

# Should monetary policy care about redistribution? Optimal monetary and fiscal policy with heterogeneous agents

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## Abstract

We present a method to determine optimal monetary policy in heterogeneous-agent economies with nominal frictions and aggregate shocks, under various assumptions regarding fiscal policy. We analyze models with either sticky prices or sticky wages. In the sticky-price economy, when fiscal policy is optimally set, optimal monetary policy implements price stability. Inflation volatility remains low when fiscal policy follows empirically relevant rules. The inflation response is more pronounced when the Phillips curve is steep and profits are skewed toward highly productive agents. In the sticky-wage economy, optimal price inflation becomes significantly more volatile, while wage inflation remains small. Under both types of nominal rigidity, agents with lower productivity tend to benefit more from optimal monetary policy.

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**JEL codes:** D31, E52, D52, E21.

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# 1 Introduction

Monetary policy generates redistributive effects through various channels, which have been studied by a vast empirical and theoretical literature. However, it is not clear how these channels should change the conduct of monetary policy. It might be possible that monetary policy should take these effects into account in order to improve welfare, and thus serve a role that is usually played by fiscal policy. Or, on the contrary, perhaps monetary policy should focus solely on monetary goals, and let fiscal tools either dampen or strengthen its redistributive effects. To distinguish between these two claims, one must consider optimal monetary policy in a realistic fiscal environment, where heterogeneity among agents generates a concern for redistribution.

To do so, we follow the so-called Bewley (1980) literature and assume incomplete insurance markets for idiosyncratic risks to be the main source of heterogeneity across agents. This framework is known to be general enough to generate realistic distributions of income and wealth. We further consider nominal frictions, leading to the class of Heterogeneous-Agent New-Keynesian (HANK) models, named after the seminal paper of Kaplan et al. (2018). In this environment, we solve for optimal monetary policy under a realistic fiscal system, focusing on optimal Ramsey policy with commitment. Our analysis is made possible by methodological contributions that enable this type of investigation within HANK models.

First, we elaborate on the Lagrangian approach of Marcet and Marimon (2019), which is particularly well-suited to HANK economies. We introduce the concept of the *net social value of liquidity* (SVL) for each agent, defined as the utility gain obtained from transferring one unit of resources to a particular agent, accounting for all general equilibrium effects. Introducing the SVL greatly simplifies the derivation of optimal policies in models with heterogeneous agents. Second, to simulate the model, we employ a truncated representation of incomplete insurance market economies, applying it to a monetary economy. This theory of *truncation* was first used in LeGrand and Ragot (2022a) to study optimal unemployment benefits. We construct a consistent and accurate approximation of the economy, in which heterogeneity depends solely on a finite but arbitrarily large number of past consecutive realizations of idiosyncratic risk. Additionally, we utilize a refinement of this *uniform truncation* method, developed in LeGrand and Ragot (2022b), which allows for different truncation lengths and addresses the curse of dimensionality associated with the uniform truncation. Both methods yield quantitatively similar results, and we verify their accuracy by comparing outcomes in economies without optimal policy to those obtained using the standard Reiter (2009) method, which is known to align closely with others approaches, such as Boppart et al. (2018) and Auclert et al. (2021). We also consider social welfare functions which enable us to derive the dynamics of the model around a steady state that features an empirically relevant fiscal system. This analysis may be of independent interest. Finally, and following the literature, we consistently examine optimal inflation volatility when the economy is near its long-run equilibrium, an approach known as the *timeless* perspective

(see Woodford, 1999, for instance). As noted by McCallum and Nelson (2000), this timeless perspective is the closest approximation to “optimal policy making according to a rule”. This approach is also immune to the difficulties that arise in the normative analysis of large inflation surprises, referred to as period-0 policies in the literature cited below. Although this paper focuses on optimal monetary policy, the tools developed in this paper can be used to derive normative implications of heterogeneous-agent models in different environments.

We apply our methodology to environments featuring one of two forms of nominal frictions: costly price adjustments or costly nominal wage adjustments. Our approach is well-suited to both frameworks, despite differences in the expression of the SVL between the sticky-price and the sticky-wage cases, as the SVL captures distinct general equilibrium effects. On the one hand, sticky prices have become a standard nominal friction in the heterogeneous-agent literature since Kaplan et al. (2018). On the other hand, the slow adjustment of nominal wages is well-documented, and sticky wages may help address issues related to the cyclicity of markups (Nekarda and Ramey, 2020). Indeed, as noted by Tobias et al. (2020) among others, the redistribution of profits is a key force affecting the dynamics of HANK models. Thus, we contrast the implications of the two types of nominal rigidities and show that optimal monetary policies differ significantly between them.

In the sticky-price economy, we first consider the case in which both fiscal and monetary policy are optimally designed. We then jointly solve for optimal monetary and fiscal policies with commitment when five fiscal instruments are available: two linear taxes on real and nominal capital income, a linear tax on labor income, lump-sum transfers, and a riskless one-period public debt. We demonstrate that, in this framework, optimal monetary policy focuses solely on implementing price stability, and optimal inflation plays no redistributive role over the business cycle. This result can be understood using the distinction made by Kaplan et al. (2018) and Auclert (2019) between the direct and indirect channels of monetary policy. Capital taxes serve as sufficient instruments for the planner to replicate any allocation achievable through the direct channels, as they affect the returns on capital. The labor tax is sufficient to replicate any allocation reachable through the indirect effects, because it creates a wedge between labor income and the marginal productivity of labor. Thus, linear taxes on capital and labor ensure that monetary policy should focus solely on price stability, while fiscal policy alone handles redistribution. This equivalence result generalizes the representative-agent finding of Correia et al. (2008) to heterogeneous-agent economies.

We then relax the assumption of the optimality of fiscal policy and consider exogenous fiscal rules. In our benchmark calibration, corresponding to the empirically relevant case of constant marginal tax rates, the planner does not implement perfect price stability, but optimal inflation volatility remains low. However, and consistently with the literature, this quantitative response of inflation is found to be sensitive to assumptions about profit distribution and the slope of the Phillips curve. In particular, inflation volatility is high if the price Phillips curve is steep and

the profit distribution is tilted toward richer agents.

In the sticky-wage economy, we model nominal rigidity following Erceg et al. (2000), an approach frequently used in the heterogeneous-agent literature (Hagedorn et al., 2019, Alves and Violante, 2025 and Auclert et al., 2024 among others). In this framework, agents are generally not on their labor supply curve, introducing an additional labor market friction. We characterize the optimal policy in the sticky-wage model using the same empirically relevant fiscal system of constant marginal tax rates. We find that the optimal policy generates a small deviation from nominal wage stability but causes significant movements in the price level, allowing the real wage to adjust to economic shocks. The sticky-wage economy exhibits much higher volatility in price inflation (and much lower volatility in wage inflation) than the sticky-price economy. Consequently, the welfare gains from deviating from price stability are much higher in the sticky-wage economy than in the sticky-price one. Deviating from nominal wage stability is also welfare enhancing, albeit to a lesser extent. Under both types of nominal rigidity, we find that departures from nominal stability disproportionately benefit lower-productivity agents, making such policies progressive..

**Related literature.** Our paper belongs to a growing literature that departs from the representative-agent model to analyse optimal monetary policy in heterogeneous-agent models. This earlier literature studied sticky prices or sticky wages (see Woodford, 2003 or Galí, 2015 for textbook treatments and references).

Our equivalence result in a HANK model with sticky prices is related to the five transmission channels of monetary policy that have been identified in the heterogeneous-agent literature (Kaplan et al. 2018, and Auclert, 2019, among others). Monetary policy has direct effects, which operate through changes in real returns (Gornemann et al., 2016). The changes in returns generate a substitution effect, already present in the representative-agent new-Keynesian model (Woodford, 2003). Inflation also affects the real value of nominal assets, through a Fisher effect (Doepke and Schneider, 2006). Changes in real returns generate a wealth effect due to unhedged interest rate exposure, identified by Auclert (2019). In addition to these three direct channels, there are also two indirect effects due to the endogeneity of labor income and to the heterogeneous exposure to income variations (Coibion et al., 2017; Acharya and Dogra, 2021). If labor and capital taxes are optimally designed, then the use of these channels by monetary policy does not increase welfare. Our equivalence results have a similar flavor to that of Correia et al. (2008), who derive equivalence results considering a consumption tax in representative-agent economies with no capital. Using alternative taxes, we prove similar results considering heterogeneous portfolio holdings with both real and nominal assets.

Other papers consider heterogeneous-agent models with sticky wages instead of sticky prices (Hagedorn et al., 2019, Auclert et al., 2024 or Alves and Violante, 2025). This avoids the countercyclical profits generated by the sticky-price assumption. Sticky wages are formalized

using the labor market model Erceg et al. (2000) developed in a representative-agent economy. The normative implication of sticky wages in representative-agent economies has been analyzed in Chugh (2006) and Galí (2015) among others. In particular, it features zero wage inflation in the case of technology shocks. To our knowledge, our paper is the first to derive optimal monetary policy in a HANK model with sticky wages.

This paper also connects to the literature investigating optimal policies with incomplete markets and heterogeneous agents. A first strand of this literature relies on tractable models featuring a simple distribution of wealth, which enables identifying the trade-offs faced by optimal policies. Challe (2020) solves for optimal monetary policy in a “zero-liquidity” environment with endogenous risk. Bilbiie and Ragot (2021) study optimal monetary policy in a tractable model with limited heterogeneity and money. Bilbiie (2024) analyzes a no-trade equilibrium with two types of agents. McKay and Reis (2021) solve for optimal simple fiscal rules (automatic stabilizers) in a tractable model considering exogenous monetary policy.

A second strand of the literature analyses optimal policies with more general distributions of wealth. This is especially true for the literature on optimal fiscal policy in real economies with incomplete-market and heterogeneous-agent models (Aiyagari et al., 2002; Werning, 2007; Bassetto, 2014; Açikgöz et al., 2022; Dyrda and Pedroni, 2022; LeGrand and Ragot, 2025 among others). In this strand, a couple of recent papers study optimal monetary policy with incomplete insurance-markets. Nuño and Thomas (2022) solve for optimal monetary policy under commitment in an economy with uninsurable idiosyncratic risk, nominal long-term bonds, and costly inflation. They propose a methodology based on the calculus of variation. They show that the optimal policy features inflation front-loading that can be sizable in a time-0 problem, but that inflation volatility is reduced in a timeless perspective. Smirnov (2022) and Dávila and Schaab (2023) build on this framework and solve for the optimal monetary policy in a closed economy. They also find that the optimal deviation from price stability is close to 0. Acharya et al. (2023) solve for optimal monetary policy using the tractability of the CARA-normal environment without capital. They show that countercyclical idiosyncratic risk creates a motive for monetary policy to be redistributive. They focus on a time-0 problem, and in their quantitative applications, the optimal deviation from price stability remains small in magnitude except when the price-adjustment cost becomes very small. Bhandari et al. (2021) quantitatively solve for optimal monetary and fiscal policies in a new-Keynesian model with aggregate shocks. They report a significant deviation from price stability at a long horizon, which is partly immune to the time-0 bias, when fiscal instruments are missing and the initial distribution differs from the steady-state one. Our results are consistent with those of these two papers. When the profit distribution is tilted toward richer agents and the cost of price adjustment is not too high, deviations from price stability have welfare-enhancing redistributive properties. However, consistent with our theoretical equivalence result, we find that fiscal policy - even in the form of simple rules - can reduce optimal inflation volatility.

McKay and Wolf (2023) solve for optimal monetary policy by considering a linear-quadratic policy problem. They show that household heterogeneity adds a term to the usual loss function due to distributional motives. Finally, Yang (2024) solves for optimal monetary policy by optimizing the coefficients of a Taylor rule in a model with three redistributive channels for inflation: an expenditure channel (households have different consumption baskets and inflation is heterogeneous across products) and the standard Fisher and earning channels. Our contribution to this literature is to characterize the dynamics of optimal monetary policy in a timeless perspective, within a framework that includes capital, and occasionally binding credit constraints, under different assumptions about fiscal policy and nominal frictions.

The paper is organized as follows. Section 2 presents the sticky-price model. Section 3 presents the optimal policies and our equivalence result in this setup. Section 4 presents the tools to simulate the general model. Section 5 reports our quantitative results in the sticky-price economy. Section 6 presents the findings for the sticky-wage economy. Section 7 concludes.

## 2 The sticky-price environment

Time is discrete, indexed by  $t \geq 0$ . The economy is populated by a continuum of agents of size 1, distributed on a segment  $J$  following a non-atomic measure  $\ell$ :  $\ell(J) = 1$ . Following Green (1994), we assume that the law of large numbers holds.

### 2.1 Risk

The sole aggregate shock in the economy affects the technology level. We denote this risk by  $z$ , which can take any real value. The economy-wide productivity, denoted  $Z$ , is assumed to relate to  $z$  through:  $Z_t = \exp(z_t)$  at all dates  $t$ . The history of aggregate risk up to period  $t$  is denoted  $z^t := \{z_0, z_1, \dots, z_t\}$ .

In addition to the aggregate shock, agents face an uninsurable idiosyncratic labor productivity shock  $y$  assumed to belong to a finite set  $\mathcal{Y}$  of strictly positive values. An agent  $i$  at any date  $t$  can adjust their labor supply, denoted by  $l_{i,t}$ , and earns the before-tax wage rate  $\tilde{w}_t$  per efficient unit. Therefore, the agent's total before-tax wage amounts to  $y_{i,t}\tilde{w}_t l_{i,t}$ . We assume that the productivity process is a first-order Markov chain with a constant transition matrix, denoted by  $(\pi_{yy'})_{y,y'}$ , where  $\pi_{yy'}$  is the probability to switch from productivity  $y \in \mathcal{Y}$  in the current period to productivity  $y' \in \mathcal{Y}$  in the following period. The share of agents with productivity  $y$ , denoted by  $S_y$ , is constant across time and equal to:  $S_y = \sum_{\tilde{y}} \pi_{\tilde{y}y} S_{\tilde{y}}$  for all  $y \in \mathcal{Y}$ . Finally, a history of productivity shocks up to date  $t$  is denoted by  $y^t$ . Using transition probabilities, we can compute the measure  $\theta_t$ , such that  $\theta_t(y^t)$  represents the share of agents with history  $y^t$  in period  $t$ .

## 2.2 Preferences

In each period, the economy has two goods: a consumption good and labor. Households are expected-utility maximizers, and they rank streams of consumption  $(c_t)_{t \geq 0}$  and of labor  $(l_t)_{t \geq 0}$  according to a time-separable intertemporal utility function equal to  $\sum_{t=0}^{\infty} \beta^t U(c_t, l_t)$ , where  $\beta \in (0, 1)$  is a constant discount factor and  $U(c, l)$  is an instantaneous utility function. As is standard in this class of models, we focus on the case where  $U$  is separable in consumption and labor and is expressed as:<sup>1</sup>  $U(c, l) = u(c) - v(l)$ , where  $u : \mathbb{R}_+ \rightarrow \mathbb{R}$  and  $v : \mathbb{R}_+ \rightarrow \mathbb{R}$  are twice continuously differentiable and increasing. Furthermore,  $u$  is concave, with  $u'(0) = \infty$ , and  $v$  is convex.

## 2.3 Production

The consumption good  $Y_t$  is produced by a unique profit-maximizing representative firm that combines intermediate goods  $(y_{j,t}^f)_j$  from different sectors indexed by  $j \in [0, 1]$  using a standard Dixit-Stiglitz aggregator with an elasticity of substitution, denoted  $\varepsilon > 0$ :

$$Y_t = \left[ \int_0^1 y_{j,t}^f \frac{\varepsilon-1}{\varepsilon} dj \right]^{\frac{\varepsilon}{\varepsilon-1}}.$$

For any intermediate good  $j \in [0, 1]$ , the production  $y_{j,t}^f$  is realized by a monopolistic firm and sold at price  $p_{j,t}$ . The profit maximization for the firm producing the final good implies:

$$y_{j,t}^f = \left( \frac{p_{j,t}}{P_t} \right)^{-\varepsilon} Y_t, \text{ where } P_t = \left( \int_0^1 p_{j,t}^{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}}.$$

The quantity  $P_t$  is the price index of the consumption good. Intermediary firms are endowed with a Cobb-Douglas production technology and use labor and capital as production factors. The production technology is such that  $\tilde{l}_{j,t}$  units of labor and  $\tilde{k}_{j,t}$  units of capital are transformed into  $Z_t \tilde{k}_{j,t}^\alpha \tilde{l}_{j,t}^{1-\alpha}$  units of intermediate good. In equilibrium, this production will exactly cover the demand  $y_{j,t}^f$  for the good  $j$ , which will be sold with the real price  $p_{j,t}/P_t$ . We denote by  $\tilde{w}_t$  the real before-tax wage rate per efficient unit and  $\tilde{r}_t^K$  the real before-tax net interest rate on capital – which are both identical for all firms. The capital depreciation rate is denoted  $\delta > 0$ . Since intermediate firms have market power that they internalize, the firm's objective is to minimize production costs, including capital depreciation, subject to producing the demand  $y_{j,t}^f$ . The cost function  $C_{j,t}$  of firm  $j$  is therefore  $C_{j,t} = \min_{\tilde{l}_{j,t}, \tilde{k}_{j,t}} \{(\tilde{r}_t^K + \delta)\tilde{k}_{j,t} + \tilde{w}_t \tilde{l}_{j,t}\}$ , subject to  $y_{j,t}^f = Z_t \tilde{k}_{j,t}^\alpha \tilde{l}_{j,t}^{1-\alpha}$ . Denoting by  $\zeta_{j,t}$  the Lagrange multiplier of the production constraint,

<sup>1</sup>Our equivalence result does not depend on this functional form. See Section 3.2 for a general function  $U$ .

first-order conditions (FOCs) imply:

$$\tilde{r}_t^K + \delta = \zeta_{j,t} \alpha \frac{y_{j,t}^f}{\tilde{k}_{j,t}} \text{ and } \tilde{w}_t = \zeta_{j,t} (1 - \alpha) \frac{y_{j,t}^f}{\tilde{l}_{j,t}}. \quad (1)$$

The optimum thus features a common value, denoted by  $\zeta_t$ , independent of firm type  $j$ , with:

$$\zeta_t = \frac{1}{Z_t} \left( \frac{\tilde{r}_t^K + \delta}{\alpha} \right)^\alpha \left( \frac{\tilde{w}_t}{1 - \alpha} \right)^{1 - \alpha}. \quad (2)$$

Firm  $j$ 's cost is then  $C_j = \zeta_t y_{j,t}^f$ , which is linear in the demand  $y_{j,t}^f$ . Following the literature, we assume the presence of a subsidy  $\tau^Y$  on the total cost, which will compensate for steady-state distortions, such that the total cost supported by firm  $j$  is  $\zeta_t y_{j,t}^f (1 - \tau^Y)$ . Integrating factor price equations (1) over all firms leads to:

$$K_{t-1} = \frac{1}{Z_t} \left( \frac{\tilde{r}_t^K + \delta}{\alpha} \right)^{\alpha - 1} \left( \frac{\tilde{w}_t}{1 - \alpha} \right)^{1 - \alpha} Y_t \text{ and } L_t = \frac{1}{Z_t} \left( \frac{\tilde{r}_t^K + \delta}{\alpha} \right)^\alpha \left( \frac{\tilde{w}_t}{1 - \alpha} \right)^{-\alpha} Y_t, \quad (3)$$

where  $Y_t$  is total production, for which (3) satisfies:

$$Y_t = Z_t K_{t-1}^\alpha L_t^{1 - \alpha} = \frac{(\tilde{r}_t^K + \delta) K_{t-1} + \tilde{w}_t L_t}{\zeta_t}. \quad (4)$$

Finally, in this setup, the usual factor price relationships do not hold, but we still have:

$$\frac{K_{t-1}}{L_t} = \frac{\alpha}{1 - \alpha} \frac{\tilde{w}_t}{\tilde{r}_t^K + \delta}. \quad (5)$$

In a real setup (featuring  $\zeta_t = 1$  for all  $t$ ), equations (2) and (5) fall back to the standard definitions of factor prices:  $\tilde{r}_t + \delta = \alpha Z_t \left( \frac{K_{t-1}}{L_t} \right)^{\alpha - 1}$  and  $\tilde{w}_t = (1 - \alpha) Z_t \left( \frac{K_{t-1}}{L_t} \right)^\alpha$ .

In addition to the production cost, intermediate firms face a quadratic price adjustment cost *à la* Rotemberg (1982) when setting their price. Following the literature, the price adjustment cost is proportional to the magnitude of the firm's relative price change and equal to  $\frac{\kappa}{2} \left( \frac{p_{j,t}}{p_{j,t-1}} - 1 \right)^2 Y_t$ , where  $\kappa \geq 0$ . We can thus deduce the real profit, denoted  $\Omega_{j,t}$ , at date  $t$  of firm  $j$ :

$$\Omega_{j,t} = \left( \frac{p_{j,t}}{P_t} - \left( \frac{\tilde{r}_t + \delta}{\alpha} \right)^\alpha \left( \frac{\tilde{w}_t}{1 - \alpha} \right)^{1 - \alpha} \frac{1 - \tau^Y}{Z_t} \right) \left( \frac{p_{j,t}}{P_t} \right)^{-\varepsilon} Y_t - \frac{\kappa}{2} \left( \frac{p_{j,t}}{p_{j,t-1}} - 1 \right)^2 Y_t - t_t^Y, \quad (6)$$

where  $t_t^Y$  is a lump-sum tax financing the subsidy  $\tau^Y$ . Computing firm  $j$ 's intertemporal profit requires us to define the firm's pricing kernel. In a heterogeneous agent economy, there is no obvious choice for the pricing kernel. We discuss this in Section 2.7. For the moment, we assume only that the firm's  $j$  pricing kernel is independent of its type, and we denote it by  $\frac{M_t}{M_0}$ . With this notation, firm  $j$ 's program, which consists in choosing the price schedule  $(p_{j,t})_{t \geq 0}$  to maximize

the intertemporal profit at date 0, can be expressed as:  $\max_{(p_{j,t})_{t \geq 0}} \mathbb{E}_0[\sum_{t=0}^{\infty} \beta^t \frac{M_t}{M_0} \Omega_{j,t}]$ . Since this program yields a solution independent of the firm's type  $j$ , all firms in the symmetric equilibrium will charge the same price:  $p_{j,t} = P_t$ . Denoting the gross inflation rate as  $\Pi_t^P = \frac{P_t}{P_{t-1}}$  and setting  $\tau^Y = \frac{1}{\varepsilon}$  to obtain an efficient steady state, we obtain the standard equation characterizing the Phillips curve in our environment:

$$\Pi_t^P (\Pi_t^P - 1) = \frac{\varepsilon - 1}{\kappa} (\zeta_t - 1) + \beta \mathbb{E}_t \Pi_{t+1}^P (\Pi_{t+1}^P - 1) \frac{Y_{t+1}}{Y_t} \frac{M_{t+1}}{M_t}. \quad (7)$$

The real profit is independent of the firm's type and can be expressed as follows:

$$\Omega_t = \left(1 - \zeta_t - \frac{\kappa}{2} (\Pi_t^P - 1)^2\right) Y_t. \quad (8)$$

## 2.4 Assets

Agents have the possibility to trade two assets. The first one is nominal public debt, whose supply size is denoted by  $B_t$  at date  $t$ . Public debt is issued by the government and is assumed to be exempt of default risk. The nominal debt pays off a nominal gross and pre-tax interest rate that is predetermined. In other words, the nominal interest rate between dates  $t - 1$  and  $t$  is known at  $t - 1$ . We denote this (gross and before tax) nominal interest rate by  $\tilde{R}_{t-1}^N$ . The associated real before-tax (gross) interest rate for public debt is  $\tilde{R}_{t-1}^N / \Pi_t^P$ . Note that due to inflation, this ex-post real rate is not predetermined. We denote by  $b_{i,t}$  the debt investment of agent  $i$ . We assume that agents face nominal borrowing constraints, and their nominal debt holdings must be higher than  $-\bar{b} \leq 0$ . In the rest of the paper, we will focus on the case where the credit limit is above the steady-state natural borrowing limit.<sup>2</sup>

The second asset consists of capital shares, which pay off a (net and before-tax) real interest rate  $\tilde{r}_t^K$  – as introduced above. We denote by  $k_{i,t}$  the share of capital held by agent  $i$ . We assume that agents cannot issue any real claim and real asset holdings must remain positive.

## 2.5 Government, fiscal tools and monetary policy

In each period  $t$ , the government has to finance an exogenous public good expenditure  $G_t$ , as well as lump-sum transfers  $T_t \geq 0$ .<sup>3</sup> These transfers can be thought of as social transfers, which can generate progressivity in the overall tax system. Heathcote et al. (2017) have shown that such transfers are needed to properly replicate the US fiscal system. The government has several tools for financing these expenditures. First, the government can rely on four different taxes. The first

<sup>2</sup>Aiyagari (1994) discusses the relevant values of the natural borrowing limit in an economy without aggregate shocks. Shin (2006) provides a similar discussion in the presence of aggregate shocks. A standard value in the literature is a zero borrowing limit, which ensures that consumption remains positive in all states of the world.

<sup>3</sup>We rule out the possibility of lump-sum taxes as a standard assumption in this literature (Aiyagari et al., 2002). See Bhandari et al. (2017) for an analysis of the case, where lump-sum taxes can be the planner's instruments.

two taxes, whose rates are denoted by  $\tau_t^K$  and  $\tau_t^B$ , are distortionary taxes, which are levied on real and nominal asset payoffs respectively. Second, the government also fully taxes the firms' profits, which limits the distortions implied by profit distribution. Finally, the last tax, whose rate is denoted by  $\tau_t^L$ , concerns labor income. In addition to these taxes, the government can also issue a one-period public nominal bond; the amount of public debt outstanding at date  $t$  is denoted by  $B_t$ . To sum up, fiscal policy is characterized by five instruments  $(\tau_t^L, \tau_t^K, \tau_t^B, T_t, B_t)_{t \geq 0}$  given an exogenous path of public spending  $(G_t)_{t \geq 0}$ .

After-tax quantities are denoted without a tilde. The real after-tax wage rate  $w_t$ , as well as the real after-tax interest rates  $r_t^K$ , and  $R_t^N$  (for capital and public debt, respectively) are as such expressed as follows:

$$w_t = (1 - \tau_t^L)\tilde{w}_t, \quad (9)$$

$$r_t^K = (1 - \tau_t^K)\tilde{r}_t^K, \quad \frac{R_t^N}{\Pi_t^P} - 1 = (1 - \tau_t^B)\left(\frac{\tilde{R}_{t-1}^N}{\Pi_t^P} - 1\right), \quad (10)$$

Taxes on interest-bearing assets are asset-specific and are levied on real returns. The period- $t$  real return on the nominal interest rate  $\tilde{R}_{t-1}^N$ , set in period  $t-1$ , is affected by both the period- $t$  inflation rate and the period- $t$  tax  $\tau_t^B$  (hence the notation  $R_t^N$  in (10)).

The government uses its financial resources, comprised of labor and asset tax revenue and public debt issuance, to finance public goods, lump-sum transfers, and debt repayment:

$$G + \frac{\tilde{R}_{t-1}^N}{\Pi_t^P} B_{t-1} + T_t \leq \tau_t^L \tilde{w}_t L_t + \tau_t^K \tilde{r}_t^K K_{t-1} + \tau_t^B \left( \frac{\tilde{R}_{t-1}^N}{\Pi_t^P} - 1 \right) B_{t-1} + \Omega_t + B_t.$$

The expression of this government budget constraint can be simplified, following Chamley (1986). Using the relationships (1) and (4), as well as the definition of post-tax rates in equations (9) and (10), the governmental budget constraint becomes:

$$G + \frac{R_t^N}{\Pi_t^P} B_{t-1} + r_t^K K_{t-1} + w_t L_t + T_t = B_t + \left( 1 - \frac{\kappa}{2} (\Pi_t^P - 1)^2 \right) Y_t - \delta K_{t-1}. \quad (11)$$

Monetary policy consists in choosing the nominal interest rate  $\tilde{R}_t^N$  on public debt (between  $t$  and  $t+1$ ), which affects the gross inflation rate  $\Pi_t^P$ . The choice of optimal monetary-fiscal policy is thus a choice of the path of the instruments  $(\tau_t^L, \tau_t^K, \tau_t^B, T_t, B_t, \tilde{R}_t^N, \Pi_t^P)_{t \geq 0}$ . These instruments are not independent of each other and are intertwined through the budget constraint of the government and the Phillips curve.

## 2.6 Agents' program, resource constraints, and equilibrium definition

Each agent  $i$  is endowed at date 0 by an initial real and nominal wealth  $k_{i,-1}$  and  $b_{i,-1}$  and an initial productive status  $y_{i,0}$ . At future dates, an agent's nominal savings pay off the post-tax

gross interest rate  $\frac{R_t^N}{\Pi_t^P}$  between period  $t - 1$  and period  $t$ , while their real savings pay off the post-tax gross rate  $1 + r_t^K$ . Formally, the agent's program can be expressed, for given initial endowments  $k_{i,-1}$  and  $b_{i,-1}$  and given initial shocks  $y_{i,0}$  and  $z_0$ , as:

$$\max_{\{c_{i,t}, l_{i,t}, k_{i,t}, b_{i,t}\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t (u(c_{i,t}) - v(l_{i,t})), \quad (12)$$

$$c_{i,t} + k_{i,t} + b_{i,t} = (1 + r_t^K)k_{i,t-1} + \frac{R_t^N}{\Pi_t^P} b_{i,t-1} + w_t y_{i,t} l_{i,t} + T_t, \quad (13)$$

$$b_{i,t} \geq -\bar{b}, k_{i,t} \geq 0, c_{i,t} > 0, l_{i,t} > 0, \quad (14)$$

where  $\mathbb{E}_0$  is an expectation operator over both idiosyncratic and aggregate risk.

Equation (13) can be used to discuss the effect of fiscal and monetary policies in relationship to the literature. First, an unexpected change in an asset tax ( $\tau_t^K$  or  $\tau_t^B$ ) affects period  $t$  income, proportionally to interest payments on past real or nominal savings payoffs ( $\tilde{r}_t^K k_{i,t-1}$  or  $(\frac{\tilde{R}_{t-1}^N}{\Pi_t^P} - 1)b_{i,t-1}$  respectively). Past savings payoffs are the amount of unhedged interest rate exposures (UREs) at period  $t - 1$ , using the wording of Auclert (2019). Second, an unexpected change in inflation affects the return on the nominal holdings,  $\frac{R_t^N}{\Pi_t^P}$ , due to a Fisher effect. Third, labor tax affects the post-tax wage rate, which generates heterogeneous income and labor-supply effects. Finally, a change in the lump-sum transfer uniformly affects total income without distortion.

At date 0, an agent decides their plans for consumption  $(c_{i,t})_{t \geq 0}$ , labor supply  $(l_{i,t})_{t \geq 0}$ , and saving  $(b_{i,t})_{t \geq 0}$  and  $(k_{i,t})_{t \geq 0}$ , which maximize their intertemporal utility (12) subject to the budget constraint (13) and the borrowing limits and positivity constraints (14). These decisions are functions of the initial state  $(b_{i,-1}, k_{i,-1}, y_{i,0})$ , of the history of the idiosyncratic shock  $y_i^t$  and of the history of the aggregate shocks  $z^t$ . Thus, there exist sequences of functions, defined over  $([-\bar{b}; +\infty) \times [0; +\infty) \times \mathcal{Y}) \times \mathcal{Y}^t \times \mathbb{R}^t$  and denoted by  $(c_t, b_t, k_t, l_t)_{t \geq 0}$ , such that an agent's optimal decisions can be written as follows:<sup>4</sup>

$$\begin{aligned} c_{i,t} &= c_t((b_{i,-1}, k_{i,-1}, y_{i,0}), y_i^t, z^t), & b_{i,t} &= b_t((b_{i,-1}, k_{i,-1}, y_{i,0}), y_i^t, z^t), \\ k_{i,t} &= k_t((b_{i,-1}, k_{i,-1}, y_{i,0}), y_i^t, z^t), & l_{i,t} &= l_t((b_{i,-1}, k_{i,-1}, y_{i,0}), y_i^t, z^t). \end{aligned} \quad (15)$$

In what follows, we simplify the notation and keep the  $i$ -index. For instance, we write  $c_{i,t}$  instead of  $c_t((b_{i,-1}, k_{i,-1}, y_{i,0}), y_i^t, z^t)$ .

<sup>4</sup>The existence of such functions is proven in Miao (2006), Cheridito and Sagredo (2016), and Açıkgöz (2018).

The FOCs corresponding to the agent's program (12)–(14) are:

$$u'(c_{i,t}) = \beta \mathbb{E}_t \left[ (1 + r_{t+1}^K) u'(c_{i,t+1}) \right] + \nu_{i,t}^k, \quad (16)$$

$$= \beta \mathbb{E}_t \left[ \frac{R_{t+1}^N}{\Pi_{t+1}} u'(c_{i,t+1}) \right] + \nu_{i,t}^b, \quad (17)$$

$$v'(l_{i,t}) = w_t y_{i,t} u'(c_{i,t}), \quad (18)$$

where the discounted Lagrange multipliers of the real and nominal credit constraints of agent  $i$  are denoted by  $\nu_{i,t}^k$  and  $\nu_{i,t}^b$ , respectively. Each of these Lagrange multipliers is null when agent  $i$  is not credit-constrained along the instrument under consideration.

We now express the economy-wide constraints:

$$\int_i b_{i,t} \ell(di) = B_t, \quad \int_i k_{i,t} \ell(di) = K_t, \quad \int_i y_{i,t} l_{i,t} \ell(di) = L_t, \quad (19)$$

$$\int_i c_{i,t} \ell(di) + G_t + K_t = \left( 1 - \frac{\kappa}{2} (\Pi_t^P - 1)^2 \right) Y_t + K_{t-1} - \delta K_{t-1}, \quad (20)$$

which correspond to the clearing of the nominal and real financial markets, of the labor market, and of the goods market, respectively.<sup>5</sup>

**Equilibrium definition.** Our definition of a market equilibrium can be stated as follows.

**Definition 1** (Sequential equilibrium). *A sequential competitive equilibrium is a collection of individual functions  $(c_{i,t}, l_{i,t}, b_{i,t}, k_{i,t}, \nu_{i,t}^b, \nu_{i,t}^k)_{t \geq 0, i \in \mathcal{I}}$ , aggregate quantities  $(K_t, L_t, Y_t, \Omega_t, \zeta_t)_{t \geq 0}$ , price processes  $(w_t, r_t^K, R_t^N, \tilde{w}_t, \tilde{r}_t^K, \tilde{R}_t^N)_{t \geq 0}$ , fiscal policies  $(\tau_t^L, \tau_t^K, \tau_t^B, B_t, T_t)_{t \geq 0}$ , and monetary policies  $(\Pi_t^P)_{t \geq 0}$  such that, for an initial wealth and productivity distribution  $(b_{i,-1}, k_{i,-1}, y_{i,0})_{i \in \mathcal{I}}$ , and for initial values of capital stock and public debt verifying  $K_{-1} = \int_i k_{i,-1} \ell(di)$  and  $B_{-1} = \int_i b_{i,-1} \ell(di)$ , and for an initial value of the aggregate shock  $z_0$ , we have:*

1. *given prices, the functions  $(c_{i,t}, l_{i,t}, b_{i,t}, k_{i,t}, \nu_{i,t}^b, \nu_{i,t}^k)_{t \geq 0, i \in \mathcal{I}}$  solve the agent's optimization program in equations (12)–(14);*
2. *financial, labor, and goods markets clear at all dates: for any  $t \geq 0$ , equations (19) and (20) hold;*
3. *the government budget is balanced at all dates: equation (11) holds for all  $t \geq 0$ ;*
4. *factor prices  $(w_t, r_t^K, R_t^N, \tilde{w}_t, \tilde{r}_t^K, \tilde{R}_t^N)_{t \geq 0}$  are consistent with condition (5), as well as with post-tax definitions (9) and (10);*

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<sup>5</sup>It would be equivalent to use the sequential representation and to integrate over initial states (of measure  $\Lambda$ ) and idiosyncratic histories (of measure  $\theta$ ). For instance, nominal savings can be written as:  $\int_i b_{i,t} \ell(di) = \sum_{y_i^t \in \mathcal{Y}^t} \sum_{y_0 \in \mathcal{Y}} \int_{b_{-1} \in [-\bar{b}, +\infty)} \int_{k_{-1} \in [0, +\infty)} b_t((b_{-1}, k_{-1}, y_0), y_i^t, z^t) \theta_t(y_i^t) \Lambda(db_{-1}, dk_{-1}, y_0) = B_t$ .

5. firms' profits  $\Omega_t$  and the quantity  $\zeta_t$  are consistent with equations (2) and (8);
6. the inflation path  $(\Pi_t^P)_{t \geq 0}$  is consistent with the Phillips curve: at any date  $t \geq 0$ , equation (7) holds.

## 2.7 The Ramsey problem

The goal of this paper is to determine the optimal monetary-fiscal policy that generates the sequential equilibrium which maximizes an explicit aggregate welfare criterion. This is a difficult question, as monetary-fiscal policy is composed of seven instruments  $(\tau_t^L, \tau_t^K, \tau_t^B, T_t, B_t, \tilde{R}_t^N, \Pi_t^P)_{t \geq 0}$  which affect the saving decisions and the labor supplies of all agents, the capital stock, and price dynamics. Interestingly, monetary policy has to balance the cost of output destruction (through price adjustment costs), nominal debt monetization, and the indirect effect on mark-ups.

**Aggregate welfare.** We consider a utilitarian welfare function, where all agents are equally weighted. Formally, the aggregate welfare criterion can be expressed as follows:

$$W_0 := \mathbb{E}_0 \left[ \sum_{t=0}^{\infty} \beta^t \int_i (u(c_{i,t}) - v(l_{i,t})) \ell(di) \right]. \quad (21)$$

**Choosing the pricing kernel.** In a heterogeneous-agent economy, there is no straightforward choice for the firm's pricing kernel. We follow Bhandari et al. (2021) and Acharya et al. (2023) and assume that firm's pricing kernel is risk-neutral. More precisely, the pricing kernel  $M_t$  is constant and normalized to 1 for all  $t$ :  $M_t := 1$ . As noted by others (Bhandari et al., 2021) and as we checked ourselves, the choice of the pricing kernel has minor quantitative effects.<sup>6</sup>

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<sup>6</sup>We also considered a firm's pricing kernel defined based on the weighted marginal utilities of agents:  $M_t := \int_i u'(c_{i,t}) \ell(di)$ . This has very small impacts on our results.

**The Ramsey program.** The Ramsey program can be expressed using post-tax notation as:

$$\max_{(\tau_t^L, \tau_t^K, \tau_t^B, B_t, T_t, \Pi_t^P, w_t, r_t^K, R_t^N, \tilde{w}_t, \tilde{r}_t^K, \tilde{R}_t^N, K_t, L_t, Y_t, \Omega_t, \zeta_t, (c_{i,t}, l_{i,t}, b_{i,t}, k_{i,t}, \nu_{i,t}^b, \nu_{i,t}^k)_i)_{t \geq 0}} W_0, \quad (22)$$

$$G + \frac{R_t^N}{\Pi_t^P} B_{t-1} + r_t^K K_{t-1} + w_t L_t + T_t = B_t + \left(1 - \frac{\kappa}{2} (\Pi_t^P - 1)^2\right) Y_t - \delta K_{t-1}, \quad (23)$$

$$\text{for all } i \in \mathcal{I}: c_{i,t} + k_{i,t} + b_{i,t} = (1 + r_t^K) k_{i,t-1} + \frac{R_t^N}{\Pi_t^P} b_{i,t-1} + w_t y_{i,t} l_{i,t} + T_t, \quad (24)$$

$$b_{i,t} \geq -\bar{b}, \nu_{i,t}^b (b_{i,t} + \bar{b}) = 0, \nu_{i,t}^b \geq 0, \quad (25)$$

$$k_{i,t} \geq 0, \nu_{i,t}^k k_{i,t} = 0, \nu_{i,t}^k \geq 0, \quad (26)$$

$$u'(c_{i,t}) = \beta \mathbb{E}_t \left[ (1 + r_{t+1}^K) u'(c_{i,t+1}) \right] + \nu_{i,t}^k, \quad (27)$$

$$u'(c_{i,t}) = \beta \mathbb{E}_t \left[ \frac{R_{t+1}^N}{\Pi_{t+1}^P} u'(c_{i,t+1}) \right] + \nu_{i,t}^b, \quad (28)$$

$$v'(l_{i,t}) = w_t y_{i,t} u'(c_{i,t}), \quad (29)$$

$$\Pi_t^P (\Pi_t^P - 1) = \frac{\varepsilon - 1}{\kappa} (\zeta_t - 1) + \beta \mathbb{E}_t \left[ \Pi_{t+1}^P (\Pi_{t+1}^P - 1) \frac{Y_{t+1}}{Y_t} \right], \quad (30)$$

$$B_t = \int_i b_{i,t} \ell(di), \quad K_t = \int_i k_{i,t} \ell(di), \quad L_t = \int_i y_{i,t} l_{i,t} \ell(di), \quad (31)$$

and subject to other constraints (which are not reported here for space constraints): the definition (2) of  $\zeta_t$ , the definition (4) of  $Y_t$ , the definition (8) of profits  $\Omega_t$ , the factor-price relationship (5), the definitions (9)–(10) of post-tax quantities, the positivity of labor and consumption choices, and initial conditions.

The constraints in the Ramsey program include: the governmental and individual budget constraints (23) and (24), the two individual credit constraints on nominal and real asset holdings (and related constraints on  $\nu_{i,t}^k$  and  $\nu_{i,t}^b$ ) (25) and (26), Euler equations for consumption and labor (27), (28), (29), the Phillips curve (30), and market clearing conditions for financial and labor markets (31). To simplify the derivation of FOCs, we use some aspects of the methodology of Marcet and Marimon (2019), which is sometimes called the Lagrangian method (Golosov et al., 2016), applied to incomplete-market environments. We denote by  $\beta^t \lambda_{i,k,t}$ ,  $\beta^t \lambda_{i,b,t}$ , and  $\beta^t \lambda_{i,l,t}$  the Lagrange multipliers of the Euler equations (27)–(29) of agent  $i$  at date  $t$ . Similarly, we denote by  $\beta^t \gamma_t$  the Lagrange multiplier of equation (30) of the Phillips curve. The Lagrange multiplier of the government budget constraint is  $\beta^t \mu_t$ .

The Ramsey program (22)–(31) could be simplified further by following Chamley (1986) and removing taxes and pre-tax quantities, such that the planner directly chooses post-tax quantities. Pre-tax quantities can then be deduced from their definitions (5) and (8). The definitions (9)–(10) of post-tax quantities can be used to recover tax paths from pre- and post-tax quantities. However, we will also consider economies where some fiscal instruments are kept fixed. We have

thus chosen to provide the expression of the full-fledged version of the program, where fixing taxes only involves adding a constraint to the program.

As a final remark, the Ramsey program can be written in a recursive form. The state space for the planner and all agents is actually very large. It is the joint distribution over past values of Lagrange multipliers, wealth, productivity levels and the current aggregate state. This inclusion of past values of Lagrange multipliers, which makes the problem difficult, stems from the commitment of the planner not to surprise agents, such that their Euler equations hold in expectation. We omit this representation as the discussion of FOCs in the sequential representation is more intuitive.

### 3 Optimal policies

This section presents our main equivalence result and analyzes fiscal and monetary policies in different institutional setups. The analysis is greatly simplified if one introduces a new concept, the *social valuation of liquidity (SVL) for agent  $i$* , denoted by  $\psi_{i,t}$ , and formally defined as:

$$\begin{aligned} \psi_{i,t} := & \underbrace{u'(c_{i,t})}_{\text{direct effect}} - \underbrace{(\lambda_{i,k,t} - (1 + r_t^K)\lambda_{i,k,t-1}) u''(c_{i,t})}_{\text{effect on real savings}} \\ & - \underbrace{\left( \lambda_{i,b,t} - \frac{R_t^N}{\Pi_t^P} \lambda_{i,b,t-1} \right) u''(c_{i,t})}_{\text{effect on nominal savings}} + \underbrace{\lambda_{i,l,t} y_{i,t} w_t u''(c_{i,t})}_{\text{effect on labor supply}}. \end{aligned} \quad (32)$$

The valuation  $\psi_{i,t}$  measures the benefit – from the planner’s perspective – of transferring one extra unit of consumption to agent  $i$ . This can be interpreted as the planner’s version of the marginal utility of consumption for the agent.<sup>7</sup> As can be seen in equation (32), this valuation consists of four terms. The first is the marginal utility of consumption  $u'(c_{i,t})$ , which is the private valuation of liquidity for agent  $i$ . The three other terms can be understood as the internalization, by the planner, of the economy-wide externalities of this extra consumption unit. More precisely, the second and third terms in (32) take into consideration the impact of the extra consumption unit on saving incentives from periods  $t-1$  to  $t$  and from periods  $t$  to  $t+1$ . The interpretation of both terms is similar, except that they involve real and nominal savings respectively. An extra consumption unit makes the agent more willing to smooth their consumption between periods  $t$  and  $t+1$ , and thus makes their Euler equation (either nominal or real) more “binding”. This more “binding” constraint reduces utility by the algebraic quantity  $u''(c_{i,t})\lambda_{i,x,t}$ , where  $\lambda_{i,x,t}$  is the Lagrange multiplier of the agent’s Euler equation at date  $t$  (whether it’s nominal with  $x = b$  or real with  $x = k$ ). The extra consumption unit at  $t$  also makes the agent less willing to smooth her consumption between periods  $t-1$  and  $t$  and therefore “relaxes” the constraint at date  $t-1$ .

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<sup>7</sup>To simplify the notation, we keep the index  $i$ , but the sequential representation can be derived along the lines of equation (15).

This is reflected in the quantity  $\lambda_{i,x,t-1}$  ( $x = b, k$ ). In the absence of savings externalities (as in the representative-agent case), the Lagrange multipliers  $\lambda_{i,x,t}$  would be 0.

Finally, the fourth term reflects the wealth effect of the labor supply. Indeed, transferring an extra consumption unit to agent  $i$  deters their labor supply incentives through their labor supply Euler equation (18). This effect has to be internalized by the planner. Note that this term is present because we have chosen a utility function that is separable in labor and consumption. It would be absent with a GHH utility function.

Another key quantity is  $\mu_t$ , the Lagrange multiplier on the governmental budget constraint. The quantity  $\mu_t$  represents the marginal cost in period  $t$  of transferring one extra unit of consumption to households. Therefore, the quantity  $\psi_{i,t} - \mu_t$  can be interpreted as the “net” SVL: this is from the planner’s perspective, the benefit of transferring one extra unit of consumption to agent  $i$ , net of the governmental cost. We thus define:

$$\hat{\psi}_{i,t} := \psi_{i,t} - \mu_t. \quad (33)$$

The interpretation of FOCs is greatly clarified by expressing them using  $\hat{\psi}_{i,t}$  rather than the multiplier on Euler equations,  $\lambda_{i,t}$ .

### 3.1 The flexible-price economy

Our main result below is that the planner reproduces the flexible-price allocations, if they are allowed to choose capital and labor taxes. We thus first analyze the flexible-price allocation, in which the price adjustment cost is  $\kappa = 0$ .<sup>8</sup> In this case, the Phillips curve does not constrain the planner’s choices and its associated Lagrange multiplier is  $\gamma_t = 0$ . We can therefore follow Chamley (1986) and express all of the planner’s constraints in post-tax prices. The Ramsey equilibrium can thus be derived using a narrower set of variables, which simplifies the algebra. Taxes are then recovered from the allocation. The before-tax rates  $\tilde{w}_t$  and  $\tilde{r}_t^K$  can be deduced from equations (2) and (5) with  $\zeta_t = 1$ . Taxes  $\tau_t^L$  and  $\tau_t^K$  are obtained from the relationships between pre-tax and post-tax rates (9) and (10). Finally, profits are null and the nominal rate  $\tilde{R}_{t-1}^N$  and the nominal tax  $\tau_t^B$  are undetermined.<sup>9</sup>

The resolution of the Ramsey program in Appendix S.1.2 shows that a solution is characterized by: (i) a real and nominal Euler-like equation for each individual valuation  $\hat{\psi}_{i,t}$  (as long as  $i$  is unconstrained), and (ii) four FOCs related to the planner’s four instruments.

The FOCs with respect to nominal individual savings for non-credit-constrained agents can

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<sup>8</sup>Within the literature on optimal fiscal policy in heterogeneous agent models (Werning, 2007; Bassetto, 2014; Açıkgöz et al., 2022; or Dyrda and Pedroni, 2022, among others), the concept of net SVL is new, to the best of our knowledge. It considerably eases the interpretation of the planner’s FOCs and numerical simulations.

<sup>9</sup>Indeed, the government pays the before-tax rate  $\tilde{R}_{t-1}^N$  and receives the nominal tax  $\tau_t^B$ , and both quantities have the same base, which is the previous-period public debt. Hence the government only cares about the post-tax nominal rate, like households.

be written as follows:

$$\hat{\psi}_{i,t} = \beta \mathbb{E}_t \left[ R_{t+1}^N \hat{\psi}_{i,t+1} \right]. \quad (34)$$

Constrained agents have no nominal Euler equation, as  $b_{i,t} = -\bar{b}$  and  $\lambda_{i,b,t} = 0$ . Equation (34) states that the net SVL should be smoothed out over time with the post-tax nominal interest rate. It can be interpreted as a Euler-like equation for the planner and generalizes the standard individual Euler equation by taking into account the externalities of saving choices. Similarly, the real Euler-like equation, corresponding to real saving choices of unconstrained agents, can be written as follows:

$$\hat{\psi}_{i,t} = \beta \mathbb{E}_t \left[ (1 + r_{t+1}^K) \hat{\psi}_{i,t+1} \right] + \beta \mathbb{E}_t \left[ (1 + \tilde{r}_{t+1}^K) \mu_{t+1} \right] - \mu_t, \quad (35)$$

while for real constrained agents, we have  $k_{i,t} = 0$  and  $\lambda_{i,k,t} = 0$ . The differences between the real and nominal Euler-like equations are twofold. First, the Euler equation (35) for  $\hat{\psi}_{i,t}$  now involves the post-tax real interest rate instead of the nominal one, as in equation (34). Equation (34) also includes a supplementary smoothing term that involves the Lagrange multiplier  $\mu$  on the governmental budget constraint. This term comes from the discrepancy between the social valuation of real savings and their cost through the governmental budget constraint. This term is absent in the nominal savings equation (34), because the costs of governmental debt and of households' nominal savings are identical and both equal to  $R_{t+1}^N$ .

The third FOC concerns the individual labor supply for each agent  $i$ , and it can be expressed as follows:

$$v'(l_{i,t}) + \lambda_{i,l,t} v''(l_{i,t}) = w_t y_{i,t} \left( \hat{\psi}_{i,t} + \mu_t \frac{\tilde{w}_t}{w_t} \right). \quad (36)$$

This equation equalizes the marginal social cost of labor (left-hand side) to its marginal benefit (right-hand side). Similarly to the expression (32) of  $\psi_{i,t}$ , the marginal social cost of labor involves the private cost  $v'(l_{i,t})$  as well as the planner's internalization of the general-equilibrium effect of modifying an individual's labor supply, which operates through the individual labor Euler equation (hence the presence of the multiplier  $\lambda_{i,l,t}$ ). The marginal benefits of an extra unit of labor come from the related increase in individual consumption (through  $\hat{\psi}_{i,t}$ ) and from the higher output and higher labor taxes that relax the governmental budget constraint (through  $\mu_t$ ).

The fourth condition, which concerns the post-tax wage rate  $w_t$ , is:

$$\int_i \hat{\psi}_{i,t} y_{i,t} l_{i,t} \ell(di) = - \int_i \lambda_{i,l,t} y_{i,t} u'(c_{i,t}) \ell(di). \quad (37)$$

In the absence of any effect on the labor supply, the planner would choose the wage rate so as to set the aggregate net liquidity value – weighted by the individual labor supply in efficient

terms – to zero:  $\int_i \hat{\psi}_{i,t} y_{i,t} l_{i,t} \ell(di) = 0$ , or equivalently, to equalize the social liquidity valuation to its marginal cost:  $\int_i \psi_{i,t} y_{i,t} l_{i,t} \ell(di) = \mu_t \int_i a_{i,t-1} \ell(di)$ . However, the planner has also to take into account the general-equilibrium distortions implied by wage variations that channel through all individual labor supplies. These distortions are proportional to the Lagrange multipliers on the labor Euler equations,  $\lambda_{i,l,t}$ .

The fifth FOC concerns the post-tax nominal interest rate  $R_t^N$  and is:

$$\int_i \hat{\psi}_{i,t} b_{i,t-1} \ell(di) = - \int_i \lambda_{i,b,t-1} u'(c_{i,t}) \ell(di). \quad (38)$$

Similarly to equation (37), in the absence of any side effects, the planner would like to set to zero the aggregate net value of liquidity among all agents – weighted by agents' nominal asset holdings. However, the planner also has to factor in the side effects of  $R_t^N$  on nominal savings incentives, through the Euler equation. This effect is proportional to the shadow cost of the nominal Euler equation. Note that the sign of this shadow cost depends on the planner's perception of the savings quantity in the economy. It is positive when the planner perceives excess nominal savings in the economy, and negative the other way around (see LeGrand and Ragot, 2022a, for a lengthier discussion). In consequence, for instance, when there is an excess quantity of nominal savings in the economy, the total net valuation of liquidity is negative.

The sixth FOC regarding the post-tax real interest rate  $r_t^K$  can be expressed as:

$$\int_i \hat{\psi}_{i,t} k_{i,t-1} \ell(di) = - \int_i \lambda_{i,k,t-1} u'(c_{i,t}) \ell(di). \quad (39)$$

This is the exact parallel of equation (38) but for real savings instead of nominal ones.

Finally, the last FOC, regarding the lump-sum transfer  $T_t$ , is:

$$\int_i \hat{\psi}_{i,t} \ell(di) \leq 0. \quad (40)$$

This is an equality when  $T_t > 0$ , and an inequality when  $T_t = 0$ . Since there are no distortions implied by the lump-sum transfer, it is set such that the redistributive effect is null.

### 3.2 The equivalence result

The monetary economy features two complementary market imperfections. The first is the monopoly power of intermediary firms, which can yield a price markup  $\zeta_t$  different from one. The second is the Rotemberg inefficiency, which prevents firms from setting their prices without incurring costs. The two imperfections are complementary. Indeed, in the absence of Rotemberg inefficiency (i.e.,  $\kappa = 0$ ), firms' profit maximization yields  $\zeta_t = 1$  and the markup inefficiency vanishes, as can be seen from the Phillips curve in equation (7). Conversely, in the absence of imperfect competition,  $\zeta_t = 1$ , and the Phillips curve implies that the Rotemberg inefficiency

plays no role. The planner’s objective – in a monetary setup – therefore includes minimizing the impact of these two inefficiencies.

We now show that linear taxes on real and nominal assets, as well as on labor, are sufficient tools to offset these two inefficiencies along the business cycle, even when agents are heterogeneous. To do so, we first solve for the optimal monetary and fiscal policies when the government has access to a full set of fiscal tools. This program can be written as:

$$\max_{(B_t, T_t, \Pi_t^P, w_t, r_t^K, R_t^N, \tilde{w}_t, \tilde{r}_t^K, K_t, L_t, Y_t, \zeta_t, (c_{i,t}, l_{i,t}, b_{i,t}, k_{i,t})_{i \geq 0})} W_0, \quad (41)$$

subject to the same equations as in the Ramsey program (22)–(31). Four observations are in order. First, we have dropped the taxes  $\tau_t^L$ ,  $\tau_t^K$ , and  $\tau_t^B$  from the Ramsey program since, as in the flexible-price case, they can be substituted by post-tax quantities  $w_t$ ,  $r_t^K$ , and  $R_t^N$  (and recovered from the resulting allocation). Second, again as in the flexible-price case, the pre-tax nominal rate  $\tilde{R}_t^N$  is also dropped since it does not play any role. Third, the before-tax rates  $\tilde{w}_t$  and  $\tilde{r}_t^K$  play a role only in the markup coefficient  $\zeta_t$  of equation (2) and in the factor price equation (5). In other words, the before-tax rates can be recovered from  $\zeta_t$  and from the allocation. Finally, the markup coefficient only appears in the Phillips curve and can thus be recovered from the path of inflation. Because the planner can optimally choose the post-tax nominal rate  $R_t^N$ , inflation only appears in the planner’s program through the output destruction term (i.e.,  $-\kappa(\Pi_t^P - 1)^2/2$ ) in the government budget constraint. Deviating from null inflation, i.e., from  $\Pi_t^P = 1$ , solely results in a shrinking of the planner’s feasible set. The latter therefore chooses to set the gross inflation rate to 1 at all dates, so as to neutralize the Rotemberg inefficiency. This also makes the price markup inefficiency vanish. In the end, the planner faces the same program – and hence chooses the same allocation – as in the real economy. We summarize this first result in the following proposition.

**Proposition 1** (An equivalence result). *When labor and both nominal and real asset taxes are available, the government exactly reproduces the flexible-price allocation and net inflation is null in all periods.*

The proof is in Appendix S.2. Proposition 1 actually holds in a more general framework, where the period utility is general (and not only separable in consumption and labor). The equivalence result would also hold with different market structures. In particular, distributing the profits to a mutual fund as in Bhandari et al. (2021) would preserve the result if a time-varying tax on the fund payoffs is available. Indeed, a noteworthy aspect of the result is that a capital tax per asset choice is needed, hence one distinct instrument for nominal and real asset holdings.

Following the analysis of Kaplan et al. (2018) and Auclert (2019), monetary policy has direct effects, due to price changes, and indirect effects through general-equilibrium feedback.

Proposition 1 states that the effects achieved by monetary policy can be achieved by labor and capital taxation. Loosely speaking, on the one hand, outcomes of the direct effects can be replicated by the linear capital tax, which globally affects the return on all savings. On the other hand, general equilibrium effects, affecting the real wage, can be replicated by the linear labor tax, which creates a wedge between the marginal labor cost of the firm, determining their pricing decision, and the labor income of households, determining their labor supply decisions. Finally, the equivalence result holds from time-0 onwards. As a consequence, it is valid both in a time-0 perspective, when instruments are chosen in the initial period before converging to a long-run equilibrium, and in a timeless perspective, when the economy is running for a long period such that the effects of initial conditions have vanished.

Note that the result of Proposition 1 would not hold anymore if the nominal tax is removed as an independent instrument and, for instance, set equal to the real capital tax. In that case inflation would be used to partly substitute for the absence of a specific nominal instrument. Formally, we could not write the program using post-tax quantities as we did, and pre- and post-tax quantities would not be independent of each other.

The result of Proposition 1 is in the same vein as Correia et al. (2008) and Correia et al. (2013), who also show that one can recover price stability if the planner has access to a time-varying consumption tax in a complete market environment. The inclusion of nominal and real asset taxes (instead of a consumption tax) allows us to connect our result to the literature on optimal capital taxation in the heterogeneous-agent literature.<sup>10</sup>

## 4 Simulating economies with optimal monetary policy and sub-optimal fiscal policies

This section introduces additional assumptions in order to simulate the model with an exogenous fiscal system. First, following the literature (Gornemann et al., 2016, Bhandari et al., 2021, among many others), we introduce a risk-neutral mutual fund in Section 4.1 to remove agents' portfolio choice. We specify the fiscal rule in Section 4.2 and present the Ramsey program in Section 4.3. Finally, Section 4.4 presents the truncation theory that is used to simulate the model.

### 4.1 Introducing a mutual fund

The mutual fund collects all interest-bearing asset payoffs, – i.e., the nominal returns of public debt and the real returns of the capital stock – and issues claims for households to invest in. Fund claims are the only asset in which households can now invest, and the fund's returns to

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<sup>10</sup>Correia et al. (2008) analyze an economy without capital and with no heterogeneity in asset holdings. In our environment with capital and heterogeneous asset holdings, we need one tax for each asset. In addition, the inclusion of capital tax may be more relevant quantitatively, at least in the US (see Trabandt and Uhlig, 2011).

households are taxed. All the theoretical results of the previous section, and in particular the equivalence result of Proposition 1, remain valid with this new market structure.

The (before-tax) interest rate paid by this fund to agents is denoted by  $\tilde{r}_t$ . The three interest rates, for public debt, capital, and the fund, are connected by two different relationships. The first reflects the non-profit condition of the fund. We denote by  $A_t$  the total asset amount in the economy, equal to the sum of public debt and capital:  $A_t = K_t + B_t$ . Since the fund holds all the public debt and the capital and sell shares, its non-profit condition at date  $t$  implies:

$$\tilde{r}_t A_{t-1} = \tilde{r}_t^K K_{t-1} + \left( \frac{\tilde{R}_{t-1}^N}{\Pi_t^P} - 1 \right) B_{t-1}. \quad (42)$$

The second relationship is the no-arbitrage condition between public debt holdings and capital shares. This condition states that one unit of consumption invested in each of the two assets should yield the same expected return. Formally, this condition can be written as:

$$\mathbb{E}_t \left[ \frac{\tilde{R}_t^N}{\Pi_{t+1}^P} \right] = \mathbb{E}_t [1 + \tilde{r}_{t+1}^K]. \quad (43)$$

Because of the fund intermediation, households make no actual portfolio choice, and we will denote by  $a_t$  their holdings in fund claims. Agents face borrowing constraints, and their fund holdings must be higher than  $-\bar{a} \leq 0$ .

With the introduction of the mutual fund, there is only a single tax on the interest payments of fund shares. We still denote  $\tau_t^K$  this unique capital tax, and the post-tax fund interest rate is:

$$r_t = (1 - \tau_t^K) \tilde{r}_t. \quad (44)$$

With this notation, households' budget constraints and credit limits are:

$$a_{i,t} + c_{i,t} = (1 + r_t) a_{i,t-1} + w_t y_{i,t} l_{i,t} + T_t, \quad (45)$$

$$a_{i,t} \geq -\bar{a}. \quad (46)$$

Because of the absence of portfolio choice, households have a unique consumption Euler equation:

$$u'(c_{i,t}) = \beta \mathbb{E}_t \left[ (1 + r_{t+1}) u'(c_{i,t+1}) \right] + \nu_{i,t}, \quad (47)$$

where  $\beta^t \nu_{i,t}$  is the Lagrange multiplier on the credit constraint (46). The labor FOC (29) is unchanged. The governmental budget constraint and the financial market clearing conditions

are:

$$G + B_{t-1} + r_t A_{t-1} + w_t L_t + T_t = B_t + \left(1 - \frac{\kappa}{2}(\Pi_t^P - 1)^2\right) Y_t - \delta K_{t-1}, \quad (48)$$

$$\int_i a_{i,t} \ell(di) = A_t = K_t + B_t. \quad (49)$$

## 4.2 The fiscal rule

We consider a fiscal system that has an affine structure, composed of lump-sum transfers and linear marginal tax rates. Such a system has often been used in the literature because it allows one to simply reproduce the redistributivity of the US fiscal system, as shown for instance by Heathcote et al. (2017) and Dyrda and Pedroni (2022). Importantly, this fiscal system is not set optimally, but through ad-hoc fiscal rules. For tax rates, we extend the analysis of Vegh and Vuletin (2015) to the 1960-2023 period and verify that the tax rates on personal and corporate incomes are acyclical in the United States. We rely on the ‘‘Global tax rate dataset’’ built by Vegh and Vuletin (2015), which they extended until 2023.<sup>11</sup> We also use GDP data and recession indicators from the FRED database provided by the Federal Reserve Bank of St. Louis.

The empirically relevant case therefore corresponds to maintaining constant marginal tax rates over the business cycle. Our empirical analysis can be found in Appendix S.3.1.<sup>12</sup> For the lump-sum tax, we follow the standard rule of Bohn (1998), in which the primary budget depends on the deviation of the public debt from its long-run target.

Formally, we assume that taxes are defined through the following rules:

$$\tau_t^L = \tau_*^L, \quad (50)$$

$$\tau_t^K = \tau_*^K, \quad (51)$$

$$T_t = T_* - \sigma^T(Z_t - Z_*) - \sigma^B(B_t - B_*), \quad (52)$$

where  $T_*$ ,  $\tau_*^L$ ,  $\tau_*^K$ ,  $B_*$ , and  $Z_*$  are steady-state values of the corresponding variables. Keeping public debt stationary requires  $\sigma^B > 0$ , and different values for  $\sigma^T$  will imply different elasticities of public debt to TFP.

<sup>11</sup>The dataset is available on Guillermo Vuletin’s website: <https://www.guillermovuletin.com/>.

<sup>12</sup>We consider time-varying tax rates in Appendix S.3.2 so as to investigate the impacts of a time-varying fiscal system.

### 4.3 The Ramsey allocation

The Ramsey planner's program can be written as:

$$\max_{(w_t, r_t, \bar{w}_t, \bar{r}_t^K, \bar{R}_t^N, T_t, K_t, L_t, \Pi_t^P, (a_{i,t}, c_{i,t}, l_{i,t}, \nu_{i,t})_{i \geq 0})} W_0, \quad (53)$$

$$\text{s.t. } \tau_t^K, \tau_t^L, B_t \text{ following the fiscal rules (50)–(52),} \quad (54)$$

and subject to: the governmental budget constraint (48), the household budget constraint (45), the household credit constraint (46), the Euler equation on consumption (47), the FOC on labor (18) – which is unchanged, the Phillips curve (7), the market clearing condition (49), the labor market clearing condition (19), the fund no-profit condition (42), the no-arbitrage condition (43), and the post-tax rate definitions (9) and (44).

Constraints (54) imply that the dynamics of tax rates are exogenous. This is the main difference with Section 3: taxes cannot be adjusted over the business cycle to implement the optimal post-tax real wage and interest rate. For this reason, there is room for inflation to be used to redistribute wealth across agents and to provide insurance against aggregate shocks. Since the algebra to determine the optimal inflation rate with fixed tax rates is more involved than in Section 3, we focus here solely on the intuitions about the trade-offs for the inflation rate. We formally derive all FOCs in Appendix S.3.2.

Deriving the FOCs of the planner for the choice of  $\Pi_t^P$  allows one to identify three mechanisms:

1. Changing inflation can affect the real wage due to the Phillips curve, which can be useful as an indirect tool to transfer resources across households.
2. Unexpected inflation specifically reduces the real return on public debt, which reduces the return on the fund and decreases real interest payments by the government.
3. Inflation destroys resources due to the adjustment cost.

These effects can be identified analytically from the program of the planner. We use the following notation:  $\mu_t$  denotes the Lagrange multiplier on the relevant expression of the government budget constraint,  $\gamma_t$  the Lagrange multiplier of the New-Keynesian Phillips curve (7),  $\Gamma_t$  the Lagrange multiplier on the no-profit condition of the fund (42), and  $\Upsilon_t$  the Lagrange multiplier on the

no-arbitrage condition (43). With this notation, the FOC on inflation can be written as follows:

$$\begin{aligned}
\underbrace{\mu_t \kappa (\Pi_t^P - 1)}_{\text{Marginal cost of inflation}} &= \underbrace{(\gamma_{t-1} - \gamma_t)(2\Pi_t^P - 1)}_{\substack{\text{Manipulation of real wage} \\ \text{with NK Phillips curve}}} \\
&- \underbrace{\beta^{-1} \Upsilon_{t-1} \frac{\tilde{R}_{t-1}^N}{Y_t (\Pi_t^P)^2}}_{\text{Change in the nominal interest rate}} + \underbrace{\Gamma_t (1 - \tau_t^K) B_{t-1} \frac{\tilde{R}_{t-1}^N}{Y_t (\Pi_t^P)^2}}_{\text{Change in the fund interest rate}}.
\end{aligned} \tag{55}$$

Equation (55) sets the marginal cost of inflation (on the left hand side) equal to its marginal benefits (right hand side). The marginal cost of higher inflation is simply related to the destruction of output, proportional to the parameter  $\kappa$ . This marginal cost is zero in the absence of inflation ( $\Pi_t^P = 1$ ). The marginal benefits include three effects that stem from the modification of prices. First, a change in the inflation rate affects the real wage rate through the NK Phillips curve (“manipulation of real wage”). Second, it also affects the level of the nominal interest through the no-arbitrage condition of the fund. Third, inflation also modifies the interest rate of the fund (which is the financial return for households) through the no-profit condition of the fund. This effect is proportional to the size of public debt, which drives how much the nominal interest matters for the return of the fund. The redistributive effects of these price changes are captured by the Lagrange multipliers.

Decreasing the fund interest rate relaxes the fund’s no-profit constraint proportionally to its Lagrange multiplier  $\Gamma_t$ . The expression of  $\Gamma_t$  is  $\Gamma_t = \mu_t - \frac{1}{A_{t-1}} \int_i (\psi_{i,t} a_{i,t-1} + \lambda_{i,t-1} u'(c_{i,t})) \ell(di)$  (see equation (S.17) in Appendix S.3.2). So, decreasing the fund interest rate relaxes the governmental budget constraint (valued with the multiplier  $\mu_t$ ), and generates redistribution across agents in proportion to their beginning-of-period wealth (term  $\int \psi_{i,t} a_{i,t-1} di$ ); it also affects their saving incentives via the Lagrange multiplier  $\lambda_i$  of the Euler equation (term  $\int \lambda_{i,t-1} u'(c_{i,t}) di$ ). These two last terms are negative because we consider a decrease in the interest rate. The other multipliers  $\gamma_t$  and  $\Upsilon_{t-1}$  have similar interpretations, which are slightly more involved because of general equilibrium effects (see the FOCs of the Ramsey program in Appendix S.3.2)

#### 4.4 Simulating the model: The truncation representation

The Ramsey problem of Section 4.3 cannot be solved with simple simulation techniques. Indeed, the Ramsey equilibrium is now a joint distribution across wealth and Lagrange multipliers, which is a high-dimensional object. The steady-state value of the set of Lagrange multipliers is not easy to find, and the planner’s instruments depend on the dynamics of this joint distribution. For this reason, we use the truncation method of LeGrand and Ragot (2022a) to determine the

joint distribution of wealth and Lagrange multipliers.<sup>13</sup> The accuracy of optimal policies found with this method has been further analyzed in LeGrand and Ragot (2023), for both the steady state and the dynamics.

#### 4.4.1 The uniform truncation method

The intuition of the method can be summarized as follows. In heterogeneous-agent models, agents differ according to their idiosyncratic history. An agent  $i$  has a period- $t$  history  $y_i^t = \{y_{i,0}, \dots, y_{i,t}\}$ . Let  $h = (\tilde{y}_{-N+1}, \dots, \tilde{y}_{-1}, \tilde{y}_0)$  be a given history of length  $N$ . In period  $t$ , an agent  $i$  is said to have *truncated history*  $h$  if the history of this agent for the last  $N$  periods is equal to  $h = \{y_{i,t-N+1}, \dots, y_{i,t}\}$ . The idea of the truncation method is to aggregate agents having the same truncated history and to express the model using these groups of agents rather than individuals. This generated the so-called *truncated model*, which features a finite state space. The “true” Bewley model features wealth heterogeneity among the agents having the same truncated history  $h$ . This simply comes from the heterogeneity in histories prior to the aggregation period (i.e., more than  $N$  periods ago). We capture this within-truncated-history heterogeneity through additional parameters – denoted by “ $\xi$ s” – which are truncated-history specific. This construction yields a finite state-space representation, which is exogenous to agents’ choices and thereby allows one to compute optimal policies.<sup>14</sup> The details of the truncated model can be found in Appendix S.4.

To find the steady-state values of the Lagrange multipliers, we use the same algorithm as in LeGrand and Ragot (2022a):

1. Set a truncation length  $N$  and guess values for the planner’s instruments.
2. Solve the steady-state allocation of the full-fledged Bewley model with the previous instrument values, using standard techniques.
3. Consider the truncated representation of the economy for a truncation length  $N$ .
  - (a) Solve for the joint distribution of wealth and Lagrange multipliers.
  - (b) Use the Ramsey FOCs to check whether the values of instruments are above or below their optimal value.
4. Change the instruments’ values accordingly (or stop if their value is close enough to the optimal value), and redo the process from Step 2.
5. Increase the truncation length  $N$ , and restart from Step 2 until increasing  $N$  has no impact on the instruments’ values.

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<sup>13</sup>Optimizing on simple rules in the spirit of Krusell and Smith (1998) is also hard to implement, as the shape of inflation is highly non-linear.

<sup>14</sup>Considering wealth bins is not possible, as the savings function and thus the transitions across wealth bins is endogenous to the planner’s policy. This would imply a fixed point which would be very hard to solve.

We analyze optimal monetary policy with a given fiscal policy. This greatly simplifies the process, as it is known that the optimal gross inflation rate is  $\Pi^P = 1$ . As a consequence, using the previous procedure it is very fast to compute the joint distribution of wealth and Lagrange multipliers.

To use our truncation method in the presence of aggregate shocks, we further assume that:

1. The parameters  $(\xi_h)_h$  remain constant and equal to their steady-state values.
2. The set of credit-constrained histories is time-invariant.

We thus assume that the time-variation of within-history heterogeneity is small enough for it to have only a second-order effect. In addition, we assume that the aggregate shock is small enough for the set of credit-constrained histories not to change in the dynamics. Both assumptions rely on the choice of the truncation length and can be checked numerically.

#### 4.4.2 The refined truncation method

The previous truncation method is simple to implement, but it has the drawback that it considers many histories, some of which are very unlikely to be experienced by agents. By the law of large numbers, these histories concern a very small number of agents. For instance, for a truncation length of  $N = 5$  used below, our calibration implies that many histories have a size smaller than  $10^{-6}$ . The idea in LeGrand and Ragot (2022b) is to consider different truncation lengths for different histories. For the sake of clarity, we will call this method the *refined* truncation, while the former one will be called the *uniform* truncation. Histories more likely to be experienced (i.e., with a bigger size) can be “refined”, which means that they can be substituted by a set of histories with higher truncation lengths. For instance, the truncated history  $(y_1, y_1)$  ( $N = 2$ ) can be refined into  $\{(y, y_1, y_1) : y \in \mathcal{Y}\}$ , where the group of agents who have been in productivity  $y_1$  for two consecutive period is split into  $Card\mathcal{Y}$  truncated histories.

A benefit of this construction is that the number of histories is a *linear* function of the maximum truncation length, instead of an exponential function. The construction of the refined method is detailed in LeGrand and Ragot (2022b). A difficulty of this construction is that the set of refined histories must form a well-defined partition of the set of idiosyncratic histories in each period. To keep the exposition simple, we solve the model with a uniform truncation method, and only use the refinement in Section 5.5 as a robustness check.

## 5 Quantitative assessment of the sticky-price model

### 5.1 The calibration and steady-state distribution

**Preferences.** The period is a quarter. The discount factor is  $\beta = 0.99$ , and the period utility function is:  $\log(c) - \chi^{-1} \frac{l^{1+1/\varphi}}{1+1/\varphi}$ .<sup>15</sup> The Frisch elasticity of labor supply is set to  $\varphi = 0.5$ , which is the value recommended by Chetty et al. (2011) for the intensive margin in heterogeneous-agent models. The scaling parameter is  $\chi = 0.076$ , to obtain an aggregate labor supply of roughly 1/3.

**Technology and TFP shock.** The production function is Cobb-Douglas:  $Y = ZK^\alpha L^{1-\alpha}$ . The capital share is set to  $\alpha = 36\%$  and the depreciation rate to  $\delta = 2.5\%$ , as in Krueger et al. (2018) among others. The TFP process is a standard AR(1) process, with  $Z_t = \exp(z_t)$  and  $z_t = \rho_z z_{t-1} + \varepsilon_t^z$ , where  $\varepsilon_t^z \stackrel{\text{iid}}{\sim} \mathcal{N}(0, \sigma_z^2)$ . We use the values  $\rho_z = 0.95$  and  $\sigma_z = 0.31\%$  to obtain a standard deviation of the TFP shock  $z_t$  equal to 1% at a quarterly frequency (see Den Haan, 2010, for instance).

**Idiosyncratic risk.** We use a productivity process:  $\log y_t = \rho_y \log y_{t-1} + \varepsilon_t^y$ , with  $\varepsilon_t^y \stackrel{\text{iid}}{\sim} \mathcal{N}(0, \sigma_y^2)$ . We calibrate a persistence of the productivity process  $\rho_y = 0.99$  and a standard deviation of  $\sigma_y = 12.3\%$ . These values are consistent with empirical evidence (Krueger et al., 2018). This process generates a realistic empirical pattern for wealth. The Gini coefficient of the wealth distribution amounts to 0.73, while the model implies an average annual capital-to-GDP ratio of 2.5. These two values are in line with their empirical counterparts. Finally, the Rouwenhorst (1995) procedure is used to discretize the productivity process into 5 idiosyncratic states with a constant transition matrix.

**Fiscal system.** The steady-state parameters of the fiscal rules are calibrated based on the computations of Trabandt and Uhlig (2011), who use the methodology of Mendoza et al. (1994) on public finance data prior to 2008. This approach consists in computing a linear tax on capital and on labor, as well as lump-sum transfers that are consistent with the governmental budget constraint. Their estimations for the US in 2007 yield a capital tax (including both personal and corporate taxes) of 36%, a labor tax of 28% and lump-sum transfers equal to 8% of the GDP. We then consider the steady-state values  $(\tau_*^L, \tau_*^K, T_*/GDP) = (28\%, 36\%, 8\%)$ . This steady-state fiscal system generates two untargeted outcomes. First, it implies a public debt-to-GDP ratio equal to 63.5%, which is very close to the value of 63% estimated by Trabandt and Uhlig (2011). Second, it also implies a public spending-to-GDP ratio equal to 12.1%. This value is consistent with other quantitative investigations (Bhandari et al., 2017), even though a little

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<sup>15</sup>Note that matching the data constrains the Intertemporal Elasticity of Substitution (IES) parameter. Considering a log utility, we can match a Gini coefficient of wealth of 0.73 close to its empirical counterpart of 0.77. Considering a CRRA function  $u(c) = \frac{c^{1-\sigma}}{1-\sigma}$  with  $\sigma = 2$  reduces the Gini coefficient to 0.57. A higher value of  $\sigma$  decreases the Gini coefficient, as agents save more to self-insure.

bit low compared to the postwar value, which has decreased to 14.1% in 2017, from 17% in the 1970s.

Considering the dynamic part of the fiscal system, we implement the fiscal rules of equations (50)–(52). Tax rates are constant and equal to their steady-state values. The two parameters,  $\sigma^T$  and  $\sigma^B$ , of the rule à la Bohn characterize how the lump-sum tax reacts to aggregate shocks and public debt. To set them, we use two constraints. First, we impose that a negative TFP shock of 1% implies an average increase of debt over GDP of 2%, which lies in the range estimated by Kim and Zhang (2021) for developed countries. Second, we also set a rule that ensures a stationary path for public debt. We obtain that our fiscal rule is characterized by the parameters  $(\sigma^T, \sigma^B) = (8.5, 4.0)$ .

**Monetary parameters.** We follow the literature and assume that the elasticity of substitution across goods is  $\varepsilon = 6$  and the price adjustment cost is  $\kappa = 100$  (see Bilbiie and Ragot, 2021, for a discussion and references). This implies a slope of the quarterly Phillips curve of 5%, or an average price duration of 5 quarters in the corresponding Calvo model. Indeed, the slope is  $(\varepsilon - 1)/\kappa$  in the Rotemberg model and it is  $(1 - \theta)(1 - \beta\theta)/\theta$  in the Calvo model, where  $1/(1 - \theta)$  is the average price duration (Galí, 2015). We further discuss the calibration of slope values in Section 5.4. Table 1 provides a summary of the model parameters.

**Steady-state equilibrium distribution.** We first simulate the full-fledged Bewley model (i.e., without aggregate shocks) with the steady-state optimal inflation rate  $\Pi^P = 1$ . In Table 2, we report the wealth distribution generated by the model and compare it to the empirical distribution. We compute a number of standard statistics – listed in the first column – including the quintiles, the Gini coefficient, and Top 5% property.

The empirical wealth distribution reported in the second and third columns of Table 2 is computed using two sources, the PSID for the year 2006 and the SCF for the year 2007 (see LeGrand and Ragot, 2022a). The fourth column reports the wealth distribution generated by our model. The Gini coefficient of the model is 0.73, whereas it is 0.77 in the data. The model reproduces well the bottom of the distribution, but doesn’t do as well for the very top. It is known that additional model features must be introduced to match the high wealth inequality in the US, such as heterogeneous discount rates, as in Krusell and Smith (1998), entrepreneurship, as in Quadrini (1999), or stochastic returns (Guvenen et al., 2023).

**Truncation.** We now construct the truncated model. We use a truncation length of  $N = 5$ , which with our 5 states, implies  $5^5 = 3125$  different truncated histories. We only focus on histories with positive size (some histories are never experienced if there is some zero probability to switch from one state to another), which reduces the number of histories to 727. LeGrand and Ragot (2022a), showed that in environments without nominal frictions, a small truncation

| Parameter                 | Description                    | Value |
|---------------------------|--------------------------------|-------|
| Preference and technology |                                |       |
| $\beta$                   | Discount factor                | 0.99  |
| $\sigma$                  | Curvature utility              | 1     |
| $\alpha$                  | Capital share                  | 0.36  |
| $\delta$                  | Depreciation rate              | 0.025 |
| $\bar{a}$                 | Credit limit                   | 0     |
| $\chi$                    | Scaling param. labor supply    | 0.076 |
| $\varphi$                 | Frisch elasticity labor supply | 0.5   |
| Shock process             |                                |       |
| $\rho_z$                  | Autocorrelation TFP            | 0.95  |
| $\sigma_z$                | Standard deviation TFP shock   | 0.31% |
| $\rho_y$                  | Autocorrelation idio. income   | 0.99  |
| $\sigma_y$                | Standard dev. idio. income     | 12.3% |
| Tax system                |                                |       |
| $\tau_*^K$                | Capital tax                    | 36%   |
| $\tau_*^L$                | Labor tax                      | 28%   |
| $T_*$                     | Transfer over GDP              | 8%    |
| Monetary parameters       |                                |       |
| $\kappa$                  | Price adjustment cost          | 100   |
| $\varepsilon$             | Elasticity of sub.             | 6     |

Table 1: Parameter values in the baseline calibration. See text for descriptions and targets.

length can yield accurate results, thanks to the introduction of the  $\xi$  parameters accounting for within-bin heterogeneity, as explained in Section 4.4.1. In Section 5.5, we show that this is also true in the current setup and use the refined truncation as a robustness check.

## 5.2 Optimal inflation dynamics

We simulate the model after a transitory negative TFP shock of one standard deviation. In period 0, we assume that the economy and the various Lagrange multipliers are initialized to their steady state values. The simulations thus involve a timeless perspective, and the economy will eventually go back to its steady state. We compare the outcomes of three economies. The fiscal system is common to the three economies and features constant marginal tax rates as detailed above. The three economies differ in their monetary policies. In the benchmark economy (labeled Economy 1), monetary policy is optimally set. In the second economy (Economy 2), the inflation path remains constant at  $\Pi_t^P = 1$  for all  $t$ . Indeed, as noted in Bhandari et al. (2021), this constant path corresponds to the optimal inflation path for a complete market economy with a TFP shock,

| Wealth statistics | Data     |         | Model |
|-------------------|----------|---------|-------|
|                   | PSID, 06 | SCF, 07 |       |
| Q1                | -0.9     | -0.2    | 0.0   |
| Q2                | 0.8      | 1.2     | 0.2   |
| Q3                | 4.4      | 4.6     | 5.2   |
| Q4                | 13.0     | 11.9    | 18.2  |
| Q5                | 82.7     | 82.5    | 76.4  |
| Top 5%            | 36.5     | 36.4    | 33.2  |
| Gini              | 0.77     | 0.78    | 0.73  |

Table 2: Wealth distribution in the data and in the model.

due to the “divine coincidence” identified by Woodford (2003). Finally, in the third economy (Economy 3), monetary policy is implemented via a Taylor Rule.<sup>16</sup> Comparing Economies 1 and 2 helps us identify the contribution of market incompleteness to the optimal inflation dynamics, while comparing Economies 1 and 3 helps us to identify the contribution of the optimal policy in reducing inflation volatility. We report in Figure 1 the Impulse Response Functions (IRFs thereafter) for key variables of the three economies, which all start from their steady state value in period 0 (i.e., timeless perspective). In panel 10, wage inflation is defined as the growth rate of the nominal wage, computed using real wage and the price level:  $\Pi_t^W = \frac{w_t P_t}{w_{t-1} P_{t-1}} = \Pi_t^P \frac{w_t}{w_{t-1}}$ .

First, price inflation (panel 9, reported with a quarterly basis) in Economy 1 moves slightly on impact and then decreases to converge back to its steady-state value. However, the variations are quantitatively modest and inflation volatility is low. The absolute maximum change in the quarterly inflation rate amounts to 0.02%. Since the inflation movements are small in magnitude, the differences between the allocations of Economies 1 and 2 (i.e., optimal inflation rate vs.  $\Pi_t^P = 1$ ) are also small. Regarding the fiscal dimension, tax rates are constant by construction and the elasticity of public debt over GDP to TFP can be verified to be around  $-2$ : a fall of TFP by one standard deviation increases public debt ratio by 0.6%. The comparison of Economies 1 and 2 allows us to check that the optimal inflation path provides some insurance against aggregate risk. This will be more clearly detailed in Section 5.3 through welfare comparisons. In Economy 3, the Taylor rule leads to a slight overreaction of inflation that decreases more than with optimal policy. This implies that the drop in GDP is lower and more persistent than in Economy 1. However, the effects are small due to the limited magnitude of the overreaction. Overall, these results are consistent with those of Bhandari et al. (2021), but exhibit lower inflation volatility, due to a different calibration strategy. Indeed, as we verify in Appendix S.5

<sup>16</sup>The functional form of the Taylor rule connecting the pre-tax nominal gross rate  $\tilde{R}_t^N$  to inflation is standard:  $\frac{\tilde{R}_t^N}{\tilde{R}^N} = \left(\frac{\Pi_t^P}{\Pi^P}\right)^{\phi_\Pi}$ , where  $\tilde{R}^N$  and  $\Pi^P$  are steady-state values and  $\phi_\Pi$  is the response of the nominal interest rate to inflation. We set  $\phi_\Pi = 1.5$ , which is also a standard value in the literature (see Galí, 2015).

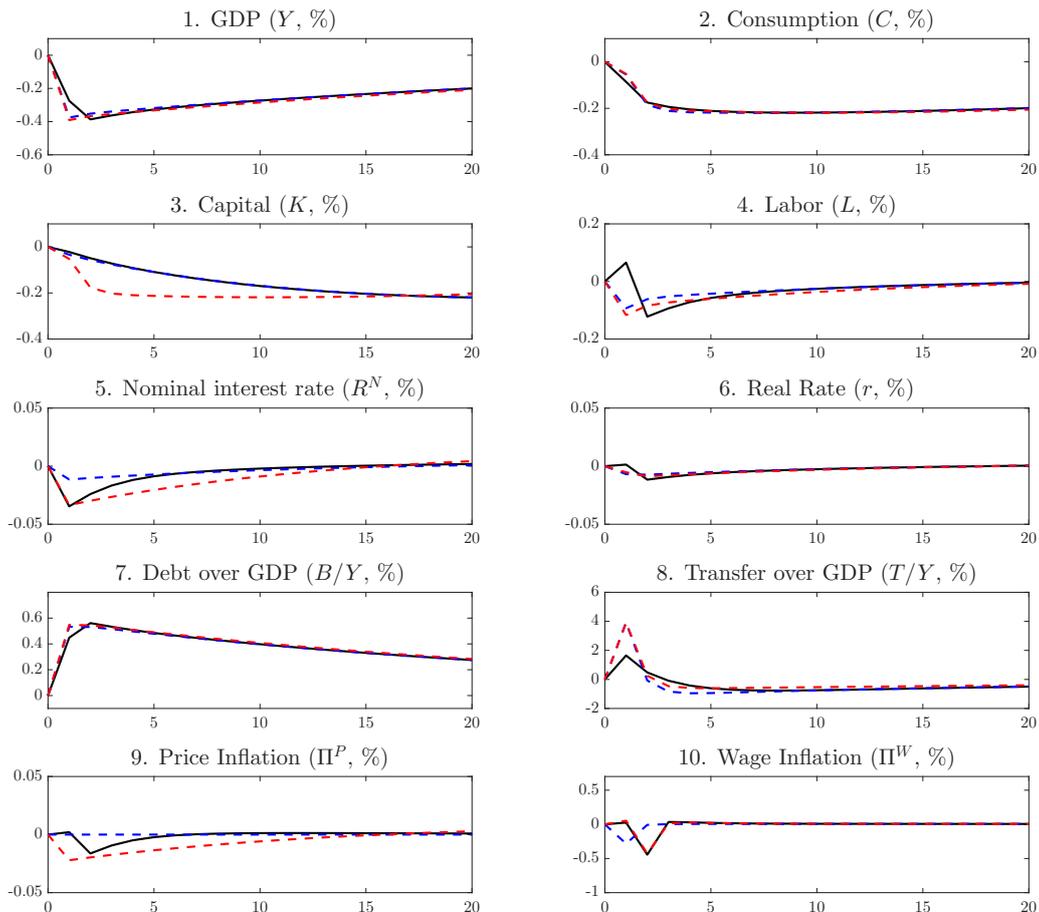


Figure 1: IRFs in percentage points after a negative productivity shock of one standard deviation for relevant variables. The black line is the benchmark economy with optimal monetary policy. The blue dashed line is Economy 2, where we impose  $\Pi_t^P = 1$ . The red dashed line is Economy 3, where monetary policy follows a Taylor rule.

below, the inflation response is quantitatively sensitive to assumptions about the slope of the Phillips curve and the distribution of profits. A steeper Phillips curve and profit distribution more tilted toward low-productivity agents contribute to magnifying the inflation response. We provide second-order moments of these three economies in Appendix S.4.6. They confirm that the differences between the three economies are small and that the volatility of consumption is slightly smaller under the optimal monetary policy.

### 5.3 Welfare comparison

We further investigate the differences between Economies 1 and 2 by computing the welfare gap in terms of consumption equivalents between the two economies. The welfare gap is defined as the constant percentage increase in consumption of Economy 1 (with optimal policy), for the intertemporal welfare of Economy 1 with increased consumption to match the one of Economy

2. Formally, using the utilitarian social welfare function (21), the welfare gap  $\Delta$  is defined as:

$$\mathbb{E}_0 \left[ \sum_{t=0}^{\infty} \beta^t \int_i \left( u((1 + \Delta)c_{i,t}^{(1)}) - v(l_{i,t}^{(1)}) \right) \ell(di) \right] = \mathbb{E}_0 \left[ \sum_{t=0}^{\infty} \beta^t \int_i \left( u(c_{i,t}^{(2)}) - v(l_{i,t}^{(2)}) \right) \ell(di) \right], \quad (56)$$

where the superscripts (1) and (2) refer to the allocation of Economies 1 and 2, respectively. Since the optimal policy is welfare-improving by definition, we expect the welfare gap to be positive:  $\Delta > 0$ .

In our environment, and following the discussions of Dyrda and Pedroni (2022) and Bhandari et al. (2023), this computation of welfare gaps captures insurance effects against aggregate risk. Indeed, we compute welfare gaps simulating the effect of two policies in the same economy, starting from the same steady state and hit by the same shocks. The fiscal policies do not change the steady state, and do not implement permanent transfers across agents. As a consequence, the welfare gaps come from the ability of the different policies to provide insurance against aggregate risks.<sup>17</sup>

To better analyze the insurance property, we can condition the welfare gaps on the productivity of each agent. We thus compute the welfare gap  $\Delta_y$  ( $y \in \mathcal{Y}$ ) conditional on an initial productivity level  $y$  as follows:

$$\mathbb{E}_0 \left[ \sum_{t=0}^{\infty} \beta^t \int_i \left( u((1 + \Delta_y)c_{i,t}^{(1)}) - v(l_{i,t}^{(1)}) \right) 1_{y_{i,0}=y} \ell(di) \right] = \mathbb{E}_0 \left[ \sum_{t=0}^{\infty} \beta^t \int_i \left( u(c_{i,t}^{(2)}) - v(l_{i,t}^{(2)}) \right) 1_{y_{i,0}=y} \ell(di) \right], \quad (57)$$

where  $1_{y_{i,0}=y} = 1$  if the initial state  $y_{i,0}$  is  $y$  and 0 otherwise. Consistently with the timeless perspective, we implement this welfare comparison assuming that the economy starts from the steady-state distribution. We then simulate the economy for 10,000 periods with 10 different realizations of the aggregate shock path. The intertemporal welfare gaps are computed as an average over these realizations, where we track agents with a given initial productivity level (which then evolves according to the stochastic process for idiosyncratic risk). As discussed above, the difference in the welfare gaps according to the initial productivity level should be understood as a decomposition of the aggregate gaps of insurance across initial types.

We find that implementing the optimal monetary policy – measured as the welfare gap between Economies 1 and 2 – generates an average welfare gain of 0.002%. This small value can be expected from Figure 1 and from the second-order moments of Table S.4. However, this value hides heterogeneity among productivity levels, as can be seen in Figure 2, which plots the welfare gaps between Economies 1 and 2 for different productivity levels. If all productivity levels experience a positive welfare gain due the optimal monetary policy, the lower the productivity,

---

<sup>17</sup>Following Floden (2001) and Benabou (2002), the literature has often decomposed the total welfare gap into three effects: a level effect, an insurance effect, and distributive effects. As we do not consider transitions starting from an initial distribution (as Bhandari et al., 2023, or Dyrda and Pedroni, 2022), we only consider the insurance effects.

the more the agents benefit from the optimal policy. Low productive agents they enjoy a higher reduction in consumption volatility, while more productive agents are able to self-insure, which reduces the welfare gains of optimal policy.

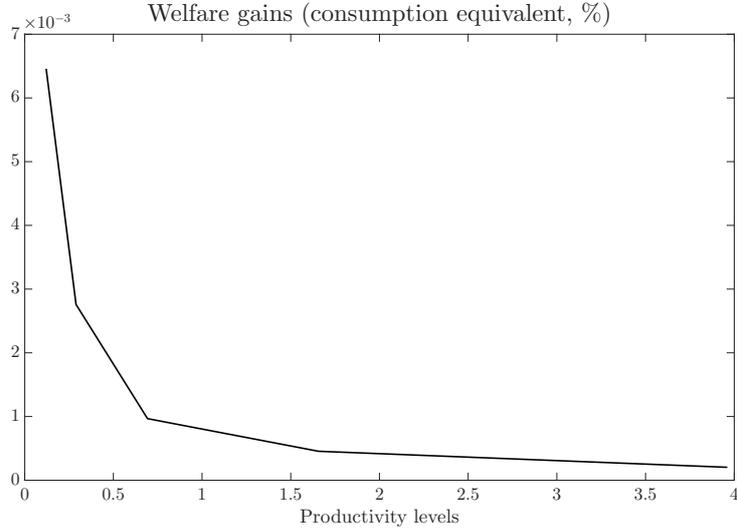


Figure 2: Welfare gains by productivity level associated to optimal monetary policy. The welfare gains are computed using equation (57).

#### 5.4 Understanding the mechanisms

**Slope of the Phillips curve.** The recent empirical literature offers a wide range of estimates for the price adjustment cost and the implied slope of the Phillips curve. We present these alternative values in Appendix S.5.1, where we consider slopes varying from the low level of 0.62% of Hazell et al. (2022) to the high one of 23% of Barnichon and Geert (2020). These two values correspond to average price durations in the Calvo model of 14.0 and 2.7 quarters, respectively. The deviation from price stability is small in any case, and nominal wage moves to adjust the real wages.

**Role of the distribution of profits.** As our analysis adds new ingredients to the existing literature (namely binding credit constraints, capital accumulation, a mutual fund, timeless perspective, and the resolution via the truncation method), we now investigate how our results compare to those of Acharya et al. (2023), Bhandari et al. (2021), or Nuño and Thomas (2022), among others. A first difference is that we consider a timeless perspective and not a time-0 program. As explained in Nuño and Thomas (2022), inflation deviation after a TFP shock is larger in a period-0 problem compared to a timeless perspective, as the planner can surprise agents with an increase in inflation in period 0, to redistribute wealth across agents.

However, some papers, such as Bhandari et al. (2021), find that inflation can sizably increase

after a TFP shock in an environment with exogenous fiscal policy, which is immune to the time-0 inconsistency. To understand these results and the role of time-varying fiscal policy, we analyze various models in Appendix S.5. First, we consider (Section S.5.2) a simple model, with only two types of agents (called TANK model in the literature). It allows us to identify the key determinants driving the inflation response, which are an unequal profit distribution, a high slope of the Phillips curve, the absence of exogenous time-varying fiscal policy, and to a lesser extent, a low IES of agents. An additional gain of the simple model is that it can be easily related to the quantitative model, with a small truncation length ( $N = 1$ ).

Second, we verify (Section S.5.3) that the factors identified in the simple model remain valid in a quantitative model (similar to the one of Section 5). This therefore reconciles our results with those of the literature and confirms that the small inflation volatility of Section 5 is not driven by the introduction of the fund nor by the truncation method.

## 5.5 Numerical robustness

The previous simulations were based on a truncation length of  $N = 5$ . As explained in Section 4.4.2, we now use LeGrand and Ragot (2022b) to consider heterogeneous truncation lengths. We set the truncation length  $N_{\max} = 20$  for the histories with the largest size. The results are provided in Appendix S.4.7. They are very similar to the results with the uniform truncation method. In particular, the volatility of aggregate variables remain almost unchanged, while the inflation volatility stays very low.

Finally, we also compare the simulation outcomes of the truncation method to those of the histogram method developed by Rios-Rull (1999), Reiter (2009), and Young (2010), which is standard for solving heterogeneous-agent models. We simulate the model calibrated with the previous values, assuming no public spending using the histogram and truncation methods. We then compare their IRFs, their second-order moments, as well as average and maximum absolute differences. The results are reported in Appendix S.6 and appear to be very close.

## 5.6 Considering constrained-optimal fiscal policy

As a final robustness check, we also simulate the model for a constrained optimal fiscal policy, in which some fiscal tools are fixed in the dynamics, whereas other tools are optimally set. To do so, we assume that the planner considers an aggregate welfare criterion with social weights that are history-specific. This allows us to construct a steady state Ramsey allocation, whose (optimal) fiscal policy is equal to the previous calibration. We can then compute the optimal dynamics around this steady state. More specifically, we consider a general welfare function that places weights on the utility of each agent. For the sake of generality, we assume that these weights are consistent with the sequential representation and depend on initial conditions and an idiosyncratic history. The weight of agent  $i \in \mathcal{I}$  at date  $t$  is  $\omega_{i,t} := \omega_t(y_i^t)$ , and the weights

satisfy  $1 = \int_i \omega_{i,t} \ell(di) = \sum_{y_i^t \in \mathcal{Y}^t} \omega_t(y_i^t) \theta_t(y_i^t)$  for  $t \geq 0$ . These history-dependent weights are also used by McKay and Wolf (2023) and Dávila and Schaab (2025). Formally, the aggregate welfare criterion can be expressed as follows:

$$W_0 = \mathbb{E}_0 \left[ \sum_{t=0}^{\infty} \beta^t \int_i \omega_t(y_i^t) U(c_{i,t}, l_{i,t}) \ell(di) \right]. \quad (58)$$

Following the inverse optimal taxation approach, we estimate the social weights such that the observed US fiscal system is optimal at the steady state. We then solve for the optimal inflation and fiscal policy holding the capital tax constant or the labor tax constant. We find that the optimal inflation rate is almost constant, with a standard deviation of 0.01% (on a quarterly basis), confirming the result that the volatility of inflation is low when fiscal policy is partly time-varying. The details of the algebra and of the resolution can be found in Section S.7.

## 6 The sticky-wage economy

We now turn to the analysis of the economy with sticky wages, instead of sticky prices. The sticky-wage rigidity is another nominal rigidity studied in the literature, which has both empirical and theoretical supports (see e.g., Chugh, 2006 or Nekarda and Ramey, 2020 and references therein). For the sake of conciseness, we focus here solely on an economy with a mutual fund, constant tax rates and a rule à la Bohn for public debt. This economy is the benchmark economy that is called Economy 1 in Section 5.2, but with sticky wages instead of sticky prices. It corresponds to the environment described in Section 4. The remainder of this section is organized as follows. In Section 6.1, we present the specificities of the sticky-wage environment compared to the previous setup. In Section 6.2, we derive the FOCs of the Ramsey problem in the sticky-wage economy. In Section 6.3, we present the calibration we use. Finally, in Section 6.4, we present the quantitative outcomes of the model and discuss how they compare to those of the sticky-price model.

### 6.1 The sticky-wage model

Our economy models sticky wages as in the model of wage bargaining of Erceg et al. (2000), which is commonly used in the heterogeneous-agent literature (e.g., Hagedorn et al., 2019, Alves and Violante, 2025 or Auclert et al., 2024). In this model, a continuum of unions of size 1 monopolistically supply labor. These union-specific labor supplies are then pooled together via a competitive aggregator with a constant elasticity of substitution  $\varepsilon_W$ . Each union  $k$  sets its wage  $W_{kt}$  so as to maximize the intertemporal welfare of its members. The adjustment of the nominal wage implies a quadratic utility cost that is proportional to the parameter  $\psi_W$ , as in Auclert et al. (2024). We focus on the symmetric equilibrium where all unions choose to set the same

wage  $W_t$ , hence all households work the same number of hours denoted  $L_t$ . This construction involves the following wage Phillips curve:

$$\Pi_t^W (\Pi_t^W - 1) = \frac{\varepsilon_W}{\psi_W} \underbrace{\left( v'(L_t) - \frac{\varepsilon_W - 1}{\varepsilon_W} w_t \int_i y_{i,t} u'(c_{i,t}) \ell(di) \right)}_{\text{labor gap}} L_t + \beta \mathbb{E}_t \left[ \Pi_{t+1}^W (\Pi_{t+1}^W - 1) \right], \quad (59)$$

where  $\Pi_t^W = \frac{W_t}{W_{t-1}}$  is the wage inflation, and  $w_t$  the real post-tax wage. The details of the derivation of the wage Phillips curve can be found in Appendix S.9. In equation (59), the *labor gap* term captures the market power of unions that prevents the marginal disutility of labor,  $v'(L_t)$ , from equalling its marginal benefit. The latter is the sum over all agents of the hourly wage (in efficient units)  $w_t y_{i,t}$  multiplied by the marginal utility of consumption ( $u'(c_{i,t})$ ). Labor supplies of the different unions are imperfect substitutes, which is captured by the term  $\frac{\varepsilon_W - 1}{\varepsilon_W}$ . When the labor gap is positive, the unions progressively increase wages (due to the wage-adjustment cost), which generates inflationary pressure and contributes to reducing the labor gap. In addition to the labor gap, current wage inflation also depends on expected wage inflation, as is standard in the New-Keynesian literature.

A consequence of this sticky-wage modelling is that agents do not optimally choose their labor supply. The household's budget constraint (45) becomes:  $a_{i,t} + c_{i,t} = (1 + r_t) a_{i,t-1} + w_t y_{i,t} L_t + T_t$ , where  $r_t$  is the fund interest rate that is defined as in Section 4.1 (equations (42)–(44)). The Euler equation (47) is unchanged, but the labor FOC (29) now does not hold. Regarding the production side, firms no longer face quadratic price-adjustment costs. Factor prices now verify the following standard definitions:

$$\tilde{r}_t + \delta = \alpha Z_t \left( \frac{K_{t-1}}{L_t} \right)^{\alpha-1} \text{ and } \tilde{w}_t = (1 - \alpha) Z_t \left( \frac{K_{t-1}}{L_t} \right)^{\alpha}. \quad (60)$$

It is worth noting that in this model with sticky wages, profits are acyclical. As a result, the distribution of profits, discussed in Section 5.4, plays no role in this environment. Admittedly, alternative models of wage rigidity may generate cyclical profits. If sticky wages were to produce pro-cyclical profits, monetary policy would have an incentive to generate less inflation during recessions in order to provide more insurance to poorer agents, who rely primarily on labor income. We treat acyclical profits as a useful benchmark, given that the empirical literature remains inconclusive on this issue (Nekarda and Ramey, 2020 among others).

## 6.2 The Ramsey problem

As in the sticky-price economy, the Ramsey planner chooses the monetary-fiscal policy that maximizes the aggregate welfare criterion, while being consistent with individual optimal choices.

The aggregate welfare criterion now includes the utility cost of wage inflation:

$$W_0 = \mathbb{E}_0 \left[ \sum_{t=0}^{\infty} \beta^t \int_i (u(c_t^i) - v(L_t)) \ell(di) - \frac{\psi_W}{2} (\Pi_t^W - 1)^2 \right]. \quad (61)$$

The fiscal policy follows the fiscal rules of Section 4.2. Labor and capital tax rates are constant, while public debt follows the Bohn rule of equation (52). The lump-sum transfers  $T_t$  is then determined by the government budget constraint, which still verifies equation (48), but with the price adjustment cost set to zero:  $\kappa = 0$ . Monetary policy is now composed of three variables: the nominal rate  $\tilde{R}_t^N$ , wage inflation  $\Pi_t^W$ , and price inflation  $\Pi_t^P$ . Price inflation is a consequence of wage inflation and real wage variations are  $\Pi_t^P = \frac{w_{t-1}}{w_t} \Pi_t^W$ . Formally, the Ramsey program can be written as follows:

$$\max_{(\Pi_t^P, \Pi_t^W, K_t, w_t, r_t, \tilde{R}_t^N, L_t, (c_{i,t}, a_{i,t}, \nu_{i,t})_i)_t} W_0, \quad (62)$$

$$G_t + B_{t-1} + r_t(B_{t-1} + K_{t-1}) + w_t L_t + T_t = B_t + Z_t K_{t-1}^\alpha L_t^{1-\alpha} - \delta K_{t-1}, \quad (63)$$

$$\text{for all } i \in \mathcal{I}: a_t^i + c_t^i = (1 + r_t) a_{t-1}^i + w_t y_t^i L_t + T_t, \quad (64)$$

$$a_t^i \geq -\bar{a}, \quad \nu_t^i(a_t^i + \bar{a}) = 0, \quad \nu_t^i \geq 0, \quad (65)$$

$$u'(c_t^i) = \beta \mathbb{E}_t [(1 + r_{t+1}) u'(c_{t+1}^i)] + \nu_t^i, \quad (66)$$

$$\Pi_t^W (\Pi_t^W - 1) = \frac{\varepsilon_W}{\psi_W} \left( v'(L_t) - \frac{\varepsilon_W - 1}{\varepsilon_W} w_t \int_i y_{i,t} u'(c_{i,t}) \ell(di) \right) L_t + \mathbb{E}_t \left[ \Pi_{t+1}^W (\Pi_{t+1}^W - 1) \right], \quad (67)$$

$$\Pi_t^P = \frac{w_{t-1}}{w_t} \Pi_t^W \quad (68)$$

together with the post tax-wage definition (9), the fund-related equations (42)–(44), the financial market clearing condition (49), the factor price definitions (60), the fiscal rules (50)–(52), the positivity constraints  $c_t^i, l_t^i \geq 0$ , and the initial conditions  $(a_{-1}^i)_{i \in \mathcal{I}}, B_{-1}$ .

The conditions of the program (62)–(68) are straightforward. Equation (S.4) is the budget of the government, expressed in post-tax terms. Equations (64)–(66) are the individual budget constraints, credit constraints, and individual Euler equations that guarantee that the chosen allocation is consistent with individual optimal choices. All these equations already appear in the Ramsey program with price-rigidity of Section 4.3. Equation (67) is the wage Phillips curve, which replaces the price Phillips curve of the sticky-price Ramsey program. Finally, equation (68) defines the price inflation that appears in the no-profit and no-arbitrage conditions of the fund.

As in the sticky-price economy, it is useful to introduce the concept of the *SVL* for agent  $i$

in a sticky-wage economy, which can be expressed as:

$$\begin{aligned} \psi_t^{SW,i} := & \underbrace{u'(c_t^i)}_{\text{direct effect}} - \underbrace{(\lambda_t^i - (1+r_t)\lambda_{t-1}^i) u''(c_t^i)}_{\text{effect on savings}} \\ & - \underbrace{\frac{\varepsilon_W - 1}{\psi_W} \gamma_t^W w_t L_t y_{i,t} u''(c_{i,t})}_{\text{effect on wage bargaining}}. \end{aligned} \quad (69)$$

The first two terms (“direct effect” and “effect on savings”) in equation (69) are identical to those of the sticky-price expression (see equation (S.13) in Appendix S.3.2). Indeed, changing consumption again has an effect on welfare and savings incentives. The main difference between the sticky-price and the sticky-wage cases is the effect on labor supply. In the sticky-price economy, the extra consumption of agent  $i$  directly affects their labor supply through the FOC on labor. In the sticky-wage economy, there is no such direct outcome as there is no optimal labor choice. However, the term “effect on wage bargaining” is an indirect outcome on the labor supply set by unions that operates through the labor gap of the wage Phillips curve. This explains why this effect is proportional to the Lagrange multiplier  $\gamma^W$ , which captures the welfare gain for the planner to change wage inflation.<sup>18</sup> The FOCs of the planner can be expressed using  $\psi_t^{SW,i}$  and are derived in Appendix S.9.3 for the sake of conciseness.

We now present a simple implementation result in the sticky-wage economy.<sup>19</sup>

**Result 1** (An implementation result). *There exists an allocation implementing zero wage inflation in an economy with exogenous fiscal rules.*

The previous result states the existence of an allocation with zero wage inflation with exogenous fiscal policy. The proof can be found in Appendix S.9.4. This zero-wage-inflation allocation is appealing. As wages are sticky but prices are not, the planner can reproduce any desired real wage dynamics by changing price inflation through monetary policy, while keeping nominal wages unchanged so as to avoid wage-adjustment cost. The zero-wage inflation would be optimal in the representative-agent economy with sticky wages (Chugh, 2006). In a heterogeneous-agent economy, this zero-wage inflation is not optimal because price inflation involves redistribution across agents, as it affects the nominal interest rate. However, as can be seen in the next section, this redistribution effect is quantitatively small, such that the planner indeed implements an allocation with a low wage inflation volatility and volatile price-inflation.

<sup>18</sup>This term does not contradict the fact that agents are atomistic for unions. Indeed, changing the consumption of a unique agent  $i$  implies the SVL of equation (69), but does not modify the wage: as the agent is of measure zero, it does not change the term  $\int_j y_{j,t} u'(c_{j,t}) \ell(dj)$  in the wage Phillips curve (67). However, the planner internalizes the fact that if the consumption of a positive mass of agents is changed, it will affect the wage through the bargaining process of unions.

<sup>19</sup>We could obtain a result similar to Proposition 1: the flexible wage allocation can be recovered when the fiscal system is sufficiently rich. However, since this would significantly lengthen the presentation, we choose to focus here on a result valid for exogenous fiscal rules.

### 6.3 The calibration

The calibration strategy is the same as in the sticky-price economy. We here discuss only those parameters that differ from the calibration values listed in Table 1 in Section 1. The fiscal rule is for instance unchanged. The new calibration parameters are reported in Table 3.

**Preferences.** The scaling parameter is now set to  $\chi = 0.061$ , so as to again match an aggregate labor supply of roughly  $\frac{1}{3}$ .

**Idiosyncratic risk.** We calibrate the productivity process with a persistence of  $\rho_y = 0.988$  and a standard deviation of  $\sigma_y = 0.154$ . We set these values so as to reproduce, as in the sticky-price economy, a steady-state wealth Gini index of 0.73 and an annual capital-to-GDP ratio of 2.5. The resulting values of  $\rho_y$  and  $\sigma_y$  are very close to those in the sticky-price economy.<sup>20</sup>

**Monetary parameters.** Following the literature and in particular Schmitt-Grohé and Uribe (2005), we assume that the elasticity of substitution is  $\varepsilon_W = 21$  across labor types. The wage adjustment cost is set to  $\psi_W = 2100$ , to obtain a slope of the wage Phillips curve equal 1%. As in the case of the price Phillips curve, the empirical literature offers a wide range of estimates for the slope of the wage Phillips curve. We show that this does not change our results in Appendix S.9.5.4. The price adjustment cost is set to  $\psi_P = 0$ .

| Parameter       | Description                     | Value | Target                             |
|-----------------|---------------------------------|-------|------------------------------------|
| $\chi$          | Scaling param. labor supply     | 0.061 | $L = 1/3$                          |
| $\rho_y$        | Autocorrelation idio. income    | 0.988 | Annual capital-to-GDP ratio of 2.5 |
| $\sigma_y$      | Standard dev. idio. income      | 15.4% | Gini of wealth of 0.73             |
| $\kappa$        | Price adjustment cost           | 0     | Slope of the price PC 0%           |
| $\varepsilon_w$ | Elasticity of sub. labor inputs | 21    | Schmitt-Grohé and Uribe (2005)     |
| $\psi_w$        | Wage adjustment cost            | 700   | Slope of the wage PC 3%            |

Table 3: Parameter values in the baseline calibration. We only report the parameter values which are different from the ones provided in Table 1. See text for descriptions and targets.

As in the sticky-price economy, this calibration generates two untargeted outcomes. The ratio of public debt to annual GDP amounts to 63%, while public spending is equal to 10.7% of annual GDP. These values are slightly different from the ones in the sticky price economy because of the different labor supply.

<sup>20</sup>As the labor supply by productivity level is different in the sticky-price and sticky-wage economy, we recalibrate the idiosyncratic productivity process to match the same targets.

## 6.4 Quantitative outcomes

We discuss IRFs and second-order moments in Section 6.4.1, while we conduct the welfare analysis in Section 6.4.2.

### 6.4.1 Optimal inflation dynamics

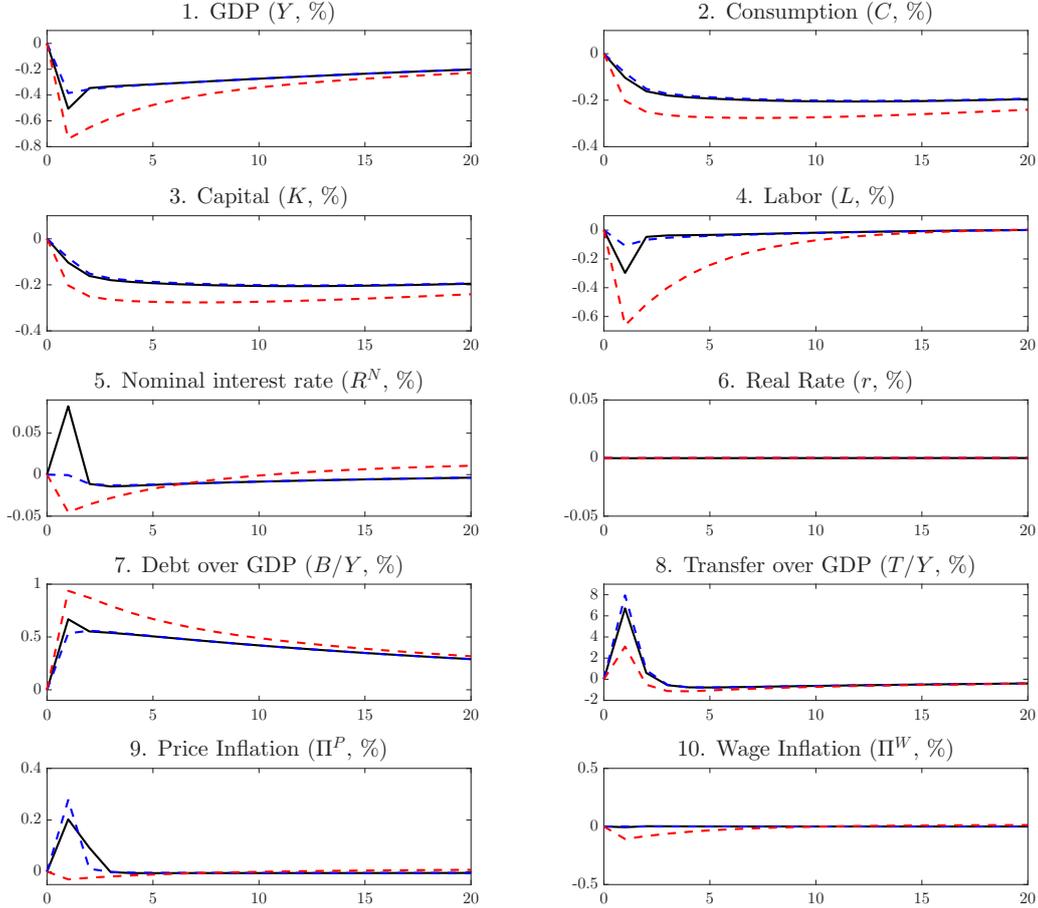


Figure 3: IRFs after a negative productivity shock of one standard deviation for relevant variables. The black line is Economy 1 with optimal monetary policy. The blue dashed line is Economy 2, with constant wage inflation. The red dashed line is Economy 3, where monetary policy follows a Taylor rule.

We simulate the model following a negative TFP shock of one standard deviation (the same as in Section 5). We also consider three economies, all of which feature the same acyclical fiscal rules of Section 4.2. Economy 1 corresponds to the benchmark economy with optimal monetary policy. Economy 2 features wage stability and hence a constant path for wages:  $\Pi_t^W = 1$  at all dates. This allows us to quantify the gains from deviating from wage stability, which is the optimal policy in the representative-agent economy. Economy 3 implements the same Taylor

rule as in Section S.3.2 instead of the optimal inflation path. In Figure 3 we report the IRFs of several key variables for the three economies, which all start from the steady state in period 0. Figure 3 shows that the optimal inflation path is close, but not identical, to nominal wage stability (Panel 7). Obviously, because price inflation has now no direct cost, the real wage adjusts through price inflation, which is now very volatile (Panel 2). The optimal allocation of Economy 1 is quantitatively close to, though different from, the allocation of Result 1. The Taylor rule of Economy 3 implies that price inflation markedly differs from the optimal reaction. Consequently, we observe a sizable deviation from optimal allocation.

#### 6.4.2 Welfare comparison

We now report the average welfare gains by productivity associated with implementing optimal policies instead of price stability. We use the same methodology as in Section 5.3, where, as in the price-rigidity case, the benchmark is the optimal monetary-policy case, Economy 1. We use Economy 2 (no wage inflation) to assess the welfare gain of implementing optimal monetary policy. Again, the welfare gaps are measured by the percentage increase in consumption. They are reported in Figure 4 for the different productivity levels. The general shape of the welfare gains per productivity level is overall similar to the one of Figure 2, obtained in the sticky-price economy. The welfare gains are heterogeneous across productivity levels and the lower the productivity level, the higher the welfare gain – even though the average welfare gain is small and of similar magnitude as in the sticky-price case. The latter amounts to 0.001%.

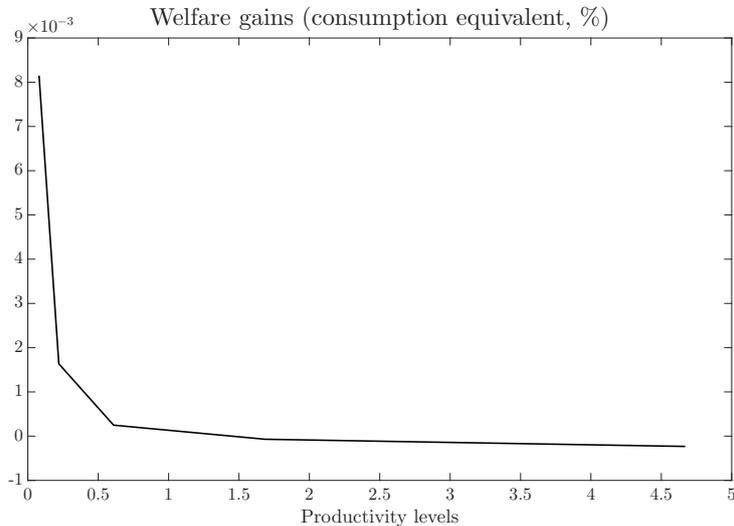


Figure 4: Welfare gaps between Economy 1 (optimal monetary policy) and Economy 2 with no wage inflation ( $\Pi^W = 1$ ). Values are reported as the percentage increase in consumption (y-axis) by productivity level (x-axis).

We have also computed the welfare gaps between the economy with optimal monetary pol-

icy and the one with price stability  $\Pi^P = 1$ . As this last policy is suboptimal even in the representative-agent economy, the welfare gain of optimal policy over fixed price is substantial and amounts to 0.06% on average, which is more than one order of magnitude above the one compared to wage stability.

Finally, we also investigate the robustness of our results to the calibration of the slope of the wage Phillips curve. We report the optimal wage and price inflation responses associated to different values of the slope in Appendix S.9.5.4. Our main finding is unchanged: price inflation reacts sizably to adjust the nominal wage, while the wage inflation response is comparatively smaller.

## 7 Conclusion

We derive optimal monetary policy with commitment in an economy with incomplete insurance markets and aggregate shocks, considering either sticky prices or sticky wages. Optimal monetary policy is analyzed under different fiscal regimes. When prices are sticky, we first show theoretically that price stability is optimal, when linear capital and labor taxes can vary optimally over the business cycle. We then examine a setting in which taxes are set exogenously according to fiscal rules. For a standard calibration and empirically relevant fiscal rules, the optimal inflation response remains modest, although it is sensitive to assumptions about the slope of the Phillips curve and the distribution of profits. When nominal wages are sticky, price inflation takes on a new role: it allows the planner to reduce the real wage following a negative supply shock, aligning it more closely with the marginal productivity of labor. In this case, we find sizable welfare gains from deviating from price stability. In contrast, the welfare gains from deviating from nominal wage stability are smaller. Under both types of nominal rigidity, the welfare gains from optimal monetary policy are higher for low-productivity workers.

## Data availability statement

The data and code underlying this research is available on Zenodo at <https://doi.org/10.5281/zenodo.18401797>.

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