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Unconventional Fiscal Policy in HANK

Hannah Seidl* Fabian Seyrich†

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Abstract

In HANK, we show that fiscal policy is an appropriate macroeconomic stabilization tool at the ZLB. Fiscal policy achieves the same macroeconomic aggregates and the same welfare as hypothetically unconstrained monetary policy by replicating its transmission mechanism. Consumption taxes and labor taxes replicate the effects of monetary policy through the intertemporal substitution channel. Debt-financed lump-sum transfers and a permanent increase in the government debt level replicate the effects of monetary policy through the redistribution channel.

Keywords: Unconventional Fiscal Policy, Heterogeneous Agents, Incomplete Markets, Liquidity Trap, Sticky Prices

JEL Codes: E12, E21, E24, E43, E52

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1 Introduction

COVID-19 has triggered a severe economic downturn pushing back central banks around the world to the zero lower bound (ZLB). This binding constraint on policy rates poses a key challenge to policymakers since conventional monetary policy proves ineffective.[1] Resorting to new tools that stimulate the economy while the ZLB binds is desirable. Correia et al. (2013) show in a Representative Agent New Keynesian (RANK) model that unconventional fiscal policy (UFP) can completely circumvent the ZLB constraint: tax policies replicate the effects through the intertemporal substitution channel and, thus, achieve the allocation associated with hypothetically unconstrained monetary policy.

Yet, recent research on Heterogeneous Agent New Keynesian (HANK) models shows that household heterogeneity matters for the transmission mechanism of monetary and fiscal policy.[2] In particular, redistribution dynamics are crucial. As monetary and fiscal policy differently redistribute among households, this raises the question: can fiscal policy replicate the outcomes of monetary policy in a model with household heterogeneity?

In this paper, we show through the lens of a standard one-asset HANK model that *4-Instrument Unconventional Fiscal Policy* (4I-UFP) achieves the same outcomes as hypothetically unconstrained monetary policy at the ZLB. 4I-UFP replicates both macroeconomic aggregates and welfare that would prevail if monetary policy could set negative nominal interest rates with four instruments: consumption taxes, labor taxes, debt-financed lump-sum transfers, and a permanently higher government debt level. The intuition for our result is that with these four instruments, 4I-UFP replicates the effects of monetary policy through both the intertemporal substitution channel and the redistribution channel.

In line with Correia et al. (2013), 4I-UFP replicates the effects through the intertemporal substitution channel with tax policies: pre-announced paths for higher future consumption

[1] Storage costs of money make the effective lower bound on nominal interest rates a small negative number. Since the exact specification of the effective lower bound is not the focus of this paper, for the sake of simplicity, we will stick to the ZLB as lower bound.

[2] See among others Auclert et al. (2018), Kaplan et al. (2018), Auclert (2019), Hagedorn et al. (2019a), Bilbiie (2020).

taxes influence the intertemporal consumption decision of households in the same way as a decrease in the real interest rate. Yet, higher consumption taxes incentivize households to reduce their labor supply. Lower labor taxes offset this incentive.

Since HANK models feature heterogeneity in marginal propensities to consume (MPC) and a precautionary savings motive of households, redistribution dynamics additionally matter for the transmission of monetary policy. In particular, expansionary monetary policy reduces the return on savings from which asset-rich households disproportionately suffer. As Kaplan et al. (2018), we assume that the government passes on its reduced interest rate payments to all households via lump-sum transfers to keep government debt constant. This way, expansionary monetary policy redistributes towards low-asset households who have higher marginal propensities to consume (MPCs).

We first highlight the importance of these redistribution dynamics in a simple Two Agent New Keynesian (TANK) model, in which there is MPC heterogeneity, but households do not have a precautionary savings motive. Expansionary monetary policy redistributes from Ricardian households, who hold all assets, to Hand-to-Mouth (HtM) households. With one additional instrument - lump-sum transfers financed by a tax on Ricardian households - fiscal policy can replicate these redistribution dynamics of monetary policy. We show analytically that these lump-sum transfers together with consumption taxes and labor taxes are sufficient for UFP to be a perfect substitute for monetary policy in TANK. The intuition is that, this way, UFP replicates the effects through both the intertemporal substitution channel and the redistribution channel.

Subsequently, we show that in HANK, 4I-UFP replicates the effects of unconstrained monetary policy through the redistribution channel with debt-financed lump-sum transfers and a higher government debt level in the long-run. The intuition for the higher lump-sum transfers is the same as in TANK: 4I-UFP needs to provide additional resources to households with high MPCs in the same periods as unconstrained monetary policy does.

Unlike unconstrained monetary policy, 4I-UFP induces a permanent increase in precautionary savings which puts downward pressure on the real interest rate in the long-run. The reason is that permanently higher consumption taxes and permanently lower labor taxes redistribute from low- to high-productivity households such that the income risk of households permanently increases. To offset this downward pressure on the real interest rate, 4I-UFP increases the asset supply by permanently increasing the government debt level. The increase in precautionary savings is strong enough to fully absorb the newly issued debt due to the higher transfers while the ZLB binds.

In our quantitative analysis, a shock to the discount factor brings the economy to the ZLB which binds for 5 quarters. When monetary policy is constrained and there is no fiscal stimulus, output drops on impact by 4.2% and inflation by 6.7 annual percentage points. We approximate the optimal response of unconstrained monetary policy to the discount factor shock by an optimized Taylor rule. Accordingly, interest rates decrease on impact to -10.3 annual percentage points. In the 4I-UFP case, fiscal policy uses its four instruments to replicate the outcomes of this unconstrained monetary policy benchmark. Future consumption taxes increase along a pre-announced path from 5% to 14.8% while the ZLB is binding. Labor taxes, in turn, decrease in the same periods, in total from 28% to 21.3%. Lump-sum transfers increase from 5.5% to at most 17.8% of GDP. The government debt level increases permanently from 90% to 98.4% of GDP. With both 4I-UFP and unconstrained monetary policy, output falls at most by 0.7% and inflation by 1.0 annual percentage point.

We show that 4I-UFP achieves the same welfare as unconstrained monetary policy both at the aggregate level and for each household. Given the equivalence in macroeconomic aggregates and in welfare, we conclude that 4I-UFP is a perfect substitute for unconstrained monetary policy at the ZLB.

We stress the importance of the two instruments targeting the redistribution channel. First, we illustrate that when fiscal policy uses only taxes and transfer policies but does not increase the government debt level in the long-run, the economy converges to a new steady state with lower output. Without the fourth instrument, fiscal policy cannot satisfy the higher precautionary savings demand induced by higher consumption taxes and lower labor taxes. The resulting lower interest rate in the new steady state worsens insurance possibilities which reduces aggregate labor supply. Second, we highlight the importance of debt-financed transfers for the short-run stimulus. When UFP purely consists of tax policies, it does not provide enough resources to constrained households while the ZLB is binding. Consequently, it fails to replicate macroeconomic aggregates, even in the short-run.

Related literature. Feldstein (2002) and Hall (2011) propose to increase future consumption taxes when monetary policy is constrained by the ZLB. Correia et al. (2013) show that, by replicating its effects through the intertemporal substitution channel, a combination of consumption taxes and labor taxes is a perfect substitute for monetary policy in RANK. We revisit their seminal result through the lens of a simple TANK model and show that their result relies on the fact that monetary policy is non-redistributive in RANK. We build our analysis in HANK on this insight.

There is a large literature on the transmission mechanism of monetary policy in HANK (see among many others Werning (2016), McKay et al. (2016), Kaplan et al. (2018), Auclert (2019), Hagedorn et al. (2019a), Auclert et al. (2020b)).[3] The transmission mechanism of monetary policy in our quantitative HANK model is in line with these findings. We design 4I-UFP accordingly.

Recently, the HANK literature has also studied fiscal policy. Auclert et al. (2018) and Hagedorn et al. (2019b) analyze fiscal multipliers in HANK models. Unlike our paper, they do not study whether fiscal policy can replicate macroeconomic outcomes of unconstrained monetary policy. Bhandari et al. (2020) examine the optimal interaction between monetary policy and distortionary taxes in a HANK model. In contrast to our paper, they abstract from consumption taxes and analyze how idiosyncratic insurance options shape optimal monetary

[3]There is also a growing literature analyzing the transmission mechanism of monetary policy in models with firm heterogeneity, see among others Reiter et al. (2013), Koby and Wolf (2020), and Ottonello and Winberry (2020).

and fiscal policy. In line with our paper, Oh and Reis (2012) and Bayer et al. (2020) show that transfer policies can have large effects in HANK models. Wolf (2021) shows that in models in which Ricardian equivalence fails, transfer policies can replicate aggregate demand sequences in response to interest rate cuts. Unlike Wolf (2021), we additionally achieve equivalence in welfare with monetary policy since 4I-UFP also manages to replicate the redistribution dynamics of monetary policy. Thus, our equivalence result is more ambitious in models with heterogeneity since we also obtain equivalence in distributional outcomes. To the best of our knowledge, we are the first to examine UFP in a HANK framework.

This paper has the following structure: Section 2 shows analytically how to design UFP such that it is a perfect substitute to monetary policy in a simple TANK model. Section 3 presents our HANK model. Section 4 shows that 4I-UFP is a perfect substitute for unconstrained monetary policy in HANK. Section 5 analyzes UFP with less instruments. Section 6 concludes.

2 UFP in TANK

In this section, we analyze UFP through the lens of a simple TANK model. We show analytically that UFP is a perfect substitute for monetary policy using consumption taxes, labor taxes, and transfers. Our TANK analysis highlights the importance of replicating the redistribution dynamics in models with household heterogeneity.

2.1 TANK model

There are two types of households: a constant fraction of HtM households, $\lambda \in (0, 1)$, does not have access to financial markets and, thus, consumes all its income in every period of time. The remaining fraction of Ricardian households, $1 - \lambda$, has access to complete financial markets. We abstract from aggregate uncertainty. In the following, we sketch the main features of our TANK model. The full description of the model is in Appendix A.

We assume that all households have CRRA utility and separable preferences over consumption and leisure. The behavior of households, that is, households' choices on consumption, labor supply, and savings, can be described by five equations. For the Ricardian household (denoted by subscript R), the Euler equation is given by:

$$c_{R,t}^{-\gamma} = \beta\bigg((1+r_t)\frac{1+\tau_t^C}{1+\tau_{t+1}^C}\bigg)c_{R,t+1}^{-\gamma}, \tag{1}$$

where $c_{R,t}$ denotes consumption, γ denotes the degree of risk aversion, β denotes the household's discount factor, r_t denotes the real interest rate, and τ_t^C denotes a proportional tax rate on consumption. Her labor-leisure equation is given by:

$$l_{R,t}^{\psi} = c_{R,t}^{-\gamma} w_t \frac{1-\tau_t^L}{1+\tau_t^C}, \tag{2}$$

where $l_{R,t}$ denotes her labor supply, ψ denotes the inverse Frisch elasticity, w_t denotes the wage,[4] and τ_t^L denotes a proportional tax rate on labor income. Her budget constraint is given by:

$$(1+\tau_t^C)c_{R,t} + \frac{b_{R,t+1}}{1+r_t} = b_{R,t} + (1-\tau_t^L)w_t l_{R,t} + D_t + Tr_t - \tau_t^R - \frac{\lambda}{1-\lambda}\iota, \tag{3}$$

where $b_{R,t}$ denotes her holdings of one-period riskless bonds, D_t denotes dividend payments from firms, Tr_t denotes lump-sum transfers, τ_t^R denotes a non-distortionary tax on Ricardian households, and ι denotes a constant transfer between both types of households. We set $\bar{\tau^R} = 0$ and $\iota = (1 - \frac{1}{1+\bar{r}})\bar{B}$ such that in steady state, both types receive the same income.[5] Since HtM-households (denoted by subscript H) have no access to financial markets, their

[4]Unless stated otherwise, all variables are denoted in real terms.

[5]Note the following: First, $\frac{\lambda}{1-\lambda}\iota$ and τ_t^R can also be interpreted as the constant steady state component and the dynamic deviation from steady state, respectively, of the same non-distortionary tax on Ricardian households. Keeping it separated solely simplifies the illustration of our argument. Second, we assume that the income of both types of households is the same in steady state since this is a common assumption in the literature, see among others Bilbiie (2008). Yet, our main insight in this section is robust to other assumptions.

behavior is entirely described by their labor-leisure equation:

$$l_{H,t}^{\psi} = c_{H,t}^{-\gamma} w_t \frac{1-\tau_t^L}{1+\tau_t^C} \tag{4}$$

and their budget constraint:

$$(1+\tau_t^C)c_{H,t} = (1-\tau_t^L)w_t l_{H,t} + D_t + Tr_t + \iota. \tag{5}$$

For simplicity, we assume that monetary policy controls the real interest rate directly.[6] The government budget constraint is given by:

$$Tr_t + \bar{B} = \frac{\bar{B}}{1+r_t} + \tau_t^C C_t + \tau_t^L w_t L_t + (1-\lambda)\tau_t^R, \tag{6}$$

where $\bar{B}$ denotes the constant government debt level, $C_t = (1-\lambda)c_t^R + \lambda c_t^H$ is aggregate consumption, and $L_t = (1-\lambda)l_t^R + \lambda l_t^H$ is aggregate labor supply. Fiscal policy sets consumption taxes, τ_t^C, labor taxes, τ_t^L, and the tax on Ricardian households, τ_t^R. Lump-sum transfers adjust to keep government debt constant.[7]

We assume a standard NK supply side with staggered production and Calvo pricing. Note that no policy variables directly show up in the firms' problem. Thus, changes in policy variables only affect the behavior of firms through a change in households' demand and labor supply.

[6] Note that this assumption solely simplifies the illustration of our argument.

[7] We assume constant government debt for two reasons: first, it is a commonly used benchmark assumption in the HANK literature, see among others McKay et al. (2016) and Kaplan et al. (2018). Second, it simplifies our derivations in closed-form. Yet, our results are more general and also hold with time-varying debt and, thus, a different timing of transfers.

2.2 Perfect Substitutability between Monetary Policy and UFP in TANK

In this section, we derive three sufficient conditions which render UFP a perfect substitute for monetary policy in TANK. In a nutshell, UFP triggers the same behavior of households, that is, the same choice of consumption and labor supply, that would arise with monetary policy. Let us therefore assume the following monetary policy experiment:

Monetary Policy Experiment. *Assume that in period $t = 0$, monetary policy sets an arbitrary path of real interest rates $\{r_t^{MP}\}_{t=0}^{\infty}$ while consumption taxes, labor taxes, and the tax on the Ricardian household are fixed at their steady state value. That is, for all t, $\tau_t^{l,MP} = \bar{\tau}^l$, $\tau_t^{C,MP} = \bar{\tau}^C$, and $\tau_t^{R,MP} = \bar{\tau}^R$.*

Monetary policy affects the consumption of households via two channels, the intertemporal substitution channel and the redistribution channel. The effects through the intertemporal substitution channel arise as a change in the real interest rate changes the *intertemporal policy wedge*, $\frac{1}{(1+r_t)} \frac{1+\tau_{t+1}^C}{1+\tau_t^C}$, in the Euler equation of the Ricardian household. This incentivizes her to intertemporally reallocate her consumption. As the HtM household has no access to financial markets, she is not sensitive to changes in the intertemporal policy wedge.

Monetary policy also affects the economy through a redistribution channel as it differently affects the incomes of households. In particular, monetary policy changes the return on savings of the Ricardian household. The change in interest rate payments of the government is directly passed through to all households via lump-sum transfers. This constitutes a *policy-induced* redistribution between both households. Since they differ in their MPCs, this redistribution has real effects on the aggregate consumption of households.[8]

[8] See among others Galí et al. (2007), Bilbiie (2008), Debortoli and Galí (2017), Bilbiie (2020). Note that our particular redistribution dynamics can lead to amplification of monetary policy. Moreover, there are potentially also other general equilibrium redistribution dynamics triggered by changes in households' behavior. Both issues are analyzed in great detail in Bilbiie (2008) and Bilbiie (2020). Note that given equivalence in households' behavior, both amplification and additional general equilibrium redistribution dynamics are the same with UFP and in the monetary policy experiment. Hence, for our analysis, it is sufficient to focus on the policy-induced redistribution.

We define this policy-induced redistribution, Ξ_t, as the shift in resources between households which is induced by changes in the policy variables assuming fixed households' and firms' behavior, i.e., $(c_{H,t}, c_{R,t}, l_{H,t}, l_{R,t}, d_t, w_t) = (\bar{c_H}, \bar{c_R}, \bar{l_H}, \bar{l_R}, \bar{d}, \bar{w})$.

Lemma 1. *In the monetary policy experiment, the policy-induced redistribution is given by* $\Xi_t^{MP} = -\lambda\bar{B}(\frac{1}{1+r_t} - \frac{1}{1+\bar{r}})$. *If* $r_t < \bar{r} \rightarrow \Xi_t^{MP} \leq 0$, *that is, expansionary monetary policy redistributes from the Ricardian household to the HtM household. Likewise, if* $r_t > \bar{r} \rightarrow \Xi_t^{MP} \geq 0$, *that is, contractionary monetary policy redistributes from the HtM household to the Ricardian household.*[9]

Let us now assume that the real interest rate is kept at its steady state level, $r_t^{UFP} = \bar{r}\ \forall t$, and fiscal policy uses its instruments τ_t^L, τ_t^C, and Tr_t^{UFP} to replicate the behavior of households in the monetary policy experiment. In this case, τ_t^R adjusts to keep government debt constant.

Proposition 1. *To replicate the behavior of households in the monetary policy experiment, it is sufficient for fiscal policy to set its instruments according to the following conditions:*

$$\Big(1+\bar{r}\Big)\frac{1+\tau_t^{C,UFP}}{1+\tau_{t+1}^{C,UFP}} = 1 + r_t^{MP}, \tag{7}$$

$$\frac{1-\tau_t^{L,UFP}}{1+\tau_t^{C,UFP}} = \frac{1-\bar{\tau^L}}{1+\bar{\tau^C}}, \tag{8}$$

$$Tr_t^{UFP} = (D_t+\iota)\left(\frac{1+\tau_t^{C,UFP}}{1+\bar{\tau^C}} - 1\right) + \frac{1+\tau_t^{C,UFP}}{1+\bar{\tau^C}} Tr_t^{MP}. \tag{9}$$

UFP set according to these three conditions is a perfect substitute for monetary policy in TANK.

The proof of Proposition 1 is in the Appendix. In a nutshell, these three conditions ensure that UFP affects the five equations determining households' behavior (Eqs. (1-5)) in the same way as the monetary policy experiment. The same behavior of households yields

[9] The proof of Lemma 1 is in the Appendix.

the same allocation through general equilibrium as firms face the same demand and the same labor supply. Hence, UFP and monetary policy are perfect substitutes in TANK.

Conditions (7) and (8) are the same as in Correia et al. (2013) and jointly replicate the transmission of monetary policy through the intertemporal substitution channel. According to condition (7), fiscal policy sets consumption taxes such that the intertemporal policy wedge for the Ricardian household is the same with UFP and with monetary policy: by changing the relative price of consumption today versus tomorrow, fiscal policy triggers the same incentive to intertemporally reallocate consumption as a change in the real interest rate does.

Yet, unlike a change in the real interest rate, adjusting consumption taxes changes the *intratemporal policy wedge*, $\frac{1-\tau_t^L}{1+\tau_t^C}$, in the labor-leisure equations of both households. When labor taxes are set according to condition (8), they offset this effect on the labor supply of households. Conditions (7) and (8) imply that in order to replicate expansionary monetary policy, fiscal policy increases future consumption taxes and decreases future labor taxes. Accordingly, replicating contractionary monetary policy implies lower future consumption taxes and higher future labor taxes.

Transfers set according to condition (9) replicate the net income stream of both households in the monetary policy experiment. To achieve this, transfers in the 4I-UFP case follow the transfer path of monetary policy, Tr_t^{MP}, adjusted for the lower purchasing power due to higher consumption taxes. In addition, transfers need to compensate for the lower purchasing power of dividends, D_t, and the steady state redistribution, ι.[10]

These transfers are redistributive if they change the tax on Ricardian households. Constant government debt implies:

$$\tau_t^{R,UFP} = \frac{1}{1-\lambda}\frac{1+\tau_t^{C,UFP}}{1+\bar{\tau^C}}\bar{B}\left[\frac{1}{1+r_t} - \frac{1}{1+\bar{r}}\right] = \frac{1}{(1-\lambda)\lambda}\frac{1+\tau_t^{C,UFP}}{1+\bar{\tau^C}}\Xi_t^{MP}. \tag{10}$$

[10]Note that condition (8) implies that labor income is already adjusted for its purchasing power.

Lemma 2. *UFP set according to Proposition 1 implies* $\Xi_t^{UFP} = \frac{1+\tau_t^C}{1+\tau^C}\Xi_t^{MP}$*, that is, UFP implies the same policy-induced redistribution as in the monetary policy experiment adjusted for its purchasing power. Hence, if UFP replicates expansionary monetary policy, it redistributes from the Ricardian household to the HtM household. If UFP replicates contractionary monetary policy, it redistributes from the HtM household to the Ricardian household.*

Lemma 2 shows that UFP set according to Proposition 1 perfectly replicates the redistribution dynamics of monetary policy.[11] This way, UFP replicates the effects of monetary policy through the redistribution channel.

Note that to replicate the behavior of both households, it is sufficient to replicate the net income of the HtM household in each period and the present value of the lifetime income of the Ricardian household. Hence, if we relax the assumption of constant government debt, Eq. (10) is interchangeable with any path $\{\tau_t^{R,UFP}\}_{t=0}^{\infty}$ which balances government debt in the long-run. This implies that debt-financed transfers can potentially induce the same effects through the redistribution channel as monetary policy. Accordingly, debt-financed transfers are one instrument of 4I-UFP in the HANK analysis in Section 4.

How does our analysis relate to the result in Correia et al. (2013)? They show in RANK, that UFP set according to condition (7) and (8) is sufficient to achieve the same allocation as monetary policy. In TANK, without condition (9), $\tau_t^R = 0$ which implies $\Xi_t^{UFP} = 0$ as Appendix B.3 shows. Hence, as long as $\bar{B} \neq 0$, that is, as long as monetary policy implies policy-induced redistribution, this is not sufficient in TANK. This is intuitive because Correia et al. (2013)'s result was developed in RANK in which there is by construction no redistribution among households.

In sum, with two agents and a non-distortionary tax on one of these agents, fiscal policy can perfectly replicate the allocations of monetary policy. In the remainder of this paper, we show in a quantitative HANK model that fiscal policy can replicate the effects of monetary policy through the intertemporal substitution channel and the redistribution channel with

[11] The proof of Lemma 2 is in Appendix B.2.

four aggregate instruments.

3 HANK Model

Our quantitative model is a standard one-asset HANK model in the style of McKay et al. (2016).

3.1 Households

The household side is a Bewley-Huggett-Aiyagari incomplete markets model. The economy is populated by a continuum of households who are identical in their preferences given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{c_{h,t}^{1-\gamma}}{1-\gamma} - \frac{l_{h,t}^{1+\psi}}{1+\psi} \right],$$

where β denotes the household's discount factor, $c_{h,t}$ denotes consumption of household h in period t, and $l_{h,t}$ denotes her labor supply. The parameters γ and ψ govern the degree of risk aversion and the inverse Frisch elasticity, respectively.

The budget constraint of the household and the borrowing constraint are given by:

$$(1+\tau_t^C)c_{h,t} + \frac{b_{h,t+1}}{1+r_t} = b_{h,t} + (1-\tau_t^L)w_t z_{h,t} l_{h,t} + D_t + Tr_t \tag{11}$$

$$b_{h,t+1} \geq 0.$$

Household h has expenditures for consumption, $c_{h,t}$, and 1-period risk-free bonds, $b_{h,t}$, which pay the real interest rate, r_t, and are issued by the government. In addition, households pay a proportional tax rate on consumption, τ_t^C, and a proportional tax rate on their individual labor income, τ_t^L. The labor income consists of the wage rate, w_t,[12] the individual productivity level, z_t, and the individual labor supply. Since $z_{h,t}$ evolves according to an exogenous finite-state Markov chain, households face idiosyncratic income risk. The invariant distribu-

[12] Unless stated otherwise, all variables are denoted in real terms.

tion of the Markov chain, $\Gamma^z(z)$, remains constant such that the share of households in each productivity level is constant. All households receive an equal share of firms' dividends, D_t, and a lump-sum transfer, Tr_t, from the government.[13]

Markets are incomplete since households cannot borrow and there are no state-contingent securities. This implies that households cannot fully insure their idiosyncratic income risk. As a consequence, households differ in their individual state, $h = (b, z)$, which consists of households' asset position, b, and their specific productivity level, z. The decision problem of a household with individual state h is given by:

$$V_t(b_{h,t}, z_{h,t}) = \max_{c_{h,t}, l_{h,t}, b_{h,t+1}} \left\{ \frac{c_{h,t}^{1-\gamma}}{1-\gamma} - \frac{l_{h,t}^{1+\psi}}{1+\psi} + \beta \sum_{z_{h,t+1}} Pr(z_{h,t+1}|z_{h,t}) V_{t+1}(b_{h,t+1}, z_{h,t+1}) \right\},$$

subject to equation (11). The Euler equation is given by:

$$c_{h,t}^{-\gamma} \geq \beta E_t \left\{ \left(\frac{1+i_t}{1+\pi_{t+1}} \frac{1+\tau_t^C}{1+\tau_{t+1}^C} \right) c_{h,t+1}^{-\gamma} \right\}, \tag{12}$$

which governs the intertemporal substitution decision of households. Both lower real interest rates and higher future consumption taxes increase the intertemporal policy wedge, $\frac{1+\pi_{t+1}}{1+i_t} \frac{1+\tau_{t+1}^C}{1+\tau_t^C}$, thereby incentivizing households to consume more today.

The labor-leisure equation is given by:

$$l_{h,t}^{\psi} = c_{h,t}^{-\gamma} z_{h,t} w_t \frac{1-\tau_t^L}{1+\tau_t^C}. \tag{13}$$

Consumption taxes and labor taxes influence the labor supply of households through the intratemporal policy wedge, $\frac{1-\tau_t^L}{1+\tau_t^C}$.

Let $c_t(b, z)$, $\ell_t(b, z)$, and $s_t(b, z)$ denote the policy functions for consumption, labor supply,

[13] The assumption of equal shares of firms influences the cyclicality of income risk. Hagedorn et al. (2019a) and Acharya and Dogra (2020) stress the importance of the cyclicality of the income risk on the effectiveness of policy measures in HANK models. Yet, the cyclicality of income risk has no implication for our results as both monetary policy and 4I-UFP are in the same way dampened (with pro-cyclical risk) or amplified (with counter-cyclical risk).

and savings, respectively, that satisfy equations (11), (12), and (13) given the household's individual state.

3.2 Firms

Final good firms produce in a perfectly competitive market using intermediate goods as inputs. Their decision problem is:

$$\max_{y_{j,t}} \left\{ P_t Y_t - \int_0^1 p_{j,t} y_{j,t} dj \right\},$$

subject to a CES production technology:

$$Y_t = \left(\int_0^1 y_{j,t}^{1/\mu} dj \right)^{\mu},$$

where $y_{j,t}$ denotes the intermediate good produced by firm j and $p_{j,t}$ is the corresponding price. Y_t denotes the final consumption good, P_t denotes the overall price index, and μ determines the degree of substitution among input factors. The aggregate price index is given by:

$$P_t = \left(\int_0^1 p_{j,t}^{1/(1-\mu)} dj \right)^{1-\mu}.$$

Solving the maximization problem yields the demand function of final good firms for the intermediate good j:

$$y_{j,t} = \left(\frac{p_{j,t}}{P_t} \right)^{\frac{\mu}{1-\mu}} Y_t. \tag{14}$$

Intermediate goods are produced by a continuum of intermediate good firms in monopolistically competitive markets. Intermediate good firms produce according to:

$$y_{j,t} = n_{j,t}.$$

Following Correia et al. (2013), we assume that price setting takes place before consumption taxes. As in Calvo (1983), we allow an intermediate good firm to reset its price only with a certain probability, θ. If a firm is allowed to reset its prices, it solves the following non-static maximization problem:

$$\max_{p_t^*, \{y_{j,s}, n_{j,s}\}_{s=t}^{\infty}} \sum_{s=t}^{\infty} \beta^{s-t}(1-\theta)^{s-t} \left(\frac{p_t^*}{P_s} y_{j,s} - w_s n_{j,s} \right),$$

subject to the final good firms' demand given in equation (14). The optimal price ratio p_t^*/P_t that solves this problem is given by:

$$\frac{p_t^*}{P_t} = \frac{\sum_{s=t}^{\infty} \beta^{s-t}(1-\theta)^{s-t} \left(\frac{P_t}{P_s}\right)^{\frac{\mu}{1-\mu}} Y_s \mu w_s}{\sum_{s=t}^{\infty} \beta^{s-t}(1-\theta)^{s-t} \left(\frac{P_t}{P_s}\right)^{\frac{\mu}{1-\mu}} Y_s}. \tag{15}$$

Let $(1+\pi_{t+1}) = \frac{P_{t+1}}{P_t}$ denote the gross inflation rate.

3.3 Policy

We close the model by specifying monetary and fiscal policy.

Monetary Policy. We assume that the central bank sets the nominal interest rate, i_t, following a Taylor rule:

$$1 + i_t = \max \left\{ \underline{I}, (1+\bar{i}) \left(\frac{\pi_t}{\bar{\pi}} \right)^{\phi_\pi} \right\}. \tag{16}$$

Variables with a bar on top denote steady state values. The parameter ϕ_π measures how responsive the central bank reacts to deviations in inflation from steady state. In the case of constrained monetary policy, the Taylor rule is truncated by the ZLB. Thus, $\underline{I} = 1$ and nominal interest rates cannot go below zero. In the counterfactual case of unconstrained monetary policy, $\underline{I} \longrightarrow -\infty$, and monetary policy follows the Taylor rule without any constraints. We approximate the optimal response of unconstrained monetary policy at the ZLB by choosing the value of ϕ_π that yields the highest average value function after the discount factor shock.[14]

The nominal interest rate and the real interest rate are linked via the Fisher equation:

$$1 + r_t = \frac{1 + i_t}{1 + \pi_{t+1}}. \tag{17}$$

Fiscal Policy. The government has expenditures for a fixed amount of government consumption, $\bar{G}$, lump-sum transfers, Tr_t, and for repaying debt, B_t. It finances its expenditure by collecting total tax payments, T_t, and by issuing future debt. The government's budget constraint is given by:

$$\bar{G} + Tr_t + B_t = \frac{B_{t+1}}{1 + r_t} + T_t. \tag{18}$$

Total tax payments are given by:

$$T_t = \tau_t^C C_t + \tau_t^L w_t L_t, \tag{19}$$

where C_t and L_t denote aggregate consumption and aggregate labor, respectively.

We distinguish two specifications of fiscal policy. When fiscal policy does not provide stimulus at the ZLB, tax rates are fixed at their steady state levels. In addition, we follow

[14] The focus of our paper is the perfect substitutability between unconstrained monetary policy and 4I-UFP. The exact dynamics of the unconstrained monetary policy case are not relevant for our result. A sensitivity analysis with different Taylor coefficients confirms that the perfect substitutability result does not depend on the value of the Taylor coefficient. Hence, approximating optimal monetary policy is sufficient for our purpose. For recent approaches on the non-trivial task of finding optimal monetary policy in HANK, see Bilbiie and Ragot (2018), Acharya et al. (2020), and Bhandari et al. (2020).

Kaplan et al. (2018) and assume that transfers adjust such that the government debt level is constant in every period.[15] When fiscal policy provides stimulus at the ZLB in the form of 4I-UFP, it sets the paths of consumption tax rates, labor tax rates, transfers, and the government debt level in the long-run to replicate the transmission mechanism of monetary policy. We specify how fiscal policy uses each instrument in Section 4.

3.4 Aggregation, Market Clearing, and Equilibrium

The aggregate production function of the economy is given by:

$$S_t Y_t = \int_0^1 n_{j,t} dj \equiv N_t, \tag{20}$$

where N_t denotes the aggregate labor demand of the intermediate good firms. S_t measures the efficiency loss that occurs whenever prices differ and is given by:

$$S_t \equiv \int_0^1 \left(\frac{p_{j,t}}{P_t}\right)^{\frac{\mu}{1-\mu}} dj \geq 1.$$

It evolves according to:

$$S_{t+1} = (1-\theta) S_t (1+\pi_{t+1})^{\frac{-\mu}{1-\mu}} + \theta \left(\frac{p^*_{t+1}}{P_{t+1}}\right)^{\frac{\mu}{1-\mu}}. \tag{21}$$

Inflation is a function of the optimal relative price of the updating firms:

$$1+\pi_t = \left(\frac{1-\theta}{1-\theta(\frac{p^*_t}{P_t})^{\frac{1}{1-\mu}}}\right)^{1-\mu}. \tag{22}$$

The distribution of households over their individual states, $\Gamma_{t+1}(\mathcal{B}, z')$, evolves following

[15] The literature shows that the response of fiscal policy to changes in monetary policy is not innocuous in HANK as it can have large quantitative effects on the transmission of monetary policy (see among others Kaplan et al., 2018). A sensitivity analysis, in which we replace the assumption of constant government debt with a debt feedback rule on transfers, shows that our perfect substitutability result does not depend on the specific response of fiscal policy. This is intuitive as the quantitative differences are triggered by changes in the same fiscal instruments that are set in the 4I-UFP case to replicate the monetary policy transmission.

the exogenous Markov chain for the productivity level and the endogenously derived savings policy functions of the households. Formally:

$$\Gamma_{t+1}(\mathcal{B}, z') = \int_{\{(b,z):s_t(b,z)\in\mathcal{B}\}} Pr(z'|z)d\Gamma_t(b,z) \tag{23}$$

for all sets $\mathcal{B} \subset \mathbb{R}$. Aggregate labor supply, consumption, and savings are:

$$L_t = \int_0^1 z\ell_t(b,z)d\Gamma_t(b,z), \tag{24}$$

$$C_t = \int_0^1 c_t(b,z)d\Gamma_t(b,z), \tag{25}$$

and

$$B_t^d = \int_0^1 s_t(b,z)d\Gamma_t(b,z), \tag{26}$$

respectively.

Labor market clearing requires:

$$L_t = N_t, \tag{27}$$

the bond market clears when:

$$B_t = B_t^d, \tag{28}$$

and the goods market clears when:

$$Y_t = C_t + \bar{G}. \tag{29}$$

Dividend payments are given by:

$$D_t = Y_t - w_t N_t. \tag{30}$$

Equilibrium. We define an equilibrium of the economy to consist of:

1. Policy and value functions $\{s_t(b,z),\, \ell_t(b,z),\, c_t(b,z),\, V_t(b,z)\}_{t=0}^{\infty}$ that solve the households' problems,

2. distributions $\{\Gamma_t(b,z)\}_{t=0}^{\infty}$ that evolve according to (23),

3. sequences of the aggregate variables

$$X \equiv \left\{C_t, L_t, N_t, Y_t, d_t, i_t, w_t, \pi_t, r_t, p_t^*/P_t, S_t, tr_t, T_t, \tau_t^C, \tau_t^L, B_t^d, B_t^s\right\}_{t=0}^{\infty}$$

   that satisfy the equilibrium equations (15), (16), (17), (18), (19), (20), (21), (22), (27), (29), (30), the household aggregation equations (24), (25), (26) as well as exogenous paths for the consumption taxes, the labor taxes, and transfers which are specified below.

3.5 Calibration

Our calibration reflects standard values in the literature (Table 1). We set the households' discount factor, β, such that the annual steady state real interest rate, $\bar{r}$, is 2%. We set both the coefficient for risk aversion, γ, and for the inverse Frisch elasticity, ψ, to 2. The latter reflects the finding of Chetty (2012) who proposes that the Frisch elasticity should be around 0.5 for plausible income effects. Following Christiano et al. (2011), we set the markup parameter, μ, to 1.2, and the price reversion rate, θ, to 0.15.

The calibration of the idiosyncratic income risk follows McKay et al. (2016). We assume that households cannot borrow. We choose the labor income risk to approximate the findings

Table 1: Benchmark Calibration

Parameter	Description	Value
β	Discount factor	0.982
γ	Risk aversion	2
ψ	Inverse of Frisch elasticity	2
μ	Markup	1.2
θ	Price reversion rate	0.15
$z \in \{z^1, z^2, z^3\}$	Individual productivity states	[0.492 1 2.031]
ρ_z	Autocorrelation of idiosyncratic risk	0.966
σ_z	Unconditional variance of idiosyncratic risk	0.501
$\Gamma^z(z)$	Invariant Distribution of Productivity Levels	[0.25 0.5 0.25]
$\bar{\tau^C}$	Consumption tax rate	5%
$\bar{\tau^L}$	Labor tax rate	28%
$\bar{G}/\bar{Y}$	Government consumption share	0.2
$\bar{Tr}/\bar{Y}$	Transfer share	0.055
$\bar{B}/(4 * \bar{Y})$	Government debt share	0.9
ϕ_π	Inflation Taylor weight	12.9

of Floden and Lindé (2001). We discretize a quarterly AR(1) process with an autoregressive coefficient of 0.966 and an innovation variance of 0.017 into a three-state Markov chain by using Rouwenhorst (1995)'s method.[16] The resulting Markov chain matches the unconditional and the conditional mean, the unconditional and the conditional variance, and the first-order autocorrelation of the underlying quarterly AR(1) process.

Following Correia et al. (2013), we choose the consumption tax rate $\bar{\tau^C} = 5\%$ and the labor tax rate $\bar{\tau^L} = 28\%$. As in Christiano et al. (2011), we set government consumption $\bar{G}/\bar{Y} = 0.2$. We follow McKay and Reis (2016) and calibrate government debt such that the interest payments of the government in steady state equal the average net interest payments per GDP by the U.S. government from 1946-2007. This yields an annual government debt share, $\bar{B}/(4 * \bar{Y})$, of 0.9 and average MPCs of 0.124.[17] Our calibration results in a steady state transfer share of $\bar{Tr}/\bar{Y} = 0.055$. We find an optimal Taylor-coefficient of $\phi_\pi = 12.9$.

[16] Floden and Lindé (2001) estimate the annual log wage process assuming that it follows an AR(1) process resulting in an autoregressive coefficient of 0.961 and an innovation variance of 0.426. The annual AR(1) process is simulated by a quarterly AR(1) process with an autoregressive coefficient of 0.966 and an innovation variance of 0.017.

[17] If we instead target average MPC of 0.25 as proposed by Auclert et al. (2020a), we obtain $\bar{B}/(4*\bar{Y}) = 0.5$. Another commonly used calibration target is the aggregate liquid wealth, which implies $\bar{B}/(4 * \bar{Y}) = 1.4$. A sensitivity analysis shows that our perfect sustitutability result is robust to these calibration choices.

3.6 Solution Method

We solve the model using the method proposed in McKay et al. (2016). We compute the perfect foresight transition paths of the economy in response to a discount factor shock and the respective UFP interventions. Initially, the economy is in steady state. Without UFP, we assume that the economy returns to its old steady state after 250 periods. With UFP, we assume that the economy has transitioned to its new steady state after 250 periods.

We guess paths of prices and quantities for all variables specified in Section 3.4. We then check whether these prices and quantities are consistent with the definition of an equilibrium in Section 3.4 in each period. This implies to solve for the aggregate behavior of households given the guessed prices in each period. We use the endogenous grid point method of Carroll (2006) to solve the individual household problem backwards. We use the non-stochastic simulation algorithm in Young (2010) to simulate the distribution of households forward.

When the aggregate behavior of households is not consistent with the guessed quantities, we update the guess for prices and quantities. For this purpose, we use an auxiliary model. It approximates the aggregate behavior of households with an auxiliary Euler equation and an auxiliary labor-leisure equation which contain time-varying heterogeneity wedges. We solve the auxiliary model with a version of Newton's method and iterate until the aggregate behavior of households is consistent with the guessed quantities and prices.

4 4-Instrument UFP

This section shows that 4I-UFP is a perfect substitute for unconstrained monetary policy at the ZLB: 4I-UFP yields the same outcome in terms of macroeconomic aggregates and welfare as monetary policy in the counterfactual without a ZLB constraint.

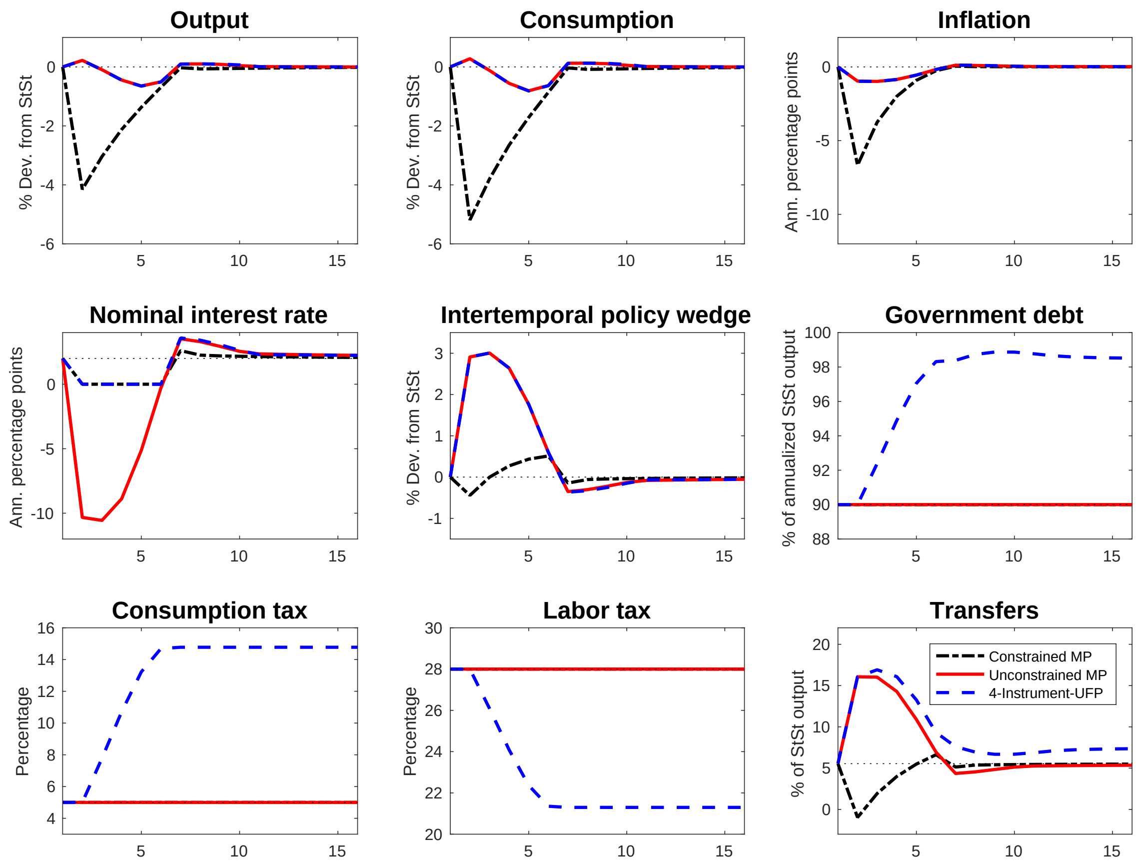

Figure 1: Impulse response functions after a shock to the discount factor with a Taylor rule truncated by the ZLB ("Constrained MP"), with a Taylor rule without a lower bound ("Unconstrained MP"), and with a truncated Taylor rule and an additional 4-Instrument-UFP stimulus ("4-Instrument-UFP"). Horizontal axes denote quarters.

4.1 Equivalence in macroeconomic aggregates

We follow Christiano et al. (2011) and approximate the effects of a binding ZLB by engineering an unexpected temporary increase in the discount factor of households. More precisely, the discount factor increases by 2.5% for 5 quarters before it jumps back to its steady state level. This brings the economy to the ZLB which binds for 5 quarters. The black, dash-dot lines in Figure 1 show the dynamics of macroeconomic aggregates without an additional fiscal stimulus. We refer to this as the constrained monetary policy case. In this case, output falls by 4.2%, consumption by 5.2%, and inflation by 6.7 annual percentage points.

How would macroeconomic aggregates react if monetary policy was not constrained by the ZLB? The red, solid lines show the unconstrained monetary policy case, in which there is no ZLB constraint in the Taylor rule and the central bank sets negative interest rates for 5 quarters. At most, they decrease to -10.3 annual percentage points. The comparison with the 4I-UFP case (blue, dashed lines) contains the main message from Figure 1: 4I-UFP perfectly replicates macroeconomic aggregates associated with the hypothetical benchmark of unconstrained monetary policy. In both cases, inflation falls only by 1.0 annual percentage point, output first overshoots before the economy falls into a mild recession with output falling by 0.7% at most. The same is true for consumption which falls by 0.8% at most.

How does 4I-UFP achieve to replicate the macroeconomic outcomes of unconstrained monetary policy? 4I-UFP uses four instruments - consumption taxes, labor taxes, debt-financed transfers, and the government debt level in the long-run - to replicate the transmission mechanism of unconstrained monetary policy through both the intertemporal substitution and the redistribution channel.[18]

Effects through the intertemporal substitution channel. The sharp decrease in the nominal interest rates in the unconstrained monetary policy case lowers the real interest rates. This increases the intertemporal policy wedge of households, which incentivizes households to consume more and save less.

As in the simple TANK model, 4I-UFP replicates this effect through the intertemporal substitution channel with consumption taxes and labor taxes. At the ZLB, fiscal policy sets consumption taxes such that the intertemporal policy wedge is the same as in the unconstrained monetary policy case. This implies for the periods in which the ZLB is

[18] We define the intertemporal substitution channel as the partial equilibrium effects caused by a change in the intertemporal policy wedge with fixed households' income. In contrast, we define the redistribution channel as the difference of the total effect and the effects through the intertemporal substitution channel. Note that our definition of the redistribution channel also includes Keynesian type multiplier effects (see Auclert et al., 2018, Kaplan et al., 2018). Yet, we do not discuss the latter in detail, as these are triggered by changes in output and not by any policy variable directly. Conditional on equivalence in macroeconomic aggregates, Keynesian type multiplier effects are the same with 4I-UFP and with unconstrained monetary policy.

binding:[19]

$$\frac{1+\pi_{t+1}^{MP}}{1+i_t^{MP}} = \frac{1+\pi_{t+1}^{UFP}}{1+i_t^{UFP}}\frac{1+\tau_{t+1}^{C,UFP}}{1+\tau_t^{C,UFP}}, \tag{31}$$

where the superscript MP denotes the unconstrained monetary policy and UFP the 4I-UFP case. Labor taxes, in turn, ensure equivalence in the intratemporal policy wedge:

$$\frac{1-\bar{\tau}^L}{1+\bar{\tau}^C} = \frac{1-\tau_t^{L,UFP}}{1+\tau_t^{C,UFP}}. \tag{32}$$

This implies that consumption taxes increase along a pre-announced path, in total from 5% to 14.8% and labor taxes, correspondingly, decrease in total from 28.0% to 21.3% as shown in Figure 1.

Effects through the redistribution channel. As in our analysis in TANK, the decrease in real interest rates redistributes from asset-rich to asset-poor households. Asset-rich households suffer disproportionately from lower returns on their savings. Yet, the reduced debt payments of the government are distributed lump-sum to all households by higher transfers. Since asset-poor households tend to have higher MPCs, this amplifies the effects of monetary policy through a redistribution channel.[20] To replicate this amplification of unconstrained monetary policy, 4I-UFP uses two additional instruments: debt-financed lump-sum transfers and a permanent increase in the government debt level.

To achieve the same expansionary effect at the ZLB, transfers increase more with 4I-UFP than with unconstrained monetary policy. The intuition carries over from our TANK analysis: Transfers follow the path of transfers of unconstrained monetary policy adjusted for the loss in purchasing power due to higher consumption taxes. Additionally, transfers compensate for the lower purchasing power of dividends.[21] Quantitatively, transfers increase

[19]Note that conditions (31) and (32) are a more general form of the conditions in Proposition (1). The only difference is that in HANK, we do not assume that the central bank controls the real interest rate directly.

[20]This amplification mechanism of the monetary transmission through the redistribution channel has been highlighted in the literature, see among others Kaplan et al. (2018) and Hagedorn et al. (2019b).

[21]Note that Eq. (32) implies that the labor income is already adjusted for the purchasing power.

from 5.5% to at most 17.8% of GDP.

With 4I-UFP, transfers have to be debt-financed such that government debt increases from 90% to 98.3% of GDP while the ZLB is binding. This newly issued debt does not have to be paid back by the government as the asset demand of households increases. The reason is that 4I-UFP permanently increases the precautionary savings motive of households due to the new tax regime. Permanently higher consumption taxes and permanently lower labor taxes redistribute from low to high productivity households. Figure 2 shows that conditional on the asset position of households, the tax payments of lower productivity households increase disproportionately. This increases the gap in disposable income among the productivity levels. Accordingly, the income risk of households permanently increases.

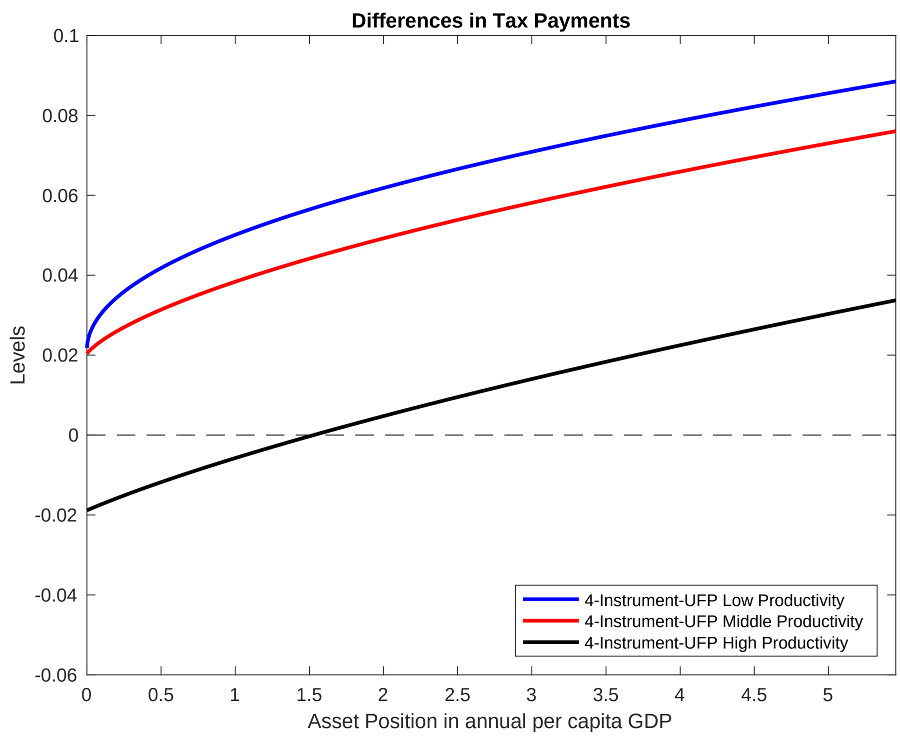

Figure 2: Differences in total tax payments between the old and the new tax regime for each individual state in the economy. Note that this is a partial equilibrium analysis as tax payments are computed by fixing households' consumption and labor supply to the old steady state policy functions.

To neutralize the downward pressure on the real interest rates due to the increase in precautionary savings, the government increases its debt level permanently such that it holds:

$$\bar{B}^{UFP} = \bar{B}^{d,UFP}(\bar{r}). \tag{33}$$

That is, the government debt level in the new steady state, $\bar{B}^{UFP}$, meets the asset demand in the new steady state, $\bar{B}^{d,UFP}$, at the old steady state real interest rate, $\bar{r}$. This implies an increase in the long-run government debt level to 98.4% of GDP. Hence, the newly issued debt to finance the increase in transfers is fully absorbed by the households' increase in precautionary savings.

Correspondingly, transfers are set according to the following rule:

$$Tr_t^{UFP} = \begin{cases} \frac{1+\tau_t^{C,UFP}}{1+\bar{\tau^C}} Tr_t^{MP} + D_t\left(\frac{1+\tau_t^{C,UFP}}{1+\bar{\tau^C}} - 1\right) & \text{for } t \leq s \\ \bar{Tr}^{UFP} - \vartheta \frac{B_t - \bar{B}^{UFP}}{\bar{Y}} & \text{for } t > s, \end{cases} \tag{34}$$

where s governs the period in which transfers stop to follow the transfers of unconstrained monetary policy and the feedback parameter ϑ governs how fast the government adjusts its debt to its new long-run level.[22]

4.2 Equivalence in Welfare

In this section, we show that 4I-UFP has the same impact on the welfare as unconstrained monetary policy. Figure 3 shows the welfare implications of both policies on each household in terms of consumption compensation.[23] The blue (low productivity households),

[22] In our baseline analysis (Figure 1), we set $s = 6$ and, hence, to the period in which the ZLB stops binding. In addition, we set $\vartheta = 0.5$. It turns out that our results are robust to these two parameter values. Given $s \geq 6$, they only determine how fast the government closes the gap between the after-crisis debt level and the new debt target. Yet, this gap is very small and the transition takes place when monetary policy is no longer constrained.

[23] We compute the consumption compensation as the consumption increase that is additionally necessary in the baseline of the constrained monetary policy case such that each household is indifferent between the baseline and the two policy cases (4I-UFP and unconstrained monetary policy). Given our specification of preferences, we cannot compute lifetime consumption compensation. Thus, we compute the consumption compensation for 4 quarters as in Kekre (2019). We conduct a sensitivity analysis with log-utility which allows us to compute the lifetime consumption compensation. We scale the discount factor such that the

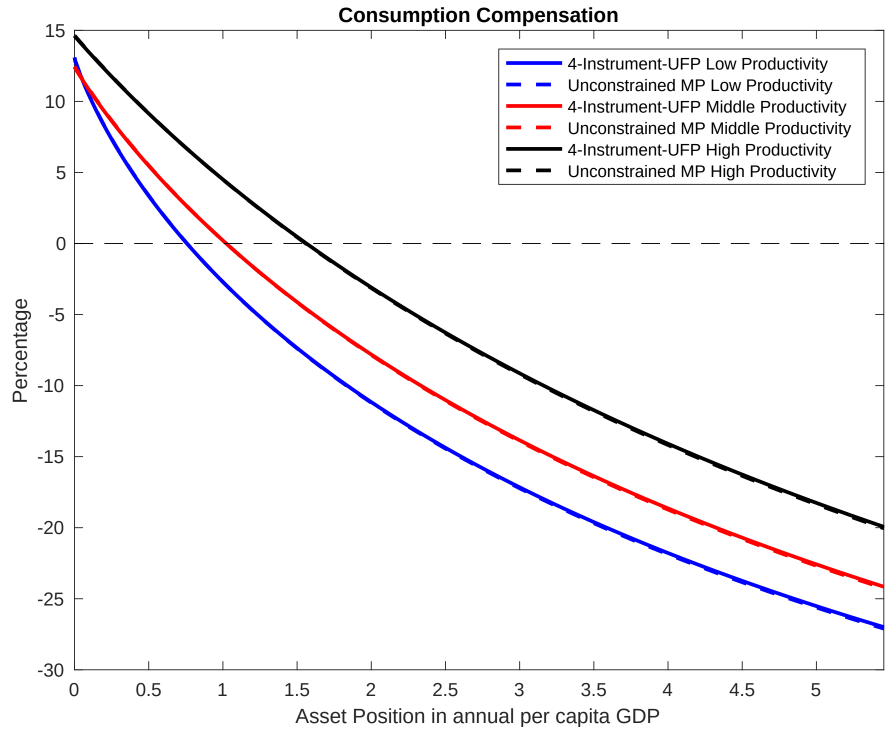

Figure 3: Consumption compensation for 4 quarters for each household such that she is indifferent between the respective policy and constrained monetary policy.

red (middle productivity), and black (high productivity) solid lines depict the consumption compensation in the 4I-UFP case. The respective dashed lines depict the consumption compensation in the unconstrained monetary policy case. Note that for each productivity group, the respective solid and dashed lines lie exactly on top of each other. In other words, each household has the same ex-ante welfare with 4I-UFP and unconstrained monetary policy. On average, consumption compensation for both policies is 4.6%.

Given the equivalence in macroeconomic aggregates and welfare, we conclude that 4I-UFP is a perfect substitute for unconstrained monetary policy at the ZLB.

drop in consumption in the constrained monetary policy case is the same as in our baseline. We obtain an average lifetime consumption compensation of 0.12 for 4I-UFP and unconstrained monetary policy.

5 Less Fiscal Instruments

How important are the instruments that replicate the redistribution dynamics of unconstrained monetary policy? In this section, we show that without lump-sum transfers and an adjustment of the government debt level in the long-run, UFP neither replicates the dynamics of macroeconomic aggregates nor the welfare of unconstrained monetary policy.

5.1 3-Instrument-UFP

First, we analyze UFP which consists of three instruments: consumption taxes, labor taxes, and debt-financed transfers set according to Eqs. (31), (32), and (34), respectively. Yet, fiscal policy does not increase the government debt level in the long-run, but brings back government debt to its old steady state level, $B^{\bar{UFP}} = \bar{B} = 90\%$ of annual GDP. Correspondingly, government debt only increases temporarily, at most to 98.3%, to finance the increase in lump-sum transfers while the ZLB is binding. Eventually, lower transfers pay back the newly issued debt.

Figure 4 compares the 3I-UFP (blue, dashed lines) case with unconstrained monetary policy (red, solid lines) in response to the same discount factor shock as in Section 4.[24] It becomes evident that 3I-UFP still nearly replicates macroeconomic aggregates of unconstrained monetary policy in the short-run because the impulse responses of output, consumption, and inflation lie almost on top of each other. Yet, without the fourth instrument, the government does not satisfy the increased asset demand of households induced by the higher precautionary savings motive with the new tax regime.[25] This puts downward pressure on the real interest rates because the supply of bonds is fixed in the long-run.

As a consequence, the real interest rate converges to a lower steady state level of 1.8%

[24] Note that the constrained monetary policy case (not shown) and the unconstrained monetary policy case are the same as in Figure 1. We increase the time horizon from 16 to 60 periods to show the long-run effects.

[25] The reason for higher precautionary savings is the same as in Section 4: conditional on the asset position, the tax payments of lower productivity households increase by more than the tax payments of higher productivity households (see Figure 2). This increases the gap in disposable income among productivity levels and, thus, the income risk.

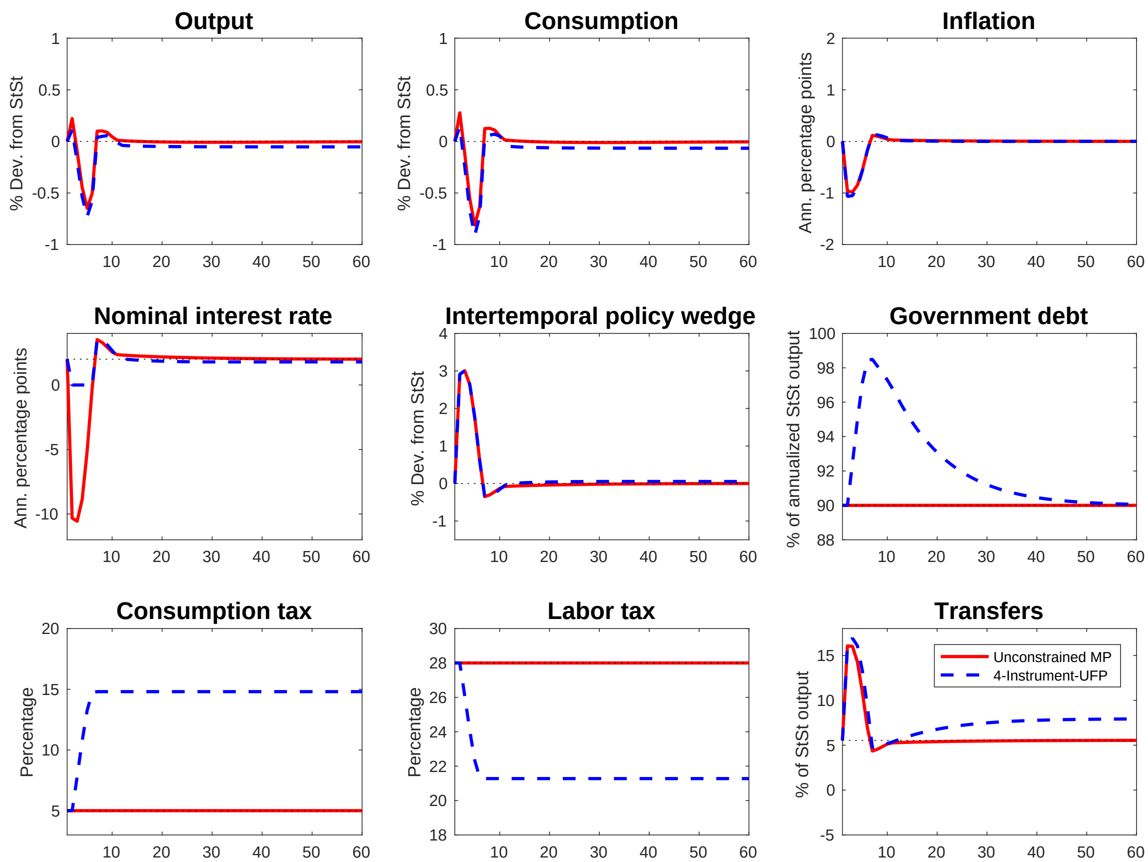

Figure 4: Impulse response functions after a shock to the discount factor with a Taylor rule without a lower bound ("Unconstrained MP") and with a truncated Taylor rule and an additional 3-Instrument-UFP stimulus ("3-Instrument-UFP"). Horizontal axes denote quarters.

instead of 2.0%. In this economy, households face worse insurance possibilities so that high productivity households decrease their labor supply. Figure 4 reflects that with 3I-UFP, the economy converges to a detrimental steady state in which output is around 0.05% smaller than in the old steady state.[26] Therefore, 3I-UFP contains a trade-off between short-run stabilization and long-run inefficiencies. Our welfare analysis in Figure 5 shows that the costs of these long-run inefficiences are substantial: each household is worse off than with 4I-UFP and average consumption compensation of 3I-UFP drops to 0.28% instead of 4.6% with 4I-UFP.

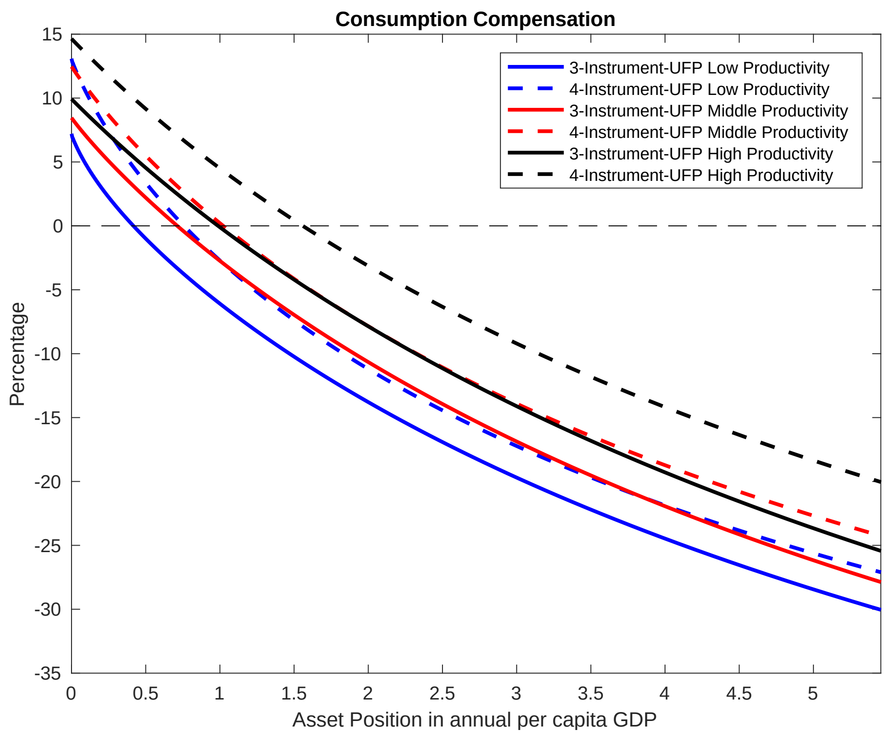

Figure 5: Consumption compensation for 4 quarters for each household such that she is indifferent between the respective policy and constrained monetary policy.

5.2 2-Instrument-UFP

This section shows how UFP as proposed by Correia et al. (2013) performs in a HANK model. This 2I-UFP consists only of two instruments: consumption taxes and labor taxes

[26]The negative effect of a lower asset supply on the new steady state output has also been highlighted by Guerrieri and Lorenzoni (2017).

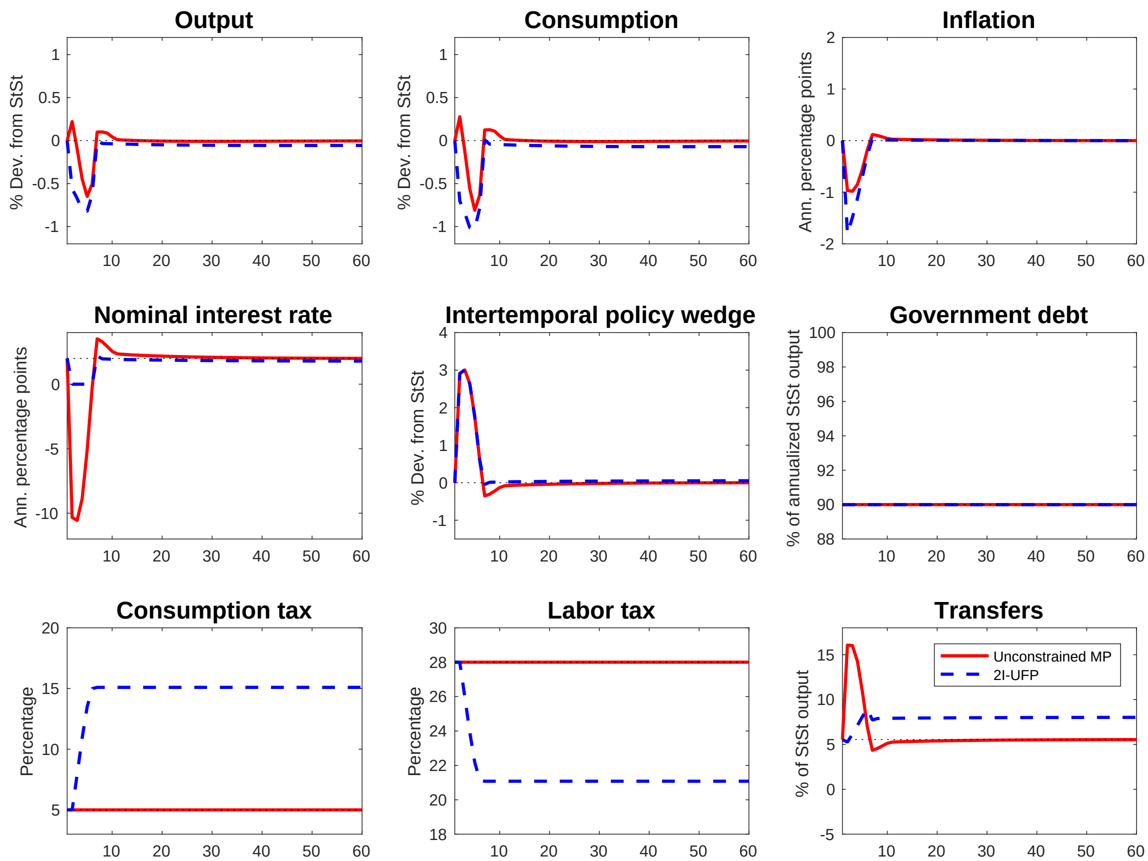

Figure 6: Impulse response functions after a shock to the discount factor with a Taylor rule without a lower bound ("Unconstrained MP") and with a truncated Taylor rule and an additional 2-Instrument-UFP stimulus ("2-Instrument-UFP"). Horizontal axes denote quarters.

set according to Eqs. (31) and (32), respectively.

Figure 6 compares the 2I-UFP (blue, dashed lines) case with unconstrained monetary policy (red, solid lines) in response to the same discount factor shock as in Section 4. With 2I-UFP, fiscal policy fails to replicate the macroeconomic dynamics even in the short-run. 2I-UFP is less stimulating than unconstrained monetary policy as it falls short in providing additional resources to asset-poor (and therefore high MPC) households while the ZLB is binding.[27] Accordingly, output drops on impact by -0.6%, consumption by -0.7%, and inflation by -1.8 annual percentage points.[28]

[27]This stimulative effect of transfer policies is a common feature in HANK models as Ricardian equivalence does not hold (Oh and Reis, 2012, Hagedorn et al., 2019b, Bayer et al., 2020, Wolf, 2021).

[28]Note that the long-run inefficiencies discussed in Section 5.1 are also present with 2I-UFP.

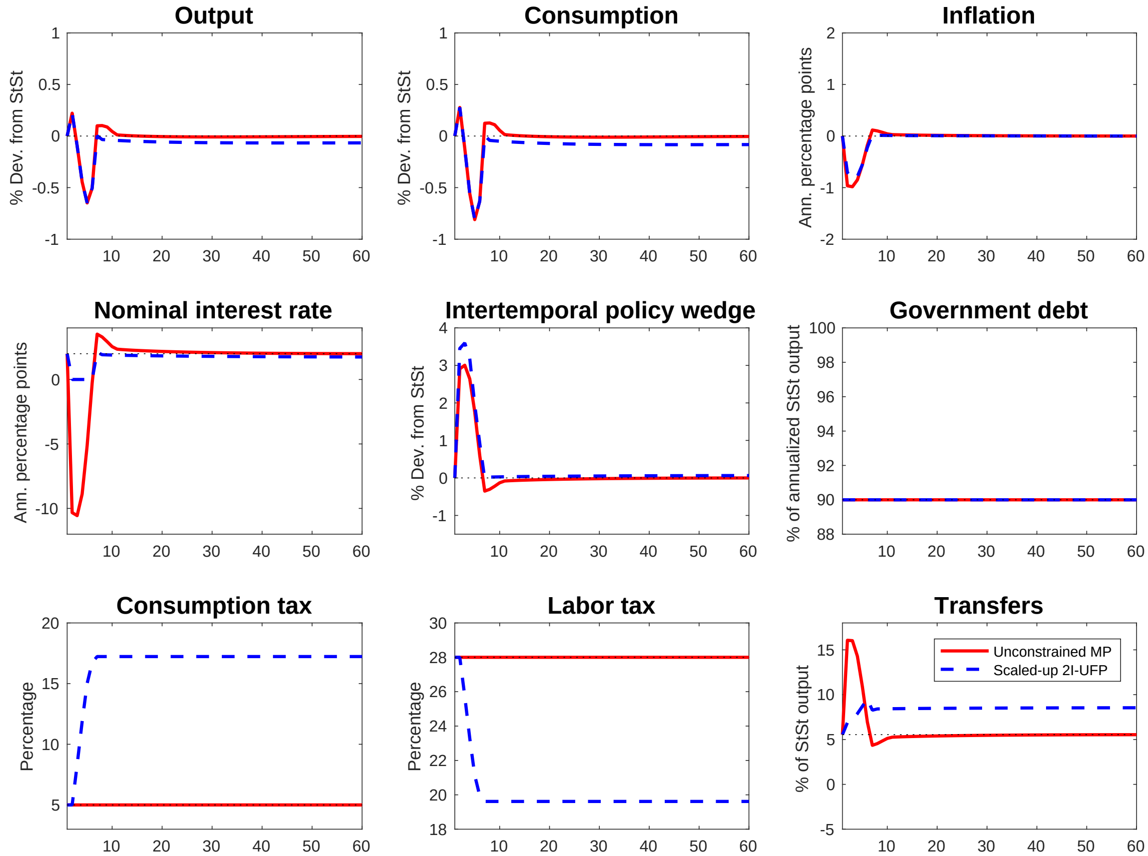

Figure 7: Impulse response functions after a shock to the discount factor with a Taylor rule without a lower bound ("Unconstrained MP") and with a truncated Taylor rule and an additional Scaled-up 2-Instrument-UFP stimulus ("Scaled-up 2I-UFP"). Horizontal axes denote quarters.

Scaling Up 2I-UFP. Figure 7 shows an experiment in which 2I-UFP compensates for the lack of stimulation through the redistribution channel by a more aggressive stimulation through the intertemporal substitution channel. Consumption taxes do no longer follow condition (31). Instead, they target the consumption dynamics of unconstrained monetary policy while the ZLB is binding. The path of consumption taxes is now scaled-up and increases in total from 5.0% to 17.2% (instead of to 14.3%). Correspondingly, the labor taxes decrease from 28.0% to 19.6% still following condition (32).

By construction, the IRFs of output and consumption of Scaled-up 2I-UFP and unconstrained monetary policy in Figure 7 lie on top of each other while the ZLB is binding. Yet, the new tax regime induces detrimental long-run effects: due to the strong increase (decrease) of consumption (labor) taxes, the downward pressure on the real interest rate is substantial. Consequently, the economy converges to a new steady state in which the real interest rate is 1.75% annual percentage points (vs. 2.0%) and steady state output declines by −0.06% compared to the old steady state output.

From a welfare perspective, these long-run costs even outweigh the gains of the short-run stabilization. Scaled-up 2I-UFP yields an average consumption compensation for 4 quarters of −0.35%. That is, on average households prefer the constrained monetary policy case compared to Scaled-up 2I-UFP.

6 Conclusion

In this paper, we show that fiscal policy achieves the same macroeconomic aggregates and the same welfare as hypothetically unconstrained monetary policy at the ZLB in HANK. The insight is that fiscal policy can replicate the transmission mechanism of monetary policy. In particular, we highlight the importance of replicating the redistribution dynamics of monetary policy in models with household heterogeneity.

Given our results, we conclude that fiscal policy is an appropriate macroeconomic stabilization tool when conventional monetary policy proves ineffective at the ZLB. In future work, it would be interesting to compare different macroeconomic stabilization policies that achieve the same macroeconomic aggregates as unconstrained monetary policy but differ in the transmission mechanism. In particular, a better understanding of their respective impact on distributional outcomes might be desirable.

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A TANK model

A.1 Households

All households are infinitely lived and have the same CRRA preferences with separable disutility from labor:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{c_{h,t}^{1-\gamma}}{1-\gamma} - \frac{l_{h,t}^{1+\psi}}{1+\psi} \right].$$

The decision problem of Ricardian households is to maximize their utility subject to equation (3) by choosing c_t^R, l_t^R, and b_t^R. The decision problem of HtM households is to maximize their utility subject to equation (5) by choosing c_t^H and l_t^H.

A.2 Firms

Final good firms produce in a perfectly competitive market using intermediate goods as inputs. Their decision problem is

$$\max_{y_{j,t}} \left\{ P_t Y_t - \int_0^1 p_{j,t} y_{j,t} dj \right\},$$

subject to a CES production technology

$$Y_t = \left(\int_0^1 y_{j,t}^{1/\mu} dj \right)^{\mu},$$

where $y_{j,t}$ denotes the intermediate good produced by firm j and $p_{j,t}$ is the corresponding price. Y_t is the final consumption good, P_t is the overall price index and μ measures the degree of substitution between the input factors. The aggregate price index is given by:

$$P_t = \left(\int_0^1 p_{j,t}^{1/(1-\mu)} dj \right)^{1-\mu}.$$

Solving the maximization problem yields the demand function of the final firm for the intermediate good j:

$$y_{j,t} = \left(\frac{p_{j,t}}{P_t} \right)^{\frac{\mu}{1-\mu}} Y_t. \tag{35}$$

Intermediate goods are produced by a continuum of intermediate good firms in monopolistic competition and μ determines their market power. Intermediate good firms produce according to:

$$y_{j,t} = n_{j,t}.$$

Following Correia et al. (2013), we assume that price setting takes place before consumption taxes. As in Calvo (1983), we allow an intermediate good firm to reset its price only with a certain probability, θ. If a firm is allowed to reset its prices, it solves the following non-static maximization problem:

$$\max_{p_t^*, \{y_{j,s}, n_{j,s}\}_{s=t}^{\infty}} \sum_{s=t}^{\infty} \beta^{s-t}(1-\theta)^{s-t} \left(\frac{\tilde{p}_t}{P_s} y_{j,s} - w_s n_{j,s} \right),$$

subject to the final good firms' demand given in equation (35).
The optimal price ratio $\tilde{p}_t / P_t$ that solves this problem is given by:

$$\frac{\tilde{p}_t}{P_t} = \frac{\sum_{s=t}^{\infty} \beta^{s-t}(1-\theta)^{s-t} \left(\frac{P_t}{P_s}\right)^{\frac{\mu}{1-\mu}} Y_s \mu w_s}{\sum_{s=t}^{\infty} \beta^{s-t}(1-\theta)^{s-t} \left(\frac{P_t}{P_s}\right)^{\frac{\mu}{1-\mu}} Y_s}.$$

Let $(1 + \pi_{t+1}) = \frac{P_{t+1}}{P_t}$ denote the gross inflation rate.

A.3 Aggregation and Market Clearing

The aggregate production function of the economy is given by:

$$S_t Y_t = \int_0^1 n_{j,t} dj \equiv N_t,$$

with N_t being the aggregate demand of labor by firms. S_t is given by:

$$S_t \equiv \int_0^1 \left(\frac{p_{j,t}}{P_t} \right)^{\frac{\mu}{1-\mu}} dj \geq 1.$$

and evolves according to:

$$S_{t+1} = (1-\theta) S_t (1 + \pi_{t+1})^{\frac{-\mu}{1-\mu}} + \theta \left(\frac{p_{t+1}^*}{P_{t+1}} \right)^{\frac{\mu}{1-\mu}}.$$

Inflation is given by:

$$1+\pi_t = \left(\frac{1-\theta}{1-\theta(\frac{p_t^*}{P_t})^{\frac{1}{1-\mu}}}\right)^{1-\mu}.$$

Aggregate labor supply, consumption, and savings are:

$$L_t = \lambda l_{H,t} + (1-\lambda) l_{R,t},$$

$$C_t = \lambda c_{H,t} + (1-\lambda) c_{R,t},$$

and

$$B_t^d = (1-\lambda) b_{R,t},$$

respectively. Given these aggregates, labor market clearing requires:

$$L_t = N_t,$$

the bond market clears when:

$$\bar{B} = B_t^d,$$

and the goods market clears when:

$$Y_t = C_t.$$

Dividend payments are given by:

$$D_t = Y_t - w_t L_t.$$

A.4 Equilibrium

We define an equilibrium of the economy to consist of sequences of variables

$$X \equiv \left\{c_{R,t}, l_{R,t}, b_{R,t}, c_{H,t}, l_{H,t}, Y_t, D_t, w_t, \pi_t, \tilde{p}_t/P_t, Tr_t, r_t, \tau_t^C, \tau_t^L, \tau_t^R\right\}_{t=0}^{\infty}$$

that

1. are consistent with the households' behavior described in Eq. (1-5)

2. are consistent with optimal behavior of the firms,

3. satisfy the government's budget constraint (6),

4. and that satisfy asset, labor, and goods markets clearing conditions.

B Policy-induced redistribution of monetary policy and UFP in TANK

B.1 Monetary policy

In this section, we derive the policy-induced redistribution Ξ_t^{MP} in the monetary policy case. We start with the budget constraint of the Ricardian household (3) in an arbitrary time t, where the real interest rate is r_t and taxes are at their steady state levels $\bar{\tau^C}, \bar{\tau^C}$. Consistent with our definition of the policy-induced redistribution, we set the remaining variables to its steady state value, $\{c_{H,t}, c_{R,t}, l_{H,t}, l_{R,t}, d_t, w_t\} = \{\bar{c_H}, \bar{c_R}, \bar{l_H}, \bar{l_R}, \bar{d}, \bar{w}\}$ and insert the asset market clearing condition $(1-\lambda)b_{R,t} = \bar{B}$:

$$\tilde{I_t^R} = -\left(1+\bar{\tau^C}\right)\bar{c_R} - \frac{1}{1-\lambda}\left(\frac{1}{1+r_t} - 1\right) * \bar{B} + \left(1-\bar{\tau^L}\right)\bar{w}\bar{l_R} + \bar{d} + \tilde{Tr}_t - \frac{\lambda}{1-\lambda}\psi. \quad (36)$$

We label $\tilde{I_t^R}$ the excess income of the Ricardian household in period t induced by changes in policy variables. Solving the government budget constraint with the interest rate at period t (but with constant behavior of the agents) gives $\tilde{Tr} = (\frac{1}{1+r_t} - 1)\bar{B} + \bar{T}$. This can be interpreted as the policy-induced partial equilibrium transfer. Hence, $\tilde{I_t^R}$ differs only from steady state through the changed savings and the direct effect of the real interest rate on transfers. Inserting $\tilde{Tr}_t$ in equation (36) and using the steady state budget constraint of the Ricardian household yields:

$$\begin{aligned}\tilde{I_t^R} &= -\frac{1}{1-\lambda}\bar{B}\left(\frac{1}{1+r_t} - \frac{1}{1+\bar{r}}\right) + \left(\frac{1}{1+r_t} - 1\right)\bar{B} + \bar{T} - \bar{Tr} \\ &= \left(1 - \frac{1}{1-\lambda}\right)\left(\frac{1}{1+r_t} - \frac{1}{1+\bar{r}}\right)\bar{B}.\end{aligned}$$

Aggregating over all Ricardian households yields:

$$(1-\lambda)\tilde{I_t^R} = -\lambda\left(\frac{1}{1+r_t} - \frac{1}{1+\bar{r}}\right)\bar{B} := \Xi_t^{MP}.$$

As $\tilde{Tr_t}$ ensures a constant government debt level, the aggregate excess income of the Ricardian households in period t needs to be the negative of the aggregate excess income of the HtM households in period t. In other words, this is the *policy-induced redistribution* of monetary policy in period t.

B.2 UFP

In this section, we derive the policy-induced redistribution Ξ_t^{UFP} in the UFP case. We start with the budget constraint of the Ricardian household (3) in an arbitrary time t where the taxes τ_t^C, τ_t^L, Tr_t are set according to Proposition (1) and the real interest rate is at its steady state level $\bar{r}$. Consistent with our definition of the policy-induced redistribution, we set remaining variables to its steady state values, $\{c_{H,t}, c_{R,t}, l_{H,t}, l_{R,t}, d_t, w_t\} = \{\bar{c_H}, \bar{c_R}, \bar{l_H}, \bar{l_R}, \bar{d}, \bar{w}\}$ and insert the asset market clearing condition $(1-\lambda)b_{R,t} = \bar{B}$:

$$\tilde{I_t^R} = -\big(1+\tau_t^C\big)\bar{c_R} - \frac{1}{1-\lambda}\left(\frac{1}{1+\bar{r}} - 1\right) * \bar{B} + \big(1-\tau_t^L\big)\bar{w}\bar{l_R} + \bar{D} + Tr_t^{UFP} - \tilde{\tau_t^R} - \frac{\lambda}{1-\lambda}\psi.$$

We label $\tilde{I_t^R}$ the excess income of the Ricardian household in period t induced by changes in policy variables. Using the steady state budget constraint and after some rearranging, we obtain:

$$\tilde{I_t^R} = Tr_t^{UFP} - (\tau_t^L\bar{w}\bar{L} + \tau_t^C\bar{C}) - \tilde{\tau_t^R} - \left(\frac{1}{1+\bar{r}} - 1\right)\bar{B}$$

Solving the government budget constraint with the tax rates and the transfers at period t (but with constant behaviour of the agents) gives $\tilde{\tau_t^R} = 1/(1-\lambda)(\bar{B}(1-1/(1+\bar{r})) + Tr_t^{UFP} - (\tau_t^L\bar{w}\bar{L} + \tau_t^C\bar{C}))$. This can be interpreted as the policy-induced partial equilibrium tax on Ricardian households. Hence $\tilde{I_t^R}$ differs only from steady state through the changed tax rates and the transfer. Inserting $\tilde{\tau_t^R}$ in equation (36) and again after some rearranging, we obtain:

$$\tilde{I_t^R} = -\frac{\lambda}{1-\lambda}\frac{1+\tau_t^C}{1+\bar{\tau^C}}\left(\frac{1}{1+r_t}-\frac{1}{1+\bar{r}}\right)\bar{B} + \frac{\lambda}{1-\lambda}\left(\tau_t^L\bar{w}\bar{L} + \tau_t^C\bar{C} + \bar{D} - \frac{1+\tau_t^C}{1+\bar{\tau^C}}(\bar{\tau^L}\bar{w}\bar{L} + \bar{\tau^C}\bar{C} + \bar{D})\right)$$
$$= -\frac{\lambda}{1-\lambda}\frac{1+\tau_t^C}{1+\bar{\tau^C}}\left(\frac{1}{1+r_t}-\frac{1}{1+\bar{r}}\right)\bar{B}$$

As the second term in the first line is 0 given that taxes are set according to condition (8).

Aggregating over all Ricardian households yields:

$$(1-\lambda)\tilde{I_t^R} = -\lambda\frac{1+\tau_t^{C,UFP}}{1+\bar{\tau^C}}\left(\frac{1}{1+r_t}-\frac{1}{1+\bar{r}}\right)\bar{B} := \Xi_t^{UFP}.$$

As $\tilde{\tau_t^R}$ ensures a constant government debt level, the aggregate excess income of the Ricardian households in period t needs to be the negative of the aggregate excess income of the HtM households in period t. In other words, this is the *policy-induced redistribution* of UFP in period t. It directly follows that $\Xi_t^{UFP} = \frac{1+\tau_t^{C,UFP}}{1+\bar{\tau^C}}\Xi_t^{MP}$.

B.3 RANK UFP

In this section, we derive the policy-induced redistribution Ξ_t^{UFP} in the UFP case, in which only the tax rates are set according to conditions (7) and (8), but $\tau_t^R = \bar{\tau}^R = 0$. We start with the budget constraint of the Ricardian household (3) in an arbitrary time t where the tax rates are τ_t^C, τ_t^L and the real interest rate is at its steady state level $\bar{r}$. Consistent with our definition of the policy-induced redistribution, we set $\{c_{H,t}, c_{R,t}, l_{H,t}, l_{R,t}, d_t, w_t\} = \{\bar{c_H}, \bar{c_R}, \bar{l_H}, \bar{l_R}, \bar{d}, \bar{w}\}$ and insert the asset market clearing condition $(1-\lambda)b_{R,t} = \bar{B}$:

$$\tilde{I_t^R} = -\big(1+\tau_t^C\big)\bar{c_R} - \frac{1}{1-\lambda}\left(\frac{1}{1+\bar{r}}-1\right) * \bar{B} + \big(1-\tau_t^L\big)\bar{w}\bar{l_R} + \bar{d} + \tilde{Tr}_t - \frac{\lambda}{1-\lambda}\psi.$$

We label $\tilde{I_t^R}$ the excess income of the Ricardian household in period t induced by changes in policy variables. Solving the government budget constraint with the tax rates at period t (but with constant behaviour of the agents) gives $\tilde{Tr} = (\frac{1}{1+\bar{r}}-1)\bar{B} + \tau_t^C\bar{C}_R + \tau_t^L\bar{w}\bar{l_R}$. This can be interpreted as the policy-induced partial equilibrium transfer. Hence $\tilde{I_t^R}$ differs only from steady state through the changed tax rates and their direct effect on transfers. Inserting $\tilde{Tr}_t$ in equation (36) and using the steady state budget constraint of the Ricardian household yields:

$$
\begin{aligned}
\tilde{I_t^R} = -\left(1+\tau_t^C\right)\bar{c_R} + \left(1+\bar{\tau^C}\right)\bar{c_R} + \left(1-\tau_t^L\right)\bar{w} - \left(1-\bar{\tau^L}\right)\bar{w} + \tilde{Tr}_t - \bar{Tr} \\
= -\left(\tau_t^C - \bar{\tau^C}\right)\bar{C_R} + \left(-\tau_t^L + \bar{\tau^L}\right)\bar{w}\bar{l_R} + \tau_t^C\bar{C_R} + \tau_t^L\bar{w}\bar{l_R} - \left(\bar{\tau^C}\bar{C_R} + \bar{\tau_t^L}\bar{w}\bar{l_R}\right) \\
= 0.
\end{aligned}
$$

As there is zero excess income of Ricardian households inducedy by policy variables, there is no policy-induced redistribution from Ricardian households to HtM households and hence, $\Xi_t^{UFP} = 0$.

C Proof of Proposition 1

Let us assume that

$$
\begin{aligned}
X^{MP} = \{c_{R,t}^*, l_{R,t}^*, b_{R,t}^*, c_{H,t}^*, l_{H,t}^*, Y_t^*, D_t^*, w_t^*, \pi_t^*, \tilde{p_t}^*/P_t^*, Tr_t^{MP}, r_t^{MP}, \tau_t^C, \tau_t^L, \tau^R\}_{t=0}^{\infty}, \\
\text{with } (\tau_t^C, \tau_t^L, \tau_t^R) = (\bar{\tau^C}, \bar{\tau^L}, \bar{\tau^R})\forall t
\end{aligned}
$$

is the equilibrium path induced by the monetary policy experiment in Section (2.2). We now show that

$$
\begin{aligned}
X^{UFP} = \{c_{R,t}^*, l_{R,t}^*, b_{R,t}^*, c_{H,t}^*, l_{H,t}^*, Y_t^*, D_t^*, w_t^*, \pi_t^*, \tilde{p_t}^*/P_t^*, Tr_t^{UFP}, r_t, \tau_t^{C,UFP}, \tau_t^{L,UFP}, \tau_t^{R,UFP}\}_{t=0}^{\infty} \\
\text{with } r_t = \bar{r}\forall t
\end{aligned}
$$

is also an equilibrium if $\tau_t^{L,UFP}, \tau_t^{C,UFP}, Tr_t^{UFP}$, and $\tau_t^{R,UFP}$ satisfy conditions (7), (8), (9), and (10), respectively. First note that since neither the real interest rate nor the policy variables show up in any equilibrium condition of the firm side, it is sufficient to show that X^{UFP} satisfies the households' equilibrium conditions and the government's budget constraint.

Satisfying the households' equilibrium conditions. Equivalence in the first-order conditions of households is straightforward: any path of consumption, $\{c_{R,t}^*\}_{t=0}^{\infty}$, that satisfies the sequence of the Ricardian's Euler equations with $\{r_t^{MP}\}_{t=0}^{\infty}$ and steady state tax rates, also satisfies the sequence of the Ricardian's Euler equations with interest rates in steady state and $\{\tau_t^{C,UFP}\}_{t=0}^{\infty}$ which satisfies condition (7). In addition, any paths of consumption and labor, $\{c_{R,t}^*, l_{R,t}^*\}_{t=0}^{\infty}$, (any paths of $\{c_{H,t}^*, l_{H,t}^*\}_{t=0}^{\infty}$) that satisfy the sequence of labor-leisure equations of the Ricardian household (the labor-leisure condition of the HtM household) with steady state taxes, satisfy the sequence of labor-leisure conditions of the Ricardian household (of the HtM household) if $\{\tau_t^{L,UFP}, \tau_t^{C,UFP}\}_{t=0}^{\infty}$ satisfy condition (8).

Let us now define the path of transfers Tr_t^{UFP} that is needed for each type of household such that their respective behavior, $\{c^*_{R,t}, l^*_{R,t}\}_{t=0}^{\infty}$ and $\{c^*_{H,t}, l^*_{H,t}\}_{t=0}^{\infty}$ is feasible. Let us start with the HtM household. In the monetary policy experiment, we have:

$$c^*_{H,t} = \frac{1-\bar{\tau^L}}{1+\bar{\tau^C}} w_t^* l^*_{H,t} + \frac{d_t^*}{1+\bar{\tau^C}} + \frac{Tr_t^{MP}}{1+\bar{\tau^C}} + \frac{\psi}{1+\bar{\tau^C}}. \tag{37}$$

Assuming $l_{H,t} = l^*_{H,t}$, in the UFP case, we have:

$$c^{UFP}_{H,t} = \frac{1-\tau_t^L}{1+\tau_t^C} w_t^* l^*_{H,t} + \frac{d_t^*}{1+\tau_t^C} + \frac{Tr_t^{UFP}}{1+\tau_t^C} + \frac{\psi}{1+\tau_t^C}. \tag{38}$$

$c^{UFP}_{H,t} = c^*_{H,t}$ if:

$$Tr_t^{UFP} = (d_t^* + \psi)\left(\frac{1+\tau_t^C}{1+\bar{\tau^C}} - 1\right) + \frac{1+\tau_t^C}{1+\bar{\tau^C}} Tr_t^{MP}, \tag{39}$$

which is exactly the transfer condition in Proposition 1.

For the Ricardian household, we have in the monetary policy experiment (using the asset market clearing condition):

$$c^*_{R,t} = \frac{1}{1-\lambda}\frac{\bar{B}}{1+\bar{\tau^C}}\left(1 - \frac{1}{1+r_t^{MP}}\right) + \frac{1-\bar{\tau^L}}{1+\bar{\tau^C}} w_t^* l^*_{R,t} + \frac{d_t^*}{1+\bar{\tau^C}} + \frac{Tr_t^{MP}}{1+\bar{\tau^C}} - \frac{\lambda}{1-\lambda}\frac{\psi}{1+\bar{\tau^C}}.$$

Assuming $l_{H,t} = l^*_{H,t}$, we have in the UFP case:

$$c^{UFP}_{R,t} = \frac{1}{1-\lambda}\frac{\bar{B}}{1+\tau_t^C}\left(1 - \frac{1}{1+\bar{r}}\right) + \frac{1-\tau_t^L}{1+\tau_t^C} w_t^* l^*_{R,t} + \frac{d_t^*}{1+\tau_t^C} + \frac{Tr_t^{UFP}}{1+\tau_t^C} - \frac{\tau_t^R}{1+\tau_t^C} - \frac{\lambda}{1-\lambda}\frac{\psi}{1+\tau_t^C}.$$

Using $\psi = \bar{B}(1 - \frac{1}{1+\bar{r}})$, $c^{UFP}_{R,t} = c^*_{R,t}$ if:

$$\begin{aligned} Tr_t^{UFP} = d_t^*\left(\frac{1+\tau_t^C}{1+\bar{\tau^C}} - 1\right) + \frac{1+\tau_t^C}{1+\bar{\tau^C}} Tr_t^{MP} t + \tau_t^R + \frac{\bar{B}}{1-\lambda}\frac{1+\tau_t^C}{1+\bar{\tau^C}}\left(1 - \frac{1}{1+r_t^{MP}}\right) \\ - \frac{\bar{B}}{1-\lambda}\left(1 - \frac{1}{1+\bar{r}}\right) - \frac{\lambda}{1-\lambda}\bar{B}\left(1 - \frac{1}{1+\bar{r}}\right)\left(\frac{1+\tau_t^C}{1+\bar{\tau^C}} - 1\right). \end{aligned}$$

If $\tau_t^{R,UFP}$ is set according to condition (10), this becomes:

$$Tr_t^{UFP} = (d_t^* + \psi)\left(\frac{1+\tau_t^C}{1+\bar{\tau^C}} - 1\right) + \frac{1+\tau_t^C}{1+\bar{\tau^C}} Tr_t^{MP},$$

and, hence, again the transfer from Proposition (1). In other words: Feasibility of $\{c^*_{R,t}, l^*_{R,t}\}^\infty_{t=0}$ (of $\{c^*_{H,t}, l^*_{H,t}\}^\infty_{t=0}$) in the monetary policy experiment implies feasibility of $\{c^*_{R,t}, l^*_{R,t}\}^\infty_{t=0}$ (of $\{c^*_{H,t}, l^*_{H,t}\}^\infty_{t=0}$) in the UFP case.

Satisfying the government's budget constraint. We now show, that $\tau_t^{L,UFP}$, $\tau_t^{C,UFP}$, and Tr_t^{UFP} set according to Proposition 1 as well as $\tau_t^{R,UFP}$ set according to equation (10) satisfy the government's budget constraint. From the government's budget constraint in the monetary policy experiment, we obtain:

$$Tr_t^{MP} = \bar{B}\left(\frac{1}{1+r_t^{MP}} - 1\right) + T_t^{MP},$$

where $T_t^{MP} = \bar{\tau^C} C^* + \bar{\tau^L} w^* L^*$. Inserting Tr_t^{UFP} set according to equation (39) (and using Tr_t^{MP}) as well as τ_t^R set according to condition (10) into the government budget constraint yields:

$$\begin{aligned}
d_t^*\left(\frac{1+\tau_t^C}{1+\bar{\tau^C}} - 1\right) + \left(\frac{1+\tau_t^C}{1+\bar{\tau^C}}\right)\bar{B}\left(\frac{1}{1+r_t^{MP}} - 1\right) + \frac{1+\tau_t^C}{1+\bar{\tau^C}} T_t^{MP} \\
+\bar{B}\left(1 - \frac{1}{1+\bar{r}}\right)\left(\frac{1+\tau_t^C}{1+\bar{\tau^C}} - 1\right) = \bar{B}\left(\frac{1}{1+\bar{r}} - 1\right) + T_t^{UFP} \\
+\left(\frac{1+\tau_t^C}{1+\bar{\tau^C}} - 1\right)\bar{B}\left(\frac{1}{1+r_t^{MP}} - \frac{1}{1+\bar{r}}\right).
\end{aligned}$$

Collecting terms gives:

$$d_t^*\left(\frac{1+\tau_t^C}{1+\bar{\tau^C}} - 1\right) + \frac{1+\tau_t^C}{1+\bar{\tau^C}} T_t^{MP} - T_t^{UFP} = 0.$$

Using the goods market clearing condition, $Y_t = C_t$, and the profit equation $d_t = Y_t - w_t L_t$, it now holds that (dropping the superscript UFP for the sake of readability):

$$\begin{aligned}
d_t^*\left(\frac{1+\tau_t^C}{1+\bar{\tau^C}} - 1\right) * \frac{1+\tau_t^C}{1+\bar{\tau^C}}(\bar{\tau^C} C^* + \bar{\tau^L} w_t^* L_t^*) = \tau_t^C C_t^* + \tau_t^L w_t^* L_t^* \\
\iff d_t^*(\tau_t^C - \bar{\tau^C}) + C_t^*(\bar{\tau^C} - \tau_t^C) = (\tau_t^L + \bar{\tau^C}\tau_t^L - \bar{\tau^L} - \tau_t^C \bar{\tau^L})(C_t^* - d_t^*) \\
\iff (\bar{\tau^C} - \tau_t^C - \tau_t^L - \bar{\tau^C}\tau_t^L + \bar{\tau^L} + \tau_t^C\bar{\tau^L})C_t^* = (\bar{\tau^C} - \tau_t^C - \tau_t^L - \bar{\tau^C}\tau_t^L + \bar{\tau^L} + \tau_t^C\bar{\tau^L})d_t^*
\end{aligned}$$

Thus, the government budget constraint is satisfied, if:

$$
\begin{aligned}
&\bar{\tau^C} - \tau_t^C - \tau_t^L - \bar{\tau^C}\tau_t^L + \bar{\tau^L} + \tau_t^C\bar{\tau^L} = 0 \\
\iff &\bar{\tau^C} - \tau_t^C - (1+\bar{\tau^C})\tau_t^L + (1+\tau_t^C)\bar{\tau^L} = 0 \\
\iff &1 + \bar{\tau^C} - (1+\tau_t^C) + (1+\tau_t^C)\bar{\tau^L} = (1+\bar{\tau^C})\tau_t^L \\
\iff &-(1-\bar{\tau^L})(1+\tau_t^C) = (\tau_t^C - 1)(1+\bar{\tau^C}) \\
\iff &\frac{1-\tau_t^L}{1+\tau_t^C} = \frac{1-\bar{\tau^L}}{1+\bar{\tau^C}}.
\end{aligned}
$$

Which holds given that τ_t^C and τ_t^L are set according to condition (8).

Consistency with optimal behavior of firms. Given the same households' behavior $\{c_{R,t}^*, l_{R,t}^*, c_{H,t}^*, l_{H,t}^*\}_{t=0}^{\infty}$ in both policy cases, the firms also face the same demand for goods and the same supply of labor. Hence, if $\{w_t^*, d_t^*, \pi_t^*, \tilde{p_t}^*/P_t^*\}_{t=0}^{\infty}$, are equilibrium paths in the monetary policy experiment, they are also equilibrium paths in the UFP case.

Market clearing conditions. Given that households and firms behave exactly the same as in the monetary policy experiment and government debt is constant in both cases, X^{UFP} clears all markets if X^{MP} clears all markets.

Thus, we have proven that UFP set according to Proposition 1 leads to the same allocation as the monetary policy experiment which implies that UFP and monetary policy are perfect substitutes in TANK.