{70}$$

where $H_x(= V_x - U))$ is the net value of getting a job in an average wholesale firm.

The wholesale firm in cohort j_w uses labor as input to produce output, using a constant returns technology. The value is then

$$\begin{aligned} J_t^{j_w}\left(w_t^{j_w}\right) &= p_t^w Z\bar{h} - w_t^{j_w}\bar{h} + \beta E_t \Lambda_{t,t+1}\alpha_{t+1}^{j_w+1}\left(\rho J_{t+1}^0\left(w_{t+1}^0\right)\right) \\ &+ \beta E_t \Lambda_{t,t+1}\left(1-\alpha_{t+1}^{j_w+1}\right)\rho J_{t+1}^{j_w+1}\left(w_{t+1}^{j_w+1}\right) \end{aligned} \tag{71}$$

with Z being a level shifter of productivity.

3.6 Wage Bargaining

To incorporate staggered state-dependent wage bargaining we model wage determination in the spirit of Haller and Holden (1990) and Holden (1994). However, in order to end up in a wage-setting formulation that is comparable to standard search and matching models we slightly modify their set-up. That is, instead of having conflicts as in Haller and Holden (1990) we have a probability of breakdown.[19] The nominal wage W_{it}^0, when wages are rebargained (i.e., changed), is chosen such that it solves the Nash product

$$\max_{W_{it}^0} \left(H_t^0\left(w_t^0\right)\right)^{\varphi}\left(J_t^0\left(w_t^0\right)\right)^{1-\varphi}, \tag{72}$$

where $w_{it}^0 = \frac{W_{it}^0}{P_t}$ and φ denotes the bargaining power of the family. Otherwise the work continues according to the old contract as in Holden (1994). The first-order condition with respect to the nominal wage W_{it}^0 corresponding to (72) is

$$\varphi J_t^0\left(w_t^0\right) D_W H_t^0\left(w_t^0\right) + (1-\varphi) H_t^0\left(w_t^0\right) D_W J_t^0\left(w_t^0\right) = 0, \tag{73}$$

where the derivatives $D_W H_t^0\left(w_{it}^0\right)$ and $D_W J_t^0\left(w_{it}^0\right)$ are computed using expressions (70) and (71).

[19] Specifically, the conflict subgame in Figure 1 in Haller and Holden (1990) is replaced by a subgame where there is a positive probability of breakdown.

The derivative of the family value function is

$$\frac{\partial H_t^{j_w}\left(w_t^{j_w}\right)}{\partial W^0}\frac{1}{P_t} = \frac{1}{P_t}\bar{h} + \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\left[\rho\left(1-\alpha_{t+1}^{j_w+1}\right)\frac{\partial H_{t+1}^{j_w+1}\left(w_{t+1}^{j_w+1}\right)}{\partial W^0}\frac{1}{P_{t+1}}\right. \\ \left. -\frac{\partial \alpha_{t+1}^{j_w+1}}{\partial W^0}\left(H_{t+1}^{j_w+1}\left(w_{t+1}^{j_w+1}\right) - H_{t+1}\left(w_{t+1}^0\right)\right)\frac{1}{P_{t+1}}\right], \tag{74}$$

and the derivative of the value function for the firm is computed similarly.[20]

3.6.1 Wage Adjustment Probabilities

In the bargaining game, to get a new rebargained wage, one of the parties must find it credible to threaten with disagreement, which is costly.[21] The disagreement costs, drawn at the start of time period t, for the firm, denoted c_J, follows the cumulative distribution function G_J and the cost c_H of the family follows the cumulative distribution function G_H with upper bounds Ω_J and Ω_H, respectively. The difference in the firm's value between adjusting the wage or not is

$$dJ_t^{j_w}\left(w_t^{j_w}\right) = J_t^0\left(w_t^0\right) - J_t^{j_w}\left(w_t^{j_w}\right), \tag{75}$$

and similarly for the family

$$dH_t^{j_w}\left(w_t^{j_w}\right) = H_t^0\left(w_t^0\right) - H_t^{j_w}\left(w_t^{j_w}\right). \tag{76}$$

The firms have incentives to call for rebargaining whenever $c_J < dJ_t^{j_w}\left(w_t^{j_w}\right)$ and the worker when $c_H < dH_t^{j_w}\left(w_t^{j_w}\right)$. Adjustment probabilities $\alpha_t^{j_w}$ can then be computed by using (75)-(76) and the disagreement cost distributions $G_J\left(dJ_t^{j_w}\left(w_t^{j_w}\right)\right)$ and $G_H\left(dH_t^{j_w}\left(w_t^{j_w}\right)\right)$. See Appendix A for a detailed description of how these objects are computed.

3.7 The Aggregate Resource Constraint and Government Budget Constraint

Total demand is given by

$$y_t^d = c_t + \kappa\nu_t. \tag{77}$$

[20] Note that the derivatives of the value functions are slightly different from those pertaining to price setting; c.f. equation (46). In price setting the effect of prices on adjustment probabilities are eliminated through the additional effects on adjustment costs $\Xi_{j,t}$ (which are not present in the value equations (70) and (71)), using an envelope argument. The effect of wages on adjustment probabilities does not vanish in wage setting because wages are not chosen to maximize either (70) or (71), but a weighted average of these two; see (73). This implies that the envelope argument used in price setting is no longer valid. The derivative of the family (firm) value function then has an additional term consisting of the derivative of the adjustment probabilities.

[21] Note that threats of conflict in wage bargaining will not be exercised along the equilibrium path, but is a credible threat to enforce a new wage offer. Hence, these costs are not paid in equilibrium, in contrast to costs associated with price setting.

Total supply is Y_t. From market clearing on the labor market, we have[21]

$$\sum_{j=0}^{J-1} \omega_t^j Y_t^j = \sum_{j=0}^{J-1} \omega_t^j \left(\frac{P_t^j}{P_t}\right)^{-\sigma} Y_t = \sum_{j_w=0}^{J_w-1} n_t^{j_w} Z\bar{h} - \sum_{j=0}^{J-1} \omega_t^j \Xi_{j,t}. \tag{78}$$

Combining the expression above with expression (77) and $Y_t = y_t^d$ gives the aggregate resource constraint

$$\sum_{j=0}^{J-1} \omega_t^j \left(\frac{P_t^j}{P_t}\right)^{-\sigma} (c_t + \kappa \nu_t) = \sum_{j_w=0}^{J_w-1} n_t^{j_w} Z\bar{h} - \sum_{j=0}^{J-1} \omega_t^j \Xi_{j,t}. \tag{79}$$

The government uses lump-sum taxes to finance unemployment benefits. Thus,

$$\tau_t = (1 - n_t)\, b_r. \tag{80}$$

3.8 Optimal Policy

As discussed above, the policy maker needs to take several distortions into account when designing optimal policy. First, there is imperfect competition in the product market. There is also a distortion due to money demand and the cost of using credit. Furthermore, there are relative price and wage distortions. Finally, there are distortions in the hiring decision on the labor market. Here, we focus on the Ramsey policy as discussed by Schmitt-Grohé and Uribe (2004), maximizing welfare, subject to the constraints given by optimizing agents in the economy, i.e., for example first-order and market-clearing conditions.

The policymaker then maximizes (54) subject to the constraints (1) - (3), (40), (42), (44), (45), (46), (47), (48), (51), the flow equation of prices

$$p_t^j = \frac{p_{t-1}^{j-1}}{\pi_t}, \tag{81}$$

expressions (59) - (65), (70) - (71), (73) - (74), wage setting adjustment probabilities as described in the Appendix A, the flow equation of wages

$$w_t^j = \frac{w_{t-1}^{j-1}}{\pi_t}, \tag{82}$$

and the aggregate resource constraint (79).

4 Quantitative Evaluation

4.1 Calibration

For our quantitative evaluation, we assume log preferences in consumption and leisure, i.e., $u(c_t) = \log c_t$ and $\phi = 1$. The baseline calibration of the structural parameters is chosen to represent the U.S. economy on a quarterly basis and is presented in Table 1. We set β to 0.9928 as in Khan, King, and

Table 1: Baseline Calibration of the Model

Parameters		
β	*Time preference*	0.9928
σ	*Product market substitutability*	10
ρ	*Match-retention rate*	0.9
φ	*Family bargaining power*	0.5
σ_a	*Matching function parameter*	1.27
Z	*Productivity shifter*	5
$1 - s^{new}$	*Share of workers entering into existing wage structure*	0.5
$\bar{h}$	*Hours worked*	0.2
κ^L	*Disutility of work parameter*	2.4035
κ	*Vacancy cost*	0.0486
b_r	*Income when unemployed*	0.3529
a_l^P	*Beta left parameter (prices)*	2.1
a_r^P	*Beta right parameter (prices)*	1
Ω_P	*The largest fixed cost (prices)*	0.0024
$a_l^J = a_l^H$	*Beta left parameter (wages)*	2.1
$a_r^J = a_r^H$	*Beta right parameter (wages)*	1
$\Omega_J = \Omega_H$	*The largest fixed cost (wages)*	0.0396
a_l^c	*Beta left parameter (credit)*	2.806
a_r^c	*Beta right parameter (credit)*	10.446
Ω_C	*The largest fixed cost (credit)*	0.0342
$\hat{\xi}$	*Mass of goods with positive credit cost*	0.361

Wolman (2003). This generates a real interest rate of slightly below 3 percent and is motivated by data on one-year T-bill rates and the GDP deflator. Note that this is a key parameter for governing the strength of the monetary distortion.[22] For σ we use a standard value of 10, generating a markup of around 11 percent. We set the bargaining power $\varphi = 0.5$, implying symmetrical bargaining in the baseline calibration. For the job separation rate $1 - \rho$, we follow Hall (2005) and set $\rho = 0.9$. The value of σ_a is set to 1.27 following Den Haan, Ramey, and Watson (2000). We set hours worked to 0.2 and Z to 5 in order to normalize output per employee to unity.

To calibrate the share of new hires that get rebargained wages, there are several sources of evidence. Micro-data studies, summarized in Pissarides (2009), seem to indicate that newly hired workers' wages are substantially more flexible than incumbents' wages speaking against the idea that a large share

[22] For example, using a lower β would give the Ramsey planner an incentive to set a lower inflation rate.

of entrants enter into an existing wage structure. However, the studies summarized in Pissarides (2009) generally fail to control for effects stemming from variations in the composition of firms and match quality over the cycle. Thus, it might be that the empirical evidence just reflects that workers move from low-wage firms (low-quality matches) to high-wage firms (high-quality matches) in boom periods and vice versa in recessions. The approach taken to address this issue is to introduce job-specific fixed effects in a regression of individual wages on the unemployment rate and the interaction of the unemployment rate and dummy variable indicating if the tenure of the worker is short, see Gertler and Trigari (2009). This dummy structure controls for composition effects in workers, firms and match quality. Importantly, the results reported by Gertler and Trigari (2009) no longer indicate that wages are more sensitive to labor market conditions at the beginning than later in the span of a match, contrasting Pissarides (2009). This finding is thus in line with a low calibration of s^{new}.[23] Moreover, if we turn to survey evidence, like Bewley (1999), Bewley (2007) for the U.S. and the study performed within the Eurosystem Wage Dynamics Network (WDN) covering about $15,000$ firms in 15 European countries, we see strong evidence that the wages of new hires are tightly linked to those of incumbents. As reported by Galuscak, Keeney, Nicolitsas, Smets, Strzelecki, and Vodopivec (2012), about 80% percent of the firms in the WDN survey respond that internal factors (like the internal pay structure) are more important in driving wages of new hires than market conditions. Taken together the results points towards a non-neglible share of new hires that enters into an existing wage structure. However, lacking any sharp evidence on the exact value of this parameter we set s^{new} to 0.5 in the baseline calibration and vary the parameter between 0 and 1 in the robustness exercises.

For credit costs, a fraction $1-\hat{\xi}$ of the goods costs zero. Then

$$G_c(v) = \left(1-\hat{\xi}\right) + \hat{\xi} G_C\left(v; a_l^i, a_r^i, \Omega_i\right). \tag{83}$$

The cost cumulative distribution functions G_P, G_H, G_J and G_C are beta distributed;

$$g_i\left(v; a_l^i, a_r^i, \Omega_i\right) = g^{beta}\left(\frac{v}{\Omega_i}; a_l^i, a_r^i\right) \tag{84}$$

for $i \in \{P, H, J, C\}$. Except for Ω_P and Ω_C, the parameters for G_P and G_C are calibrated following Lie (2010) closely.[24] For the parameters for the disagreement cost distributions G_H and G_J we set $a_l^H = a_l^J = 2.1$ and $a_r^H = a_r^J = 1$ (similar to the values for a_l^P and a_r^P taken from Lie, 2010). We also set $\Omega_J = \Omega_H$ and then choose the parameters κ^L, κ, b_r, Ω_H, Ω_P and Ω_C so that the sticky price and

[23] As discussed in Gertler and Trigari (2009), additional findings on employment effects of wage contracting presented in Card (1990) and Olivei and Tenreyro (2007, 2010) provide further evidence in line with a low calibration of s^{new}.

[24] The reason for this modification of Ω_C is that other variables enter the money-demand first-order condition (59) in a slightly different way as compared to Khan, King, and Wolman (2003) and Lie (2010), thus motivating a change so that inflation under flexible wages is in line with their model.

wage model under two percent inflation has vacancy costs of one percent of output, a replacement rate of 40 percent as in Hall (2005), a matching function elasticity of 0.6, which is the midpoint of the interval $0.5-0.7$ as suggested by Petrongolo and Pissarides (2001), a mean duration of wage contracts of a year as in Taylor (1993), a mean duration of prices of a year in line with Nakamura and Steinsson (2008) and that the flexible wage model has an optimal policy steady-state deflation rate of 0.76, as in Khan, King, and Wolman (2003). The results are presented in Table 1. This calibration implies that we need to set $J = 5$ and $J_w = 8$ in order to avoid price/wage setting cohorts without mass.

To solve for the efficient allocation we maximize family welfare, as described in (54), given that the Friedman rule holds, subject to the matching function (1), the flow equation of employment $n_t = \rho n_{t-1} + \mu_t$ and the aggregate resource constraint

$$c_t + \kappa v_t = n_t Z\bar{h}. \tag{85}$$

4.2 Quantitative Results

To solve for the Ramsey optimal steady-state inflation rate, we follow Schmitt-Grohé and Uribe (2009).[25] In Table 2 we present the Ramsey optimal steady-state inflation rates implied by our model. In the absence of price or wage rigidities we find, in line with previous literature, that the Ramsey optimal inflation rate is -2.85 percent per year. In other words, with no frictions to price or wage setting, the model replicates the finding of Friedman (1969) that deflation is optimal when there is a role for money as a medium of exchange.

Table 2: Yearly optimal inflation rate under the Ramsey policy

	π
No Price or Wage Rigidities	-2.85
State Dependent Prices only	-0.76
State Dependent Prices and Wages	1.15
No monetary frictions (cashless)	1.52
Exogenous adjustment probabilities	2.95

When introducing price rigidities, we see that the Ramsey optimal inflation rate increases, but remains below zero, as previously pointed out by Khan, King, and Wolman (2003) and Schmitt-

[25] The first-order condition in the Ramsey optimal policy consists of the derivatives of the objective with respect to the control and state variables and derivatives with respect to the Lagrange multipliers for the constraints. Note that the derivative with respect to the Lagrange multipliers is just the equation system defining the competitive equilibrium for a given inflation rate. Following along the lines of Schmitt-Grohé and Uribe (2009), we posit an inflation rate π^0 and then solve for the competitive equilibrium given the inflation rate. Then a candidate for the Lagrange multiplier vector is computed using the remaining first-order conditions (i.e. with respect to the control and state variables) as if these hold, relying on a least-squares method. The candidate Lagrange multiplier is then used to compute the squared residuals from these first-order conditions. A standard iterative minimization routine can then be used to find the value of inflation that leads to the sum of squared residuals of these first-order conditions being zero.

Grohé and Uribe (2010). In the baseline model, also introducing impediments to continuous wage rebargaining, the Ramsey optimal inflation rate is 1.15 percent.[26] Thus, we see that the Ramsey optimal inflation rate increases by almost two percentage points in a calibration that implies that employment is 1.87 percentage points lower than the efficient allocation.

Removing the monetary friction and looking at the cashless economy as often done in the monetary policy literature, see Woodford (2003), increases inflation to 1.52 percent. Thus, the monetary distortion has a moderately negative effect on the optimal policy.

Furthermore, we analyze the importance of endogenous price and wage adjustment probabilities by fixing the price and wage adjustment probabilities to the values when steady-state inflation is two percent. Then we solve for the Ramsey policy under these exogenous adjustment probabilities. The optimal inflation rate increases by slightly less than two percentage points in this case, as compared to the case with endogenous adjustment probabilities. Thus, the ability of agents to self-select into adjustment has strong effects on the Ramsey planner's choice. This result contrasts with Lie (2010), who finds that endogenizing adjustment probabilities is not important in a model with flexible wages.

To explore the robustness of the results, we next vary the replacement rate. The results from this exercise can be seen in Table 3. When the replacement rate parameter, b_r, is increased (decreased), the optimal inflation rate increases (decreases) by 0.14 (0.21) percentage points. The intuition is that an increase in the replacement rate makes the economy less efficient due to an increasing wage as can be seen from equation (33) in the simple example, thus increasing the net gain for the Ramsey planner to use inflation to move the economy towards the efficient allocation, as can also be seen in the Hosios condition (32). Note also that the gross replacement rate, i.e., also taking into account the disutily of work, is 0.952 for the high b_r calibration and 0.881 for the low, as compared with 0.921 for the baseline. Thus, the high b_r case pushes the calibration close to the Hagedorn and Manovskii (2008) calibration.

Varying the share of new hires receiving rebargained wages has big effects. If all new hires get rebargained wages ($s^{new} = 1$), the wage is, as expected, the same as when wages are flexible, while when all workers enter into an existing wage structure as in Gertler and Trigari (2009) ($s^{new} = 0$), the optimal inflation rate is 1.35 percent.[27]

Varying the bargaining power has moderate effects on the results; increasing the worker bargaining power to 0.6 increases optimal inflation to 1.27 percent, while reducing it to 0.4 leads to inflation of about 0.97 percent. The reason is that an increase (decrease) in the bargaining power pushes the

[26] Experimenting with introducing capital accumulation, as in Gertler and Trigari (2009), yields a very similar Ramsey optimal inflation rate of 0.88 percent.

[27] Note that the share of workers in the first cohort is always larger than s^{new}, except when $s^{new} = 1$, since some of the workers entering an existing wage structure will enter into the first cohort. In the baseline calibration, the share of new hires entering into the first cohort and hence getting rebargained wages is 0.59 while it is 0.21 when $s^{new} = 0$.

economy further away from (closer towards) the Hosios wage, see equation (17) when $\varphi \gtrless \varphi_{H,F}$ in section 2, inducing the Ramsey planner to use inflation more (less) aggressively.

Finally, varying the matching elasticity η, also affecting the degree of efficiency in the economy via the Hosios condition (32), has a moderate effect on the optimal steady-state inflation rate. When the matching elasticity is 0.5, i.e., the lower bound suggested in Petrongolo and Pissarides (2001), the optimal inflation rate is 1.08 while it increases to 1.19 when the matching elasticity is at the upper bound of 0.7.

Table 3: Yearly optimal inflation rate under the Ramsey policy

	$b_r' = 1.125 b_r$	$s^{new} = 1$	$\varphi = 0.6$	$\eta = 0.7$
	1.29	-0.76	1.27	1.08
Baseline	1.15	1.15	1.15	1.15
	$b_r' = 0.875 b_r$	$s^{new} = 0$	$\varphi = 0.4$	$\eta = 0.5$
	0.84	1.35	0.97	1.19

5 Concluding Discussion

This paper explores how the interaction of nominal wage and labor market search and matching frictions can affect the planner's trade-off when choosing the Ramsey optimal inflation rate. In a stylized model with search frictions where some newly hired workers enter into an existing wage structure we show that inflation not only affects real-wage profiles over a contract spell, but also redistributes surplus between workers and firms since incumbent workers impose an externality on new hires through the entry wage. This affects the wage-bargaining outcome through its effect on the workers' outside option and hence the expected present value of total labor costs for a match and thus also firms' incentives for vacancy creation. We derive a Hosios condition for the stylized model and show that the Ramsey planner has incentives to increase inflation if employment and vacancy creation are inefficiently low in order to push the economy towards the efficient allocation. Note that in an efficient allocation this incentive vanishes (and the reverse occurs when employment is inefficiently high). Also, the Ramsey planner loses the ability to affect real wage costs via inflation if all new workers get to rebargain their wage. In this case, the full effect of inflation on entry wages is internalized in the wage bargain, and firm and worker surpluses, as well as real-wage costs, become neutral to inflation. This is also the case if search frictions vanish since the Ramsey planner loses any leverage over vacancy creation. Thus, models without an extensive margin on the labor market lack the mechanism described here (as e.g. in Erceg, Henderson and Levin, 2000).

Overall, the key insight from the stylized model is that if both search and wage-setting externalities are present, there is an incentive for the Ramsey planner to vary the inflation rate to increase welfare through its effect on job creation and unemployment.

In the baseline quantitative evaluation, featuring many of the aspects that have been deemed important in determining the optimal inflation rate, we find that the Ramsey optimal inflation rate is 1.15 percent per year. When comparing with a model with flexible wages for new hires, this is an increase of almost two percentage units, confirming that the mechanism is important in an elaborate general equilibrium context. Moreover, this result is robust to reasonable variations in the match elasticity, the workers' bargaining power, the replacement rate and fairly large variations in the share of new hires entering into an existing wage structure. When shutting down the monetary distortion and looking at the cashless economy as is done in a large part of the monetary-policy literature, see Woodford (2003), we find that the Ramsey optimal inflation rate increases to 1.52 percent. Thus, the monetary distortion has a moderately negative effect on the Ramsey planner's choice.

In conclusion, we show that the combination of nominal wage and search externalities can generate a Ramsey optimal steady-state inflation rate that is significantly positive and provide a mechanism that helps reconcile theories of monetary non-neutrality with observed inflation targets of central banks.

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Appendix

A Wage Adjustment Probabilities

The fraction of firms that calls a conflict is

$$
\begin{array}{cc}
1 & \text{if } \Omega_J < dJ_t^{j_w}\left(w_t^{j_w}\right), \\
G_J\left(dJ_t^{j_w}\left(w_t^{j_w}\right)\right) & 0 \leq dJ_t^{j_w}\left(w_t^{j_w}\right) \leq \Omega_J, \\
0 & dJ_t^{j_w}\left(w_t^{j_w}\right) < 0.
\end{array} \tag{86}
$$

Similarly, the fraction of workers that has an incentive to call a conflict to force a rebargain of the wage contract is

$$
\begin{array}{cc}
1 & \text{if } \Omega_H < dH_t^{j_w}\left(w_t^{j_w}\right), \\
G_H\left(dH_t^{j_w}\left(w_t^{j_w}\right)\right) & 0 \leq dH_t^{j_w}\left(w_t^{j_w}\right) \leq \Omega_H, \\
0 & dH_t^{j_w}\left(w_t^{j_w}\right) < 0.
\end{array} \tag{87}
$$

The adjustment probabilities are then

$$
\alpha_t^{j_w} = \left\{
\begin{array}{cc}
1 & \text{if } \Omega_J < dJ_t^{j_w}\left(w_t^{j_w}\right) \text{ or if } \Omega_H < dH_t^{j_w}\left(w_t^{j_w}\right), \\
G_J\left(dJ_t^{j_w}\left(w_t^{j_w}\right)\right) + G_J\left(dH_t^{j_w}\left(w_t^{j_w}\right)\right) & 0 \leq dJ_t^{j_w}\left(w_t^{j_w}\right) \leq \Omega_J \\
-G_H\left(dH_t^{j_w}\left(w_t^{j_w}\right)\right) G_J\left(dJ_t^{j_w}\left(w_t^{j_w}\right)\right) & \text{and } 0 \leq dH_t^{j_w}\left(w_t^{j_w}\right) \leq \Omega_H, \\
G_J\left(dJ_t^{j_w}\left(w_t^{j_w}\right)\right) & 0 \leq dJ_t^{j_w}\left(w_t^{j_w}\right) \leq \Omega_J \text{ and } dH_t^{j_w}\left(w_t^{j_w}\right) < 0, \\
G_H\left(dH_t^{j_w}\left(w_t^{j_w}\right)\right) & dJ_t^{j_w}\left(w_t^{j_w}\right) < 0 \text{ and } 0 \leq dH_t^{j_w}\left(w_t^{j_w}\right) \leq \Omega_H, \\
0 & dJ_t^{j_w}\left(w_t^{j_w}\right) < 0 \text{ and } dH_t^{j_w}\left(w_t^{j_w}\right) < 0.
\end{array}
\right. \tag{88}
$$

The derivative of the family value function is then, using expressions (70) and (71),

$$
\begin{aligned}
\frac{dH_t^{j_w}\left(w_t^{j_w}\right)}{dW^0}\frac{1}{P_t} = {} & \frac{1}{P_t} + \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\rho\left(1-\alpha_{t+1}^{j_w+1}\right)\frac{dH_{t+1}^{j_w+1}\left(w_{t+1}^{j_w+1}\right)}{dW^0}\frac{1}{P_{t+1}} \\
& -E_t\left[\left(\frac{d\alpha_{t+1}^{j_w+1}}{dH_t\left(w_t^{j_w}\right)}\frac{dH_{t+1}^{j_w+1}\left(w_{t+1}^{j_w+1}\right)}{dW^0}\frac{1}{P_{t+1}} + \frac{d\alpha_{t+1}^{j_w+1}}{dJ_t\left(w_t^{j_w}\right)}\frac{dJ_{t+1}^{j_w+1}\left(w_{t+1}^{j_w+1}\right)}{dW^0}\frac{1}{P_{t+1}}\right)\right. \\
& \left.\times\beta\rho\frac{\lambda_{t+1}}{\lambda_t}\left(H_{t+1}^{j_w+1}\left(w_{t+1}^{j_w+1}\right) - H_{t+1}^0\left(w_{t+1}^0\right)\right)\right].
\end{aligned} \tag{89}
$$

Multiplying by $\lambda_t W^0$ gives

$$\begin{aligned} \frac{dH_t^{j_w}\left(w_t^{j_w}\right)}{dW^0}\lambda_t W^0 \frac{1}{P_t} &= \frac{\lambda_t W^0}{P_t} + \beta E_t \lambda_{t+1}\rho\left(1-\alpha_{t+1}^{j_w+1}\right)\frac{dH_{t+1}^{j_w+1}\left(w_{t+1}^{j_w+1}\right)}{dW^0}\frac{W^0}{P_{t+1}} \\ &\quad -E_t\left[\left(\frac{d\alpha_{t+1}^{j_w+1}}{dH_t\left(w_t^{j_w}\right)}\frac{dH_{t+1}^{j_w+1}\left(w_{t+1}^{j_w+1}\right)}{dW^0}\frac{W^0}{P_{t+1}} + \frac{d\alpha_{t+1}^{j_w+1}}{dJ_t\left(w_t^{j_w}\right)}\frac{dJ_{t+1}^{j_w+1}\left(w_{t+1}^{j_w+1}\right)}{dW^0}\frac{W^0}{P_{t+1}}\right)\right. \\ &\quad \left.\times\beta\rho\lambda_{t+1}\left(H_{t+1}^{j_w+1}\left(w_{t+1}^{j_w+1}\right) - H_{t+1}^0\left(w_{t+1}^0\right)\right)\right]. \end{aligned} \tag{90}$$