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Financial Regulation, Interest Rate Responses, and Distributive Effects[1]

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Abstract

This paper examines financial regulation and distortionary taxes in a heterogeneous-agents economy with pecuniary externalities induced by a collateral constraint. Limiting the loan-to-value ratio benefits only few unconstrained borrowers and reduces ex-ante social welfare. A Pigouvian-style symmetric debt tax (that subsidizes savings) raises collateral prices and lowers interest rates, which stimulates borrowing and generates welfare gains for almost all income groups. A Pigouvian-style asset subsidy induces a wealth appreciation, while an asset tax particularly benefits low-wealth borrowers and enhances social welfare. Overall, collateral effects are of minor importance and interest rate rather than asset price responses are decisive for welfare effects.

JEL classification: D31, E44, G28, H23

Keywords: Financial regulation, heterogeneous agents, collateral constraint, pecuniary externalities

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1 Introduction

The financial crisis of 2008-09 has steered attention toward the interaction between de-leveraging and asset prices. Given that the scope to borrow against collateral crucially depends on the price of (pledgeable) assets, borrowers tend to de-leverage in states where asset prices fall, giving rise to a financial amplification mechanism (see e.g. Kiyotaki and Moore, 1997). This can even be more pronounced when adverse effects of de-leveraging induce a further decline in the price of collateral. Given that (borrowing) agents do not internalize the impact of their behavior on prices, they might tend to overborrow. This pecuniary externality with regard to the collateral price provides a straightforward rationale for macroprudential financial regulation, as for example shown by Lorenzoni (2008), Bianchi (2011), Benigno et al. (2016), Jeanne and Korinek (2019, 2020), or Bianchi and Mendoza (2018).[3] These analyses are conducted in a class of models with exogenously determined interest rates and either an representative agent or agents with exogenously fixed characteristics, and focus on asset price and collateral effects induced by financial frictions. They show that the pecuniary externality regarding the collateral price can be corrected by an ex-ante policy that constrains or dis-incentivizes borrowing, such as the introduction of a limit on the loan-to-value ratio or a Pigouvian tax on borrowing.[4]

We contribute to this literature by developing an incomplete markets model with heterogeneous agents and with a price-dependent borrowing constraint to quantitatively explore distributive and welfare effects of financial regulation and Pigouvian-style taxes in financial markets.[5] To provide a sensible quantitative analysis, the model builds on a well-established heterogeneous agents framework (see Huggett, 1993) with an empirically relevant specification of household debt.[6] In this framework, individual agents cannot fully insure against idiosyncratic income risk and might face a binding collateral constraint depending on their stochastic income and their wealth. The interest rate adjusts endogenously and the borrowing constraint occasionally binds for individual agents, while it is permanently binding for a non-zero fraction of the population. We focus on policy effects in a stationary equilibrium and over a transition phase, complementing the analysis in the above-cited literature on policy effects under aggregate risk. We abstract from uncertainty stemming from aggregate shocks and from financial intermediation, such that our analysis is silent on the potential impact of the considered policy instruments on financial stability and intermediaries. The model is calibrated to match several aggregate and distributional targets based on US data, and we apply it to address the following questions:

1. What are the effects of financial regulation under idiosyncratic risk and an empirically plausible

[3] Based this mechanism, policy interventions with several types of instruments can be justified (Fornaro, 2015; Benigno et al. 2016; Korinek, 2018).

[4] An exception is Schmitt-Grohé and Uribe (2021), who find underborrowing under equilibrium multiplicity.

[5] Gottardi and Kubler (2015) examine a complete markets model with a collateral constraint and find that tighter restrictions on borrowing can enhance (constrained) efficiency.

[6] Since the 1980s, household debt secured by durable consumption goods (like vehicles or especially residential real estate) has accounted for more that 90% of US household debt in the United States (see Hintermaier and Koeniger, 2016), which we will calibrate our model to. Similar to Diaz and Luengo-Prado (2010), our model can replicate several distributional statistics observed in the data (see Section 3.1). This framework has been shown by Aaronson et al. (2012) to be consistent with individual household consumption behavior (see also Parker et al. 2013). A related model is used by Guerrieri and Lorenzoni (2017) to quantitatively analyze a debt-deleveraging crisis.

distribution of debt?

2. Are distributive effects of regulatory interventions in financial markets important for social welfare?

3. How relevant are changes in the interest rate compared to asset prices when borrowing is constrained by collateral?

To summarize, we find that policy interventions in credit and asset markets exert substantial effects on the interest rate and on the wealth distributition, which are – by construction – disregarded in the literature on macroprudential regulation.[7] In contrast, effects of externalities related to asset prices and collateral play a minor role. Our analysis shows that social welfare gains can predominantly be attributed to interest rate reductions and distributive effects, and that beneficial policies stimulate rather than dis-incentivize borrowing.

Our approach is motivated as follows: Davila and Korinek (2018) have shown that borrowing constraints can give rise to pecuniary externalities and inefficiencies based on effects exerted via a collateral constraint and via distributive effects between agents with distinct marginal rates of substitution. Using a model with two distinct groups of agents, they show that externalities are not only based on asset prices that determine the collateral value, but also on the interest rate on debt. Importantly, distributive effects induced by changes in asset/debt prices are scaled by individual debt and asset positions, such that a quantitative assessment of these distributive effects relies on modeling a meaningful wealth/debt distribution (which is beyond the scope of their analysis). As the main contribution, we extend the analysis of distributive and collateral effects by applying a model with an endogenous wealth/debt distribution. Specifically, we consider durables and secured household debt to facilitate calibration and to match several aggregate and distributional targets (see Diaz and Luengo-Prado, 2010, Aaronson et al. 2012, or Guerrieri and Lorenzoni, 2017). Complementary to this paper, Schabert (2021) shows for a stylized (three-period) version of our model that collateral effects and distributive effects stemming from pecuniary externalities are also relevant in this framework and that prudential policies (ex-ante debt taxes) as well as non-state-contingent policies (like savings subsidies) can enhance efficiency. Like in studies on macroprudential regulation, agents do not internalize that a higher demand for assets tends to increase its price and to thereby raise the borrowing limit. Moreover, agents do not internalize that more savings (less borrowing) induce a lower interest rate, which tends to decrease the amount of issued debt and thereby the likelihood of constrained borrowing. In this paper, we therefore consider policies that can potentially address pecuniary externalities with regard to the asset price as well as to the interest rate. We thereby restrict our attention to a small set of ad-hoc policy interventions,[8] which, on the one hand, are able to – at least partially – correct for the externalities associated with changes in asset prices

[7] An exception is Davila and Korinek (2018) who restrict their study to an analytically tractable (rather than quantitative) framework.

[8] Given that the distribution of wealth and the market price of collateral both are endogenous in the model, optimal corrective policies would require a set of individual tax rates that depend on income and wealth states, which cannot be computed in a straightforward way. Davila et al. (2012) calculate optimal corrective taxes for an Aiyagari (1994)-type economy by first directly solving for the constrained-efficient allocation. Doing so is not feasible in our model due to the presence of a borrowing constraint that depends on the endogenous collateral price. See Nuño and Moll (2018) for an approach similar to Davila et al. (2012) in continuous time.

and interest rates and, on the other hand, facilitate a transparent analysis of distributive and welfare effects. Concretely, we unexpectedly and permanently introduce a cap on the loan-to-value ratio, as a typical measure of financial regulation, and Pigouvian-style taxes in the markets for debt and durables.[9]

First, we examine the cap on the loan-to-value ratio (LTV), which has direct and indirect effects.[10] It directly limits the borrowing capacity of constrained agents and thereby leads to a decline in the credit volume, which further causes indirect price effects. The reduction in credit demand leads to a lower equilibrium interest rate. Savers respond by raising their demand for durables as a store of value, such that the price of durables increases. The effective LTV reduction tends to reduce welfare of agents in all income groups. For only few borrowers with relatively high income the indirect price effects dominate the direct effect such that they experience a welfare improvement. These unconstrained agents reduce their borrowing, which contributes to the lower interest rate. Hence, these agents would have been better off under laissez faire if they would internalize the interest rate effects of the borrowing decision. While the LTV reduction can in principle address this pecuniary externality, social welfare falls.[11] We further find that the effects of the LTV reduction on prices and welfare are slightly more pronounced in an artificial case of a price-inelastic borrowing constraint (PIBC) where the borrowing limit depends on the value of collateral at a fixed price. Thus, we do not find support for a substantial role of collateral (price) effects for this credit market intervention.

Second, we examine a potentially corrective tax in the debt market as a related policy instrument. Specifically, we introduce an anonymous and symmetric debt tax, which taxes borrowing and subsidizes savings. This policy intervention is particularly aimed at manipulating the interest rate by addressing – in contrast to the LTV reduction – both sides of the credit market. We neutralize effects on agents' available resources by type-specific lump-sum transfers/taxes (as in Davila and Korinek, 2018). Due to this Pigouvian-style tax, lenders tend to save more and borrowers tend to dis-save less, such that the interest rate declines. This induces an increase in the demand for durables (as a substitute for bonds) and thus in the price of durables/collateral. Compared to a LTV reduction, interest rate responses are relatively more pronounced than collateral price responses. In sharp contrast to the LTV reduction, the symmetric debt tax raises rather than lowers the aggregate credit volume, with constrained borrowers also issuing more debt. Overall, we find that welfare in all (except the highest) income states increases and that the symmetric debt tax enhances social welfare. Precisely, borrowers tend to gain and lenders tend to lose from the decline in the interest rate. Thus, this policy intervention induces price changes that provide partial insurance for borrowers from an ex-ante perspective, which is not internalized by individual agents in the laissez-faire economy. Our results, including a PIBC case, show that interest rate responses are more relevant than collateral price responses for the overall welfare effects under the

[9] Thus, we introduce all policy measures as so-called MIT shocks.

[10] Gottardi and Kubler (2015) find that tighter restrictions on borrowing can enhance efficiency in a model with state-contingent debt and an endogenous collateral constraint.

[11] Following several normative studies in the incomplete markets literature (see Conesa et al. 2009, Krueger et al. 2016, or Nuño and Moll, 2018), we measure social welfare as ex-ante expected lifetime utility, which is identical to utilitarian welfare.

symmetric debt tax.[12]

Third, we introduce a likewise Pigouvian-style tax/subsidy on end-of-period holdings of durables (again with lump-sum compensations). As a direct effect, a tax on durables dis-incentivizes purchases of durables and lowers their price. Agents substitute investment in durables in favor of savings (credit supply), such that the interest rate decreases. Thus, low-wealth borrowers tend to benefit from the intervention, whereas high-wealth savers tend to lose. Like the symmetric debt tax, the durables tax induces price changes that partially insure borrowers from an ex-ante perspective. Overall, the durables tax induces an increase in social welfare over the transition phase as well as in the long run. We find a higher welfare gain under a price-inelastic borrowing constraint (PIBC), where the borrowing constraint is not tightened by a lower durables price, indicating non-negligible collateral effects for this direct intervention in the market for durables/collateral. Nonetheless, we find that borrowing increases, regardless of the price-elasticity, indicating the crucial role of interest rate responses. In contrast to the durables tax, the social welfare effects differ between the short run and the long run under the opposite policy, i.e. a subsidy on durables. Under the latter policy, the durables price and the interest rate increase, such that high-wealth agents tend to gain and low-wealth agents tend to lose in the long run.[13] Given that the adverse effects on the latter group dominate, the durables subsidy leads to a social welfare loss in the long-run. Over the transition phase, when the distribution of bonds and durables is not yet adjusted, all income groups tend to gain from the wealth increase induced by the durables price appreciation. Given that the latter leads to an upward shift of the entire wealth distribution, social welfare including the transition phase increases under a durables subsidy. These results indicate that the distribution of wealth/debt matters for the effects of policy interventions and vice versa, i.e. policy interventions alter the distribution of wealth/debt.

To facilitate comparisons, the tax interventions in the markets for debt and durables were scaled to induce equally-sized effects on the long-run price of collateral. We then observe that the simultaneous change in the interest rate is much more pronounced under the tax/subsidy on debt. More specifically, whereas a tax on debt of 5% lowers the long-run real interest rate by 5.9 percentage points, a subsidy on durables of 0.6%, which results in the same long-run price of durables, yields an interest rate increase of 0.7 percentage points. We further find that the overall welfare effects of the former tax is about 20-times larger than under the tax/subsidy on durables. Hence, the impact of the policy interventions on the price of collateral is much less relevant than the impact on the interest rate under an empirically relevant debt distribution. This finding suggests that the role of collateral price effects is exaggerated when credit supply, interest rates changes, and distributive effects are disregarded. Yet, to disclose if there is nevertheless a role for macroprudential regulation requires an analysis under aggregate risk, which is beyond the scope of this paper.

The remainder of this paper is structured as follows. Section 2 develops the model and defines the

[12] In fact, price and welfare effects are almost identical under a price-inelastic borrowing constraint, indicating a negligible role of collateral effects.

[13] The latter do not internalize that raising their holdings of durables contributes to a beneficial increase in the durables price, which can be addressed by the durables subsidy.

recursive competitive equilibrium. Section 3 describes the calibration and presents results for our policy experiments. Section 4 concludes.

2 A model with incomplete markets and limited commitment

In this section, we develop an incomplete markets model with limited commitment to assess effects of policy interventions in financial markets. The model features infinitely many agents (households) facing idiosyncratic income shocks that are only partially insurable due to market incompleteness and a financial constraint that restricts borrowing. While households are identical ex-ante, the financial frictions lead to ex-post heterogeneity in assets and induce a non-degenerate wealth distribution. Furthermore, the financial constraint gives rise to inefficiencies due to pecuniary externalities.

There are infinitely many households of mass one $i \in [0,1]$ with preferences $E_t \sum_{s=0}^{\infty} \beta^s u_{i,t}$, where $\beta \in (0,1)$ denotes the discount factor and E_t the expectation operator. In each period t, a household i derives utility from consumption of a non-durable good, $c_{i,t}$, and a durable good, $d_{i,t}$, as given by the function

$$u_{i,t} = u(c_{i,t}, d_{i,t}), \tag{1}$$

which is strictly increasing and concave with respect to both arguments. Households face a random, idiosyncratic period income $y_{i,t} \in Y \equiv \{y_1, y_2, ..., y_N\}$, with $y_1 < y_2 < ... < y_N$, which follows a first-order Markov process with conditional transition probabilities $\pi(y_{i,t+1}|y_{i,t})$. The period-t budget constraint of a household i is given by

$$c_{i,t} + q_t(d_{i,t} - d_{i,t-1}) + b_{i,t}/r_t = b_{i,t-1} + y_{i,t}, \tag{2}$$

where q_t is the price of durables and $1/r_t$ (r_t) is the bond price (interest rate). The household's exogenous endowment, $y_{i,t}$, is in terms of non-durable goods. We assume that financial markets are incomplete and that the only financial asset is a non-state-contingent one-period bond. A bond issued in period t trades at price $1/r_t$ and promises the payment of one unit of a non-durable good, which serves as the numeraire in the model, in period $t+1$.

We further assume that there exists a financial friction, which gives rise to a borrowing constraint that can induce pecuniary externalities. Specifically, we assume that borrowers cannot commit to repay debt and that debt can be renegotiated after issuance in the same period. We allow borrowers to make a take-it-or-leave-it offer to reduce the value of debt. If the lender rejects the offer, he can seize a fraction $\gamma > 0$ of the borrower's assets (durable goods), which he can sell at the competitive market price q_t. Offers are therefore accepted when the repayment value of debt at least equals the current value of seizable assets. Without loss of generality, we assume that default and renegotiation never happen in equilibrium. Hence, when debt is issued, an individual borrower i has to take into account that the amount of debt $-b_{i,t}$ is constrained by

$$-b_{i,t} \leq \gamma q_t d_{i,t}, \tag{3}$$

where $d_{i,t}$ denotes the amount of the asset (durable good) held during the debt contract.

Given that renegotiation of debt issued in period t takes place in period t rather than in the subsequent period $t+1$, the borrowing constraint (3) features the price of the asset for the period of issuance q_t. Such a type of borrowing constraint is shared by many recent studies on macroprudential regulation (see, e.g., Bianchi and Mendoza, 2018, or Jeanne and Korinek, 2020), it is also common in quantitative studies with collateralized debt (see e.g. Favilukis et al. 2017, Lorenzoni and Guerrieri, 2017, or Berger et al. 2018), and it is consistent with empirical evidence (see Cloyne et al. 2019).[14]

Given initial bond and durable endowments $b_{i,-1} = 0$ and $d_{i,-1} > 0$, $\forall i$, a household i aims at maximizing $E_t \sum_{s=0}^{\infty} \beta^s u(c_{i,t+s}, d_{i,t+s})$ subject to (2) and (3). The first-order conditions for consumption, durables, and debt can be summarized as follows

$$u_c(c_{i,t}, d_{i,t})q_t = u_d(c_{i,t}, d_{i,t}) + \beta E_t \left[q_{t+1} u_c(c_{i,t+1}, d_{i,t+1})\right] + \mu_{i,t}\gamma q_t, \tag{4}$$

$$u_c(c_{i,t}, d_{i,t})/r_t = \beta E_t \left[u_c(c_{i,t+1}, d_{i,t+1})\right] + \mu_{i,t}, \tag{5}$$

where $\partial u_x / \partial x$ for $x \in \{c, d\}$, and $\mu_{i,t} \geq 0$ denotes the multiplier on the collateral constraint (3), which satisfies $\mu_{b,t}(b_{b,t} + \gamma q_t d_{b,t}) = 0$. On the one hand, the two conditions (4)-(5) describe the agents' optimal choices for durables, non-durables and (with 2 and 3) debt. On the other hand, they show how equilibrium prices (r_t, q_t) adjust with changes in the allocation. The latter channel is not taken into account by individual agents, giving rise to relevant pecuniary externalities under potentially binding borrowing constraints.

Note that a household's (net) wealth position, $x_{i,t} \equiv b_{i,t} + q_t d_{i,t}$, serves as the endogenous (necessary) individual state variable in the model. Let $\{b_t(x,y), c_t(x,y), d_t(x,y)\}$ that solve the period-t decision problem of a household with wealth $x_{i,t} = x$ and income $y_{i,t} = y$, given prices $\{r_t, q_t\}$. The joint distribution of wealth and income across households in period t is denoted as $\Phi_t(x,y)$. To close the model, we assume that the supply of durables in each period is fixed and equal to $\bar{d}$, whereas bonds are in zero net supply. The definition of the competitive equilibrium is given as follows.

Definition 1 *Given an initial distribution Φ_{-1}, a competitive equilibrium consists of a sequence of prices $\{r_t, q_t\}_{t=0}^{\infty}$, household policy functions $\{b_t(x,y), c_t(x,y), d_t(x,y)\}_{t=0}^{\infty}$ and wealth distributions $\{\Phi_t(x,y)\}_{t=0}^{\infty}$, such that for $\forall t$,*

(i) the policy functions $b_t(x,y)$, $c_t(x,y)$ and $d_t(x,y)$ solve the household problem given $\{r_t, q_t\}$,

(ii) the distribution $\Phi_t(x,y)$ is consistent with the household policy functions,

[14] Notably, the assumption that collateral is given by the current value of durables is crucial for inefficiency of the laissez faire equilibrium, as shown by Ottonello et al. (2021).

Parameter	Value	Target
α	0.9480	$qd/c = 1.4$
β	0.8811	Real interest rate 4%
γ	0.8000	Empirical LTV ratio
δ	0.4500	Literature
θ	2.0000	Standard value
ρ	0.9895	Diaz and Luengo-Prado (2010)
σ	0.1257	Diaz and Luengo-Prado (2010)
$\pi_{R,S} \times 100$	0.0125	Gini coefficient income
$\pi_{S,R} \times 100$	0.2063	Gini coefficient wealth
$\bar{d}$	0.0724	Relative durable distribution

Table 1: Model parameters

(iii) the markets for bonds and durables clear,

$$\begin{aligned} \int\int b_t(x,y)d\Phi_t(x,y) &= 0, \\ \int\int d_t(x,y)d\Phi_t(x,y) &= \bar{d}. \end{aligned}$$

The market for non-durable goods clears via Walras' Law, given that the policy functions ensure that all household budget constraints are satisfied. For a stationary equilibrium, we additionally require the distribution of wealth and income, the individual policy functions as well as prices to be constant over time, i.e. $\Phi_{t+1}(\cdot) = \Phi(\cdot)$, $b_t(\cdot) = b(\cdot)$, $c_t(\cdot) = c(\cdot)$, $d_t(\cdot) = d(\cdot)$, $r_t = r$ and $q_t = q$ for all t.

3 Quantitative analysis

In this section, we describe the model calibration and assess the effects of policy interventions.[15] As a first experiment, we examine the consequences of introducing a limit/cap on the loan-to-value ratio, which directly affects households via the collateral constraint and also indirectly via general equilibrium price effects. Then, we look at Pigouvian-style taxes on debt and end-of-period durables, which are able to – at least partially – correct for pecuniary externalities with regard to the durables price and the interest rate. These tax policies are imposed in an anonymous and symmetric way. All three policy measures are introduced by an unexpected and permanent change the policy tool of interest, starting the laissez-faire economy.[16] We then examine the equilibrium effects along the transition path to the new long-run equilibrium, and analyze the welfare implications of these policy experiments.

3.1 Calibration

To solve the model, functional forms and parameters have to be specified.[17] We calibrate the model by choosing suited parameter values from related studies and by targeting selected statistics of the income, wealth, and durables distribution observed for the United States, similar to Diaz and Luengo-Prado (2010), based on data from the Survey of Consumer Finances (SCF) for 1998. The parameter values are summarized in Table 1. In contrast to the latter study we define the empirical counterpart of durable consumption not only as residential housing but add vehicles as well, given that these two categories account for the majority of collateral used for household credit. For the household utility function, we use the specification

$$u(c,d) = \frac{\left[\alpha c^{\delta} + (1-\alpha) d^{\delta}\right]^{\frac{1-\theta}{\delta}}}{1-\theta},$$

where $0 < \theta \neq 1$ is the inverse of the intertemporal elasticity of substitution with respect to a constant-elasticity-of-substitution (CES) consumption aggregate that consists of non-durable and durable consumption, c and d, with $\delta > 0$ controlling the degree of substitution between the two types of consumption goods. For θ, we choose a standard value of two, whereas δ is set to 0.45, which is the average of values used by Benhabib et al. (1991), McGrattan et al. (1997), and Piazzesi et al. (2007), who use the same functional form for the utility function. The values for the utility function parameter α (0.948) and the discount factor β (0.8811) are set to match two empirical targets, namely, the ratio of aggregate durable-to-non-durable-consumption of 1.4 and a real interest rate of 4%. The fraction of seizable collateral γ is set at 0.8, implying an empirically plausible loan-to-value ratio of 80% (see Diaz and Luengo-Prado, 2010).

The income support Y and the associated income transition probabilities π are chosen to match the Gini coefficients for income $y_{i,t}$ (0.43) and (net-)wealth $x_{i,t}$ (0.8). As is well known in the literature (see e.g. Di Nardi et al. 2015), without additional assumptions, a standard Bewley-Aiyagari-Huggett-type incomplete-markets model fails to match important features of the wealth distribution, the concentration of wealth at the top in particular. To address this shortcoming, we follow Diaz and Luengo-Prado (2010) and assume that individual income follows a log-normal AR(1) process,

$$\ln y_{i,t} = \rho \ln y_{i,t-1} + \sigma \varepsilon_{i,t},$$

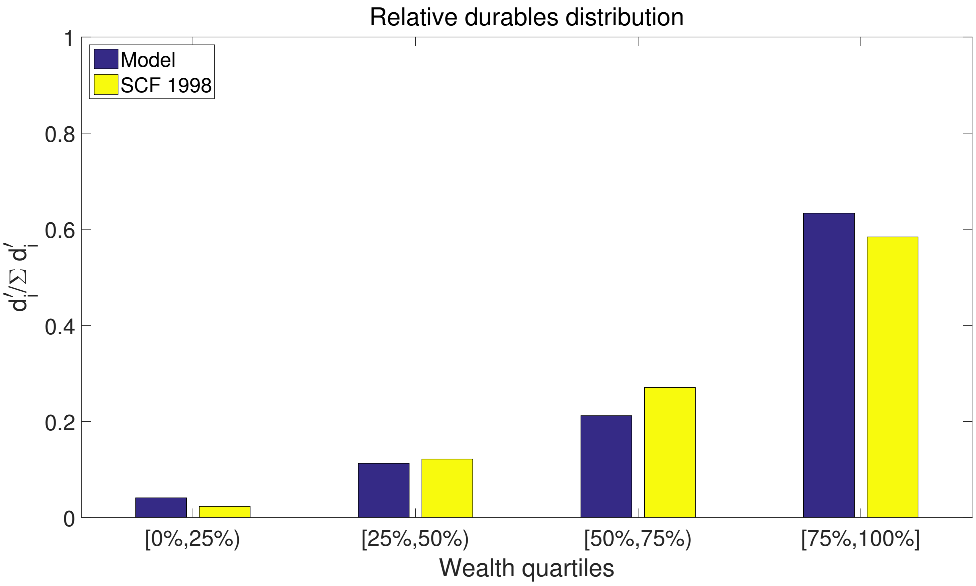
with autocorrelation $\rho = 0.9895$ and standard deviation $\sigma = 0.1257$, and that, additionally, there is also a small probability $\pi_{R,S}$ of transitioning to a "superstar" income state, which is left with probability $\pi_{S,R}$. While the AR(1) process provides a good fit for most of the population, it cannot suitably account for the top 1% of the income distribution. The "regular" income states y_1 to y_6 are obtained by discretizing the AR(1) process via the method proposed by Tauchen and Hussey (1991), while the superstar income

[15] Details on the numerical computation are provided in Appendix A.1.

[16] While it would be interesting to impose such a tax on borrowers only, i.e. asymmetrically, doing so makes the household problem non-convex, such that first-order conditions are no longer sufficient to find the optimal decision rules. A solution approach like this is however necessary to solve a model with Pigouvian-type taxes.

[17] Details about the numerical solution procedure can be found in Appendix A.1.

Figure 1: Relative durable holdings for different wealth quartiles (data vs model)



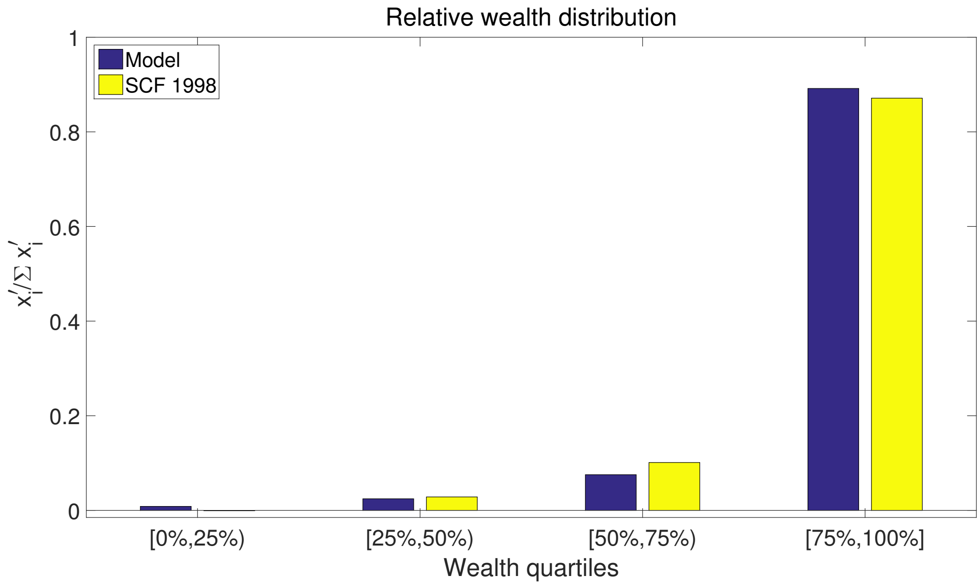
value y_7 is set to match the empirical ratio $y_7/y_6 = 6$ and the transition probabilities are $\pi_{R,S} = 0.000125$ and $\pi_{S,R} = 0.002063$. Combining these values with the transition probabilities for the regular income states, obtained by discretizing the AR(1) process, yields the transition probabilities $\pi(y_{i,t+1}|y_{i,t})$, which are given in Appendix A.1.3. Lastly, the aggregate supply of the durable good $\bar{d} = 0.0724$ is chosen to provide a reasonable fit for the durable distribution, as given by Figure 1. Figure 2 shows the distribution of net-wealth for the model and the data.

3.2 A limit on the loan-to-value ratio

In this section, we discuss the effects of unexpectedly and permanently introducing a limit on the loan-to-value ratio. Consider, that a regulator applies the cap θ, which limits the loan-to-value to a level below the market value $\gamma : -b_{i,t} \leq \theta q_t d_{i,t}$ with $\theta < \gamma$. Although, type-dependent Pigouvian taxes on borrowing can induce (welfare-improving) corrections of prices, they are unlikely going to be implemented in practice. The cap on the loan-to-value ratio by contrast is a policy instrument that is typically considered as an useful instrument to regulate borrowing. For convenience, we abstract from referring to the additional policy parameter θ and we specify the policy experiment as if policy maker directly reduces γ.

In the model, changes in the loan-to-value ratio have two types of effects. First, they directly affect households' decisions to borrow and – as a result – to buy durable goods. Second, the resulting reactions affect equilibrium prices of debt and durables, which in turn lead households to (re-)adjust their behavior. In the remainder, we will refer to effects of the first kind as "direct effects" and those of the second kind as "indirect effects". The direct effects work in an expected way, such that it will be particularly important to understand the indirect effects. To do so, we will look at the responses of equilibrium prices as well as of the aggregate credit volume in the short run and in the long run following an unexpected change

Figure 2: Relative net-wealth for different wealth quartiles (data vs model)



of γ. Figure 3 visualizes the results by plotting the transition path for prices, their ratio and the credit volume, which we denote as B_t^-.[18]

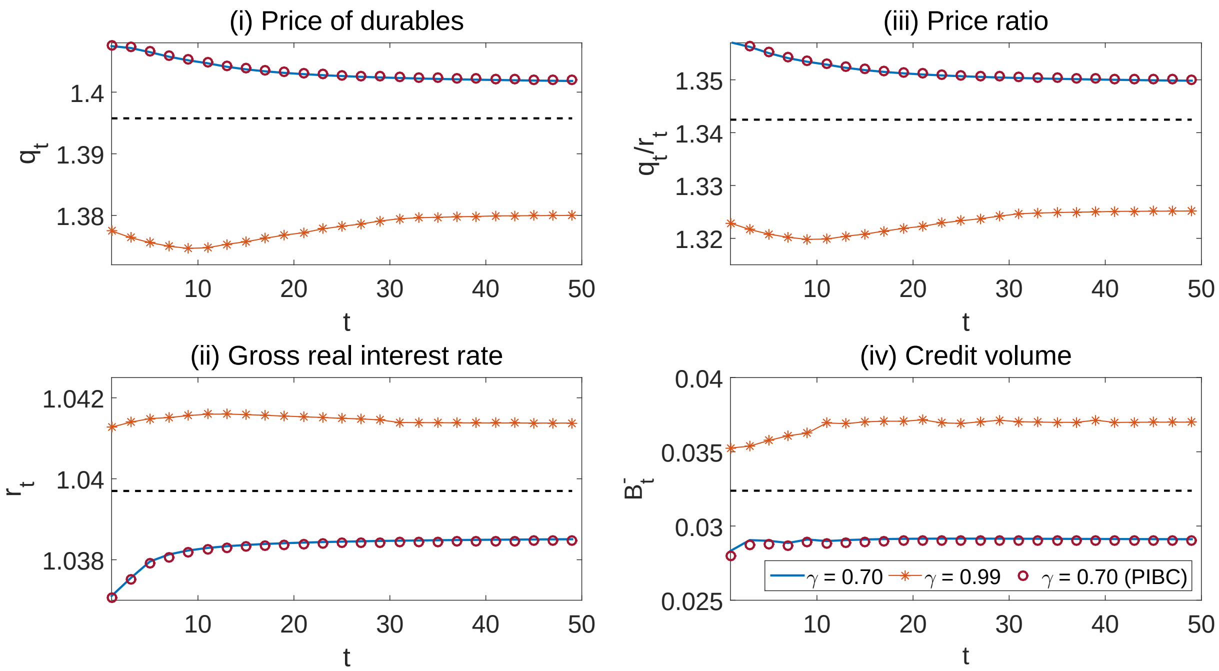
Consider an effective reduction of the loan-to-value ratio (from $\gamma = 0.8$) to $\gamma = 0.7$, which tightens the collateral constraint for all households. Ceteris paribus, this change directly reduces the borrowing limit of constrained households and low-income/low-wealth borrowers who have previously been unconstrained become constrained as well. As a direct effect, these types of households respond by reducing their debt as well as their holdings of durables since debt-financing becomes more restricted. The effect on the debt market is in line with the intuition suggested by the direct effects. Credit volume declines and the interest rate falls and settles at a higher value that is nevertheless lower compared to the old steady state.

Notably, the durables price q_t increases, as shown by the solid blue line in Panel (i) of Figure 3 (which almost coincides with the magenta-colored circles displaying a reference case, see below). The response of q_t particularly depends on how savers and richer unconstrained borrowers respond. These types of households are not directly affected by the tightening of the collateral constraint and also unlikely going to be in the near future. Their response therefore mainly depend on borrowers' de-leveraging. The lower real interest rate makes investing in bonds less attractive for these households who increase their holdings of durables. These responses create upward pressure on both prices, q_t and $1/r_t$, while the price ratio q_t/r_t increases (see Panel (iii) of Figure 3). Although a higher value for q_t counteracts the lower loan-to-value ratio, it is not sufficient for γq_t to go up and to relax household borrowing constraints.

For demonstrative purposes, we also consider a higher loan-to-value ratio $\gamma = 0.99$, which can apparently not be induced by policy. Reverting the direction of the change in γ (marked orange line) leaves the propagation mechanism unchanged and switches the sign of the effects. We further examine an artificial reference case, which allows abstracting from the collateral effects of pecuniary externalities. Specifically,

[18] Credit volume is calculated by aggregating all negative end-of-period bond positions across agents.

Figure 3: Transition paths for prices and credit after an effective change in loan-to-value ratio



Notes: The panels also show the transition paths for a price-inelastic constraint (PIBC). The dashed black lines denote the respective laissez-faire steady-state values.

we consider a price-inelastic borrowing constraint (PIBC), for which we hold the durables price in the collateral constraint fixed at the laissez-faire equilibrium level. The magenta-colored circles in Figure 3 show that interest rate effects are almost identical and the impact on the durables price during the transition phase is slightly less pronounced under the price-inelastic borrowing constraint. Panel (iv) in Figure 3 further shows that there is only a tiny difference between both cases with respect to the credit volume, indicating that these effects are hardly affected by price-induced changes in the collateral constraint.

Welfare implications What do the effects of the policy experiments imply for welfare? To assess the welfare effects, taking into account the transition to the new steady state, we consider three measures. The first one is the welfare-equivalent consumption bundle variation $CEV_i \equiv CEV(x, y)$ with

$$CEV_i = \left[\frac{\tilde{V}_1(x,y)}{V(x,y)}\right]^{\frac{1}{1-\theta}} - 1,$$

where $V(\cdot)$ denotes the value of a household with beginning-of-period wealth $x = b + qd$ and income y in the laissez-faire economy, which satisfies

$$\begin{aligned} V(x,y) &= \max_{b',c,d'} \left\{ u(c,d') + \beta \sum_{y' \in Y} \pi(y'|y) \, V(b' + qd', y') \right\} \\ \text{s.t.} &: \quad c + q(d' - d) + b'/r = b + y, \; -b' \leq \gamma q d', \end{aligned}$$

and $\tilde{V}_1(\cdot)$ denotes the corresponding value of a household in the impact period $t = 1$ of an economy that is experiencing a policy change. Note that we have adopted recursive notation above and dropped time indices for individual states, with a prime ("′") denoting next period values, i.e. $b' = b_{i,t}$ and $y' = y_{i,t+1}$. The value $\tilde{V}_t(\cdot)$ carries a time index because the prices q_t and r_t change during the transition period and are therefore a function of time in this case. By contrast, prices in the stationary laissez-faire economy are constant in all periods and the associated individual household values only change over time via the individual states x and y. The welfare measure CEV_i allows assessing how welfare of individual types of households changes after the policy intervention, where a positive (negative) value for CEV_i means that a household is better (worse) off.

We further want to examine policy effects on social welfare. Pareto improvements are hardly possible under dispersed agents' endowments of wealth and income (see Davila et al. 2012). Thus, we consider ex-ante expected lifetime utility (see e.g. Conesa et al. 2009, Krueger et al. 2016, or Nuño and Moll, 2018) and compute variations of this measure expressed in equivalent consumption bundle units

$$CEV = \left[\frac{\int\int \tilde{V}_1(x,y)\mathrm{d}\tilde{\Phi}_1(x,y)}{\int\int V(x,y)\mathrm{d}\Phi(x,y)} \right]^{\frac{1}{1-\theta}} - 1,$$

where $\Phi(\cdot)$ denotes the time-invariant joint distribution of household wealth and income in the laissez-faire economy and $\tilde{\Phi}_1(x,y)$ the corresponding distribution in the period $t = 1$ of the policy change under consideration.[19] This welfare criterion, which is identical to a utilitarian welfare measure, can be interpreted as measuring whether an unborn household, who is randomly assigned to an idiosyncratic state, would prefer to be born into the laissez-faire economy or into an economy that experiences a sudden policy change.

The final welfare measure that we use is the income-specific measure CEV_{y_i} which is defined as

$$CEV_{y_i} = \left[\frac{\int \tilde{V}_1(x,y_i)\mathrm{d}\tilde{\Phi}_1(x|y_i)}{\int V(x,y_i)\mathrm{d}\Phi(x|y_i)} \right]^{\frac{1}{1-\theta}} - 1,$$

where $\Phi(x|y_i)$ and $\tilde{\Phi}_1(x|y_i)$ are the distribution functions for wealth x in the laissez-faire economy and in the economy subject to a policy change, respectively, conditional on income value y_i. This welfare measure is a refinement of CEV that takes into account the distribution of wealth conditional on income y_i, which will help to shed light on the source of aggregate social welfare changes (see also Krueger et al. 2016).

Figure 4, which displays CEV_i for different income and wealth levels, shows that almost all types of households are worse off after a decrease in the loan-to-value ratio (see solid blue lines). Constrained borrowers can borrow less, whereas savers suffer from lower interest rates. The only types of households

[19] While individual holdings of bonds and durables are predetermined, wealth $x_{i,t} = b_{i,t} + q_t d_{i,t}$ also depends on the price q_t, which can shift the wealth distribution on impact.

Figure 4: Welfare effects conditional on income and wealth type (effective change in LTV)

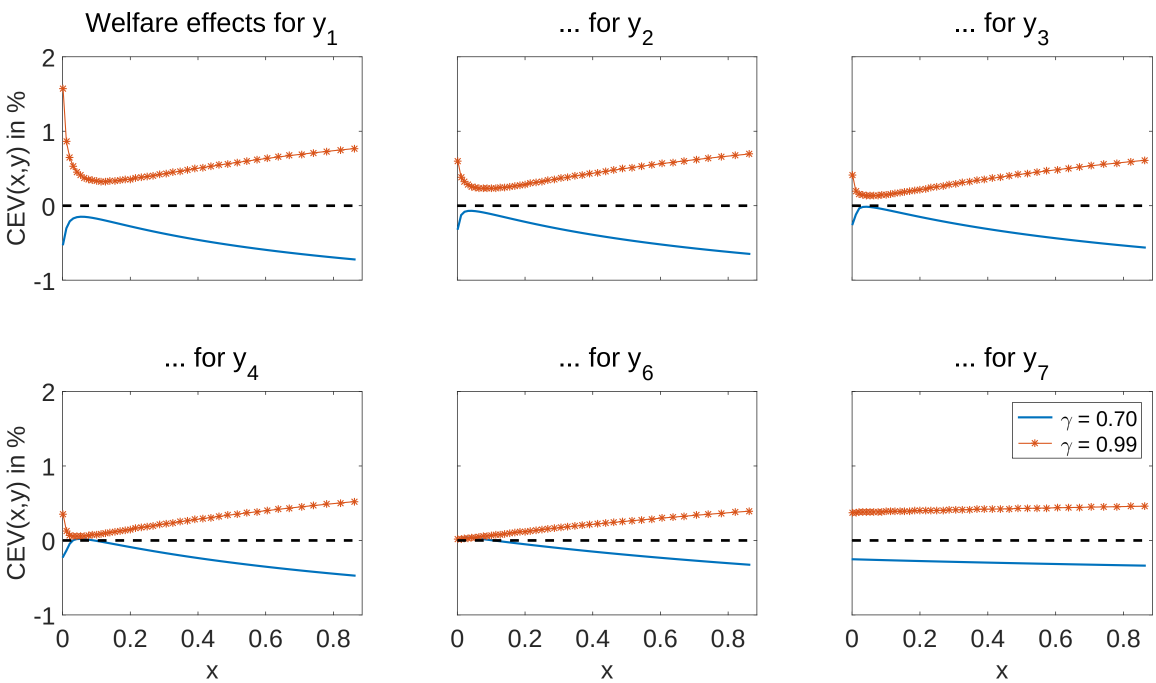
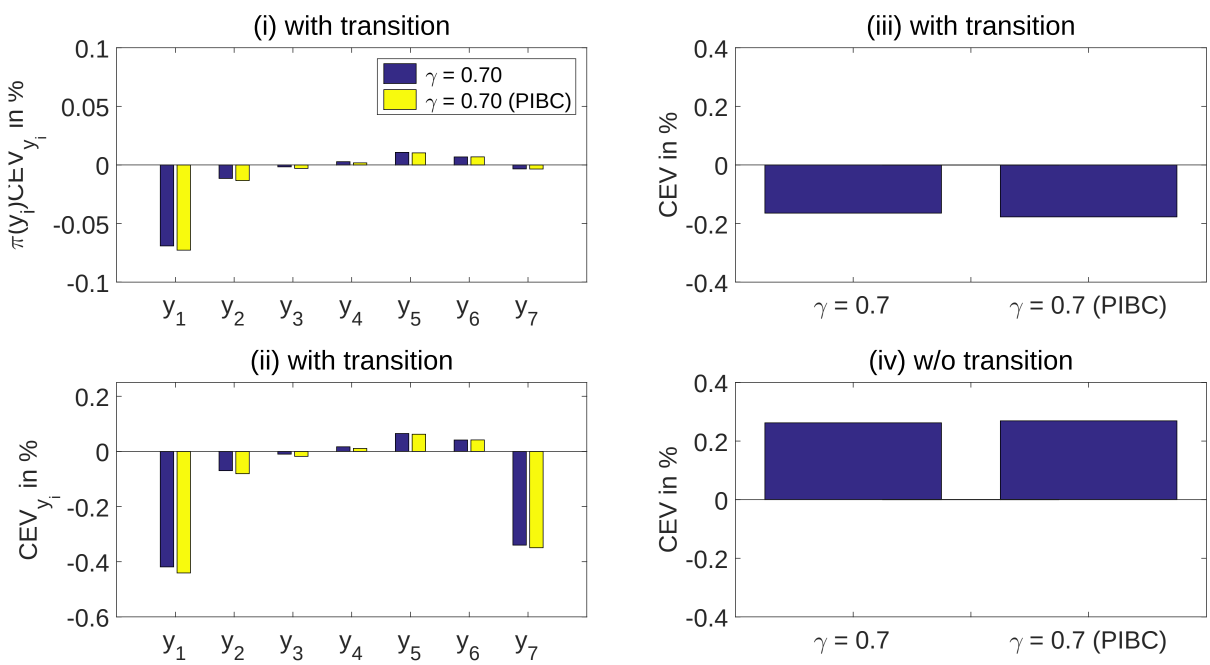
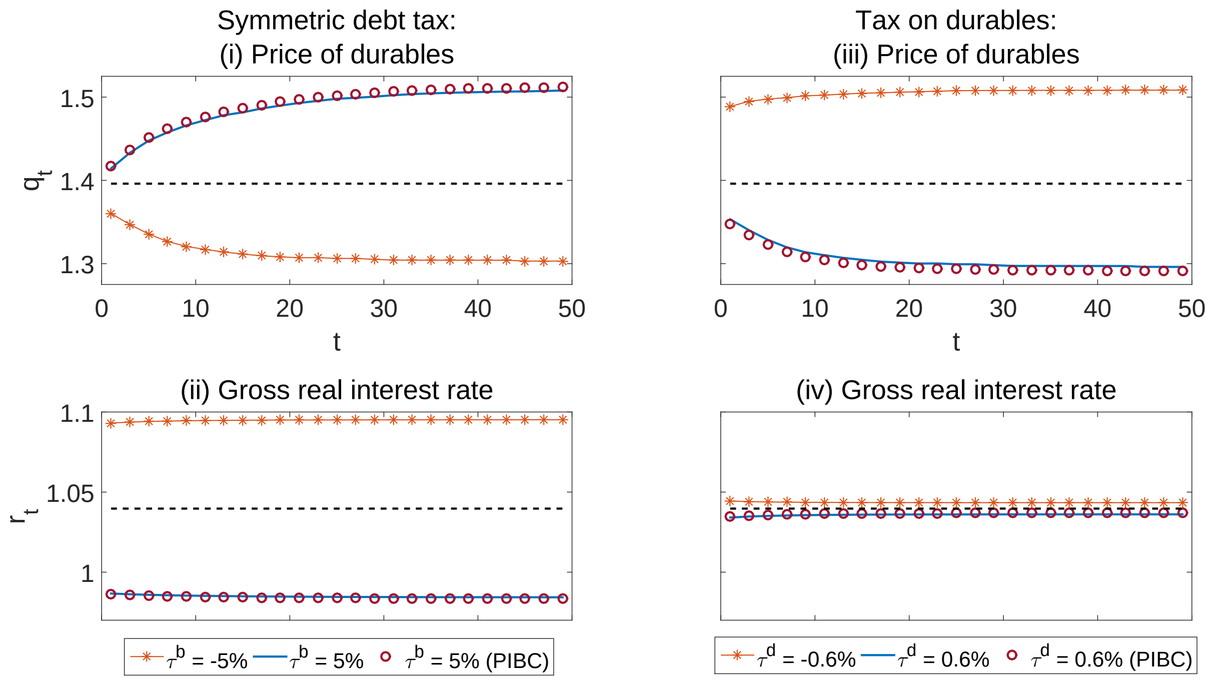


Figure 5: Welfare effects of an effective change in the loan-to-value ratio



Notes: Panels (i) and (ii) display welfare conditional on the income state. In Panel (i) the welfare effects are weighted with the probability mass of the respective income states. Panels (iii) and (iv) display aggregate welfare with and without taking into account the transition periods. The case of a price-inelastic collateral constraint is denoted as “PIBC”.

Figure 6: Price transition paths after an introduction of taxes



Notes: The panels also show the transition paths for a price-inelastic constraint (PIBC). The dashed black lines denote the respective laissez-faire steady-state values.

who gain under a lower γ-value are income-rich unconstrained borrowers who are not directly affected by the tighter collateral constraint but benefit from the lower interest rate. These unconstrained households reduce their borrowing (see Figure 14 in Appendix A.2), which contributes to the lower interest rate. Hence, these agents would have benefited under laissez faire if they internalized the price effects of their behavior. These types of households, however, constitute a small fraction of households in the economy.

Panel (i) of Figure 5 depicts welfare conditional on specific income states and weighted with the respective probability, i.e. $\pi(y_i)CEV_{y_i}$. The unweighted welfare measure CEV_{y_i} is displayed in Panel (ii). These figures reveal that the welfare losses clearly dominate. Consistently, social welfare effects as measured by CEV are negative for $\gamma = 0.7$ (see Panel (iii)). When the transition is however not taken into account, these results are reversed, since the increase (decrease) in the price of durables due to the LTV reduction (increase) leads to a general upward shift in wealth (see Panel (iv)).[20] Figure 5 further shows that the welfare losses of a LTV reduction under a price-inelastic borrowing constraint (PIBC) are slightly larger for low income groups and that social welfare effects hardly change. According to this experiment, we do not find evidence for substantial collateral effects.

[20] In this case, the computed welfare measure is $CEV = \left[\{\int\int \bar{V}(x,y)\mathrm{d}\bar{\Phi}(x,y)\} / \{\int\int V(x,y)\mathrm{d}\Phi(x,y)\}\right]^{\frac{1}{1-\theta}}$. The bars denote that the distribution and the value function are associated with the new long-run equilibrium.

3.3 Distortionary taxes

This section examines the effects of distortionary taxes that are imposed in an anonymous way. These taxes affect prices by altering the marginal valuation of goods and assets, while payments or receipts of funds are individually compensated in a lump-sum way. Thereby, these Pigouvian-style tax policies do not directly redistribute resources across households and affect the economy via price effects that can address pecuniary externalities. We first consider a symmetric tax on debt $-b_{i,t}$ at the rate τ_b, which implies a tax on borrowing and a subsidy on savings. We focus on local effects in the neighborhood of the laissez faire equilibrium induced by $\tau^b > 0$ and $\tau^b < 0$; the latter implying a subsidy on borrowing and a savings tax. As a second Pigouvian-style tax policy, we introduce an anonymous tax on end-of-period holdings of durables τ^d. To facilitate comparisons between both Pigouvian-style tax policies, the values for τ^d are chosen to yield equally-sized changes in the long-run durable price q_t.

3.3.1 A symmetric debt tax

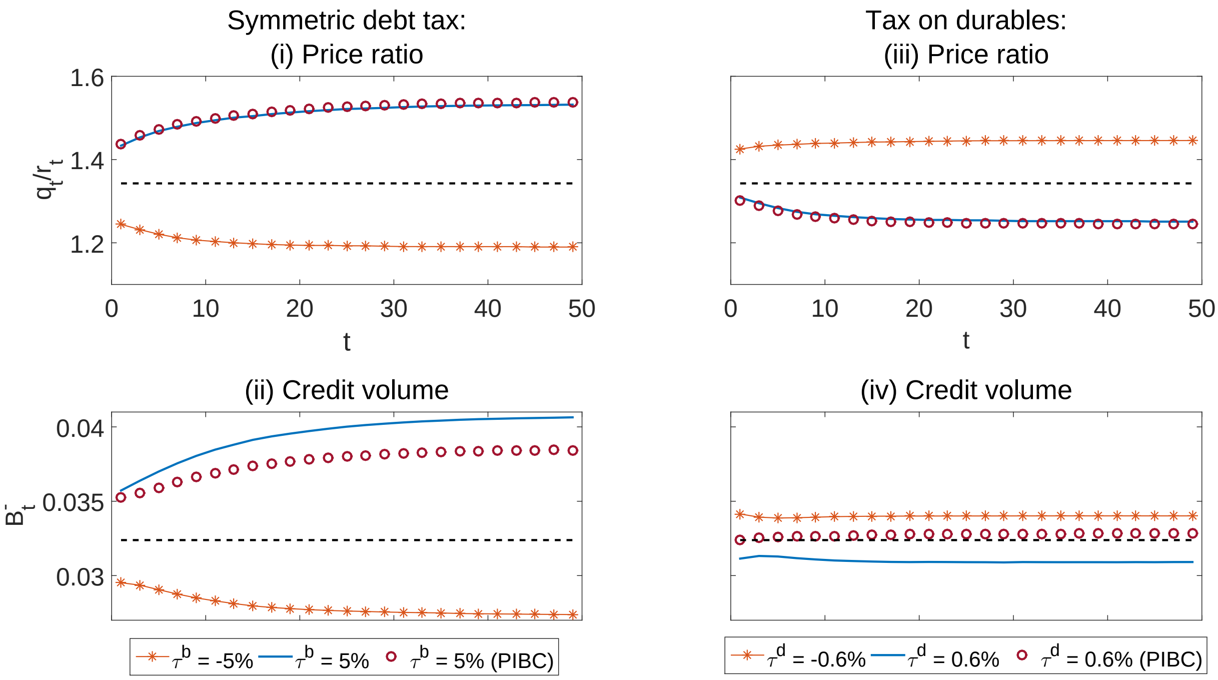
First, suppose that the tax on durables is kept at zero ($\tau^d = 0$) and a symmetric tax on debt, which implies a subsidy on savings, is unexpectedly and permanently imposed ($\tau^b = 0.05$). The agents' borrowing/saving decision is then governed by

$$u_c(c_{i,t}, d_{i,t})(1 - \tau^b)/r_t = \beta E_t \left[u_c(c_{i,t+1}, d_{i,t+1})\right] + \mu_{i,t},$$

instead of (4), while the tax/subsidy is compensated by a lump-sum transfer/tax satisfying $T_{i,t} = \tau^b b_{i,t}/r_t$. To illustrate the policy effects, we examine time paths of prices and of the credit volume in the left hand columns of Figures 6 and 7. Relative to the laissez-faire steady-state values (dashed black lines), the durables price q_t and the interest rate r_t, given by the solid blue lines in the left hand column of Figure 6, move into opposite directions. The price of durables q_t jumps up and then gradually moves up to a higher new steady-state value, while the interest rate r_t immediately drops and further declines until it arrives at the new (lower) long-run value.

What drives these responses? Since it is imposed symmetrically, the tax τ^b induces all types of households to – ceteris paribus – save more or to dis-save less, i.e. to choose higher values of $b_{i,t}$. These direct effects in turn create downward pressure on the interest rate r_t to ensure market clearing for debt and simultaneously also upward pressure on the price q_t (see solid blue line in Panels (i) and (ii) of Figure 6). The reason for the latter is that durables are untaxed and now hence provide a relatively higher return, which stimulates the demand for durables. The responses of both prices tend to ease borrowing conditions, while the increase in the price ratio q/r (see panel (i) of Figure 7) raises the amount of funds borrowed per unit of collateral. Consistently, we observe an increase in the aggregate credit volume (see solid blue line in Panel (ii) of Figure 7), reflecting that income- and wealth-poor households tend to increase their borrowing. It should be noted that also constrained borrowers issue more debt. At the same time, savers are incentivized to save more, which induces the interest rate to decline and the credit

Figure 7: Transition path for price ratio and credit volume after an introduction of taxes



Notes: The panels also show the transition paths for a price-inelastic constraint (PIBC). The dashed black lines denote the respective laissez-faire steady-state values.

volume to increase, even though the policy (tax on debt) tends to make it less attractive for households to borrow. Under a subsidy on borrowing ($\tau^b = -0.05$), given by the marked orange lines, prices and the credit volume move into the opposite direction, showing that the mechanism just discussed operates in a symmetric way.

As in Section 3.2, we further consider a price-inelastic borrowing constraint (PIBC) where we fix the durables price in the collateral constraint at the steady-state laissez-faire value. In this case, we hardly observe any difference with regard to the responses of q_t and r_t to the introduction of the symmetric debt tax compared to the reference case of a price-inelastic borrowing constraint (see magenta circles in Figure 6).[21] In contrast to the LTV-reduction, the credit volume response is however substantially affected by keeping the durables price fixed in the collateral constraint: The increase in the collateral price raises the borrowing limit only in the benchmark case, such that the increase in the credit volume is apparently less pronounced under a price-inelastic borrowing constraint (see Panel (ii) of Figure 7).

Welfare implications The welfare effects of a symmetric debt tax are visualized in Figures 8 and 9. As shown by the solid blue lines in Figure 8, wealth-poor households in all income groups (except the highest) gain from a symmetric debt tax ($\tau^b > 0$). Both price effects of the symmetric debt tax, i.e. a higher price of durables and lower interest rates, are beneficial for borrowers. The symmetric debt tax thus induces price responses that provide a partial insurance for borrowers from an ex-ante perspective. While the price effects are qualitatively identical to the effects of a LTV reduction, they are

[21]The debt-subsidy/savings-tax has the same qualitative implications with the responses having the opposite sign.

Figure 8: Welfare effects of a symmetric debt tax conditional on income and wealth type

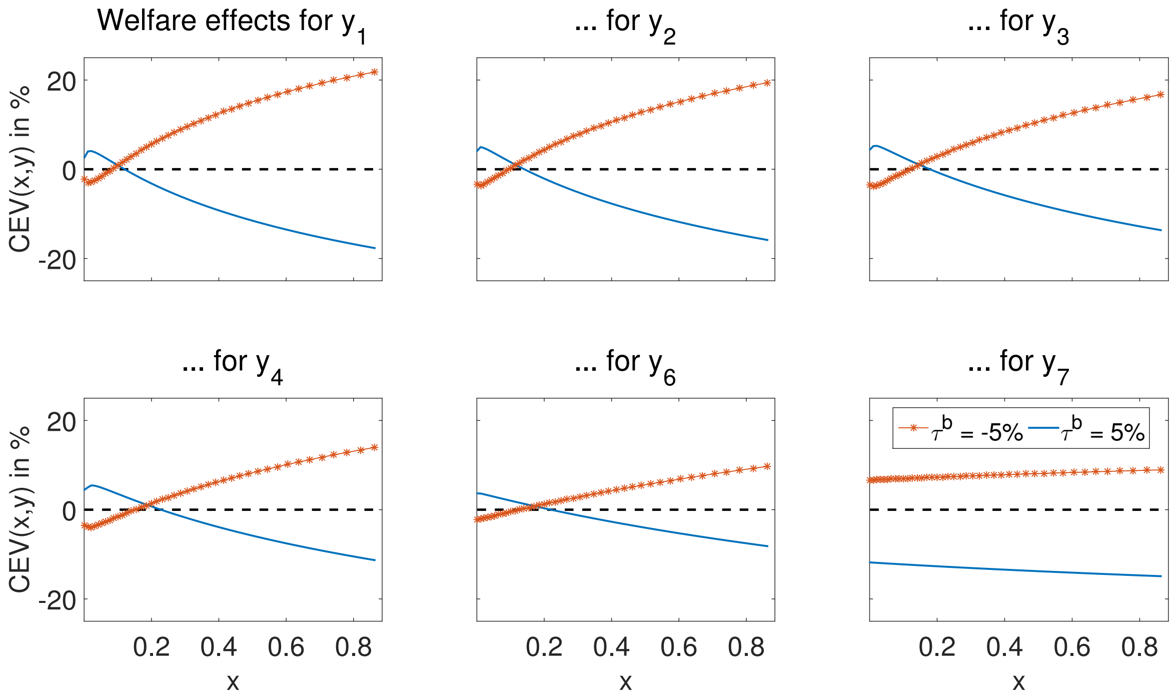
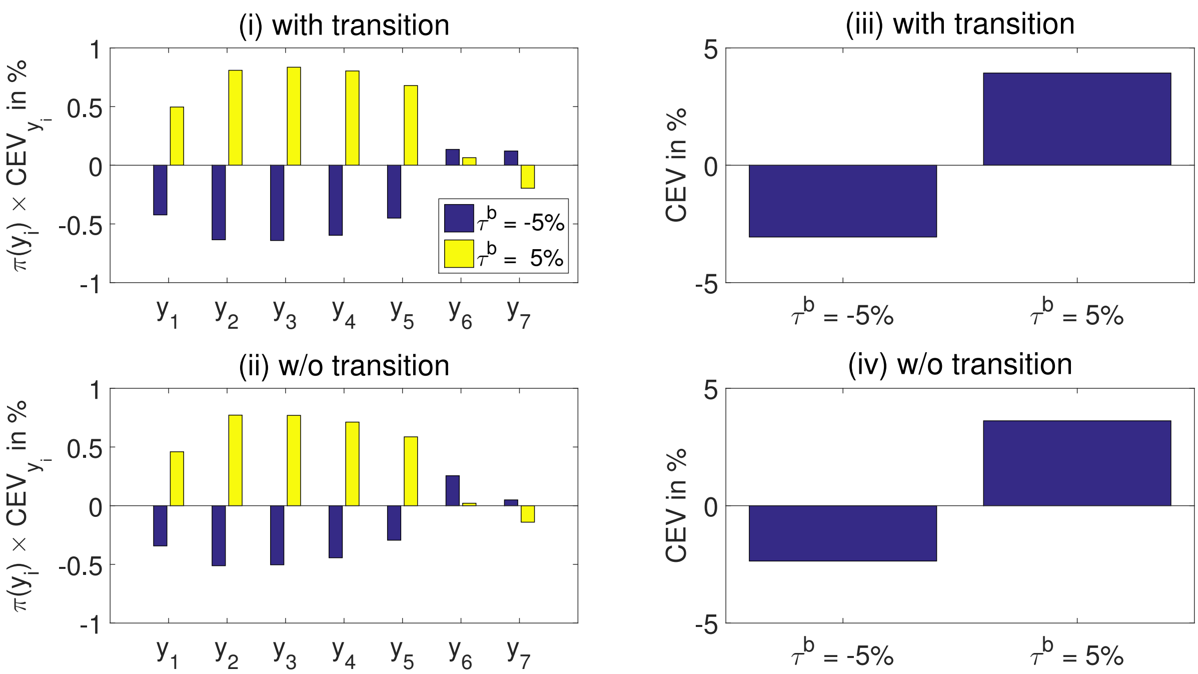
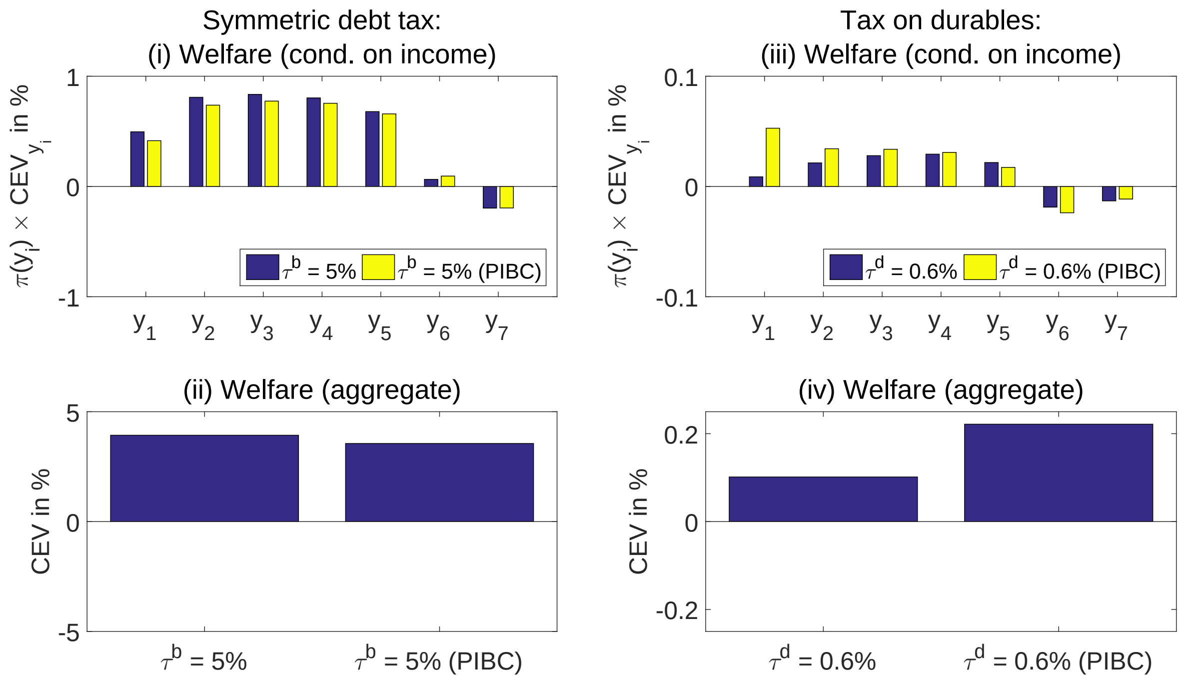


Figure 9: Welfare effects of a symmetric debt tax



Notes: Panels (i) and (ii) display welfare conditional on the income state, with and without taking into account the transition periods Panels (iii) and (iv) display aggregate welfare with and without transition periods.

Figure 10: Welfare effects of taxes with and without price-inelastic borrowing constraint



here associated with a higher credit volume supported by savers' increased willingness to lend. Notably, wealth-rich agents tend to lose, as they earn a lower interest rate on their savings. To understand the welfare effects displayed by the yellow bars in Panels (i) and (ii) of Figure 9 (compared to Figure 8), one has to further take into account that endogenous shifts in the durables price q_t lead to a change in agents' wealth $x_{i,t} = b_{i,t-1} + q_t d_{i,t-1}$ and does so the more a household owns durables $d_{i,t-1}$. When aggregating within income groups, which takes changes of the wealth distribution into account, one can see that all income groups except the highest benefit from a symmetric debt tax, which reflects that this group mostly consists of lenders. Panels (iii) and (iv) of Figure 9, which display the social welfare gains/losses with and without transition, reveal that the welfare gains from the symmetric debt tax ($\tau^b = 0.05$) are due to positive short-run and long-run effects. Furthermore, the welfare effects hardly change under a price-inelastic borrowing constraint, indicating a minor role of collateral effects for welfare, both within income groups as well as for aggregates (see Panels (i) and (ii) of Figure 10).

3.3.2 Durables tax

Now consider an unexpected permanent increase in the tax (subsidy) on end-of-period holdings of durables $d_{i,t}$ by $\tau^d > 0$, which is compensated by lump-sum transfers (taxes). The symmetric debt tax is set at zero ($\tau^b = 0$). The agents' durable holdings are governed by

$$u_c(c_{i,t}, d_{i,t})(1 + \tau^d)q_t = u_d(c_{i,t}, d_{i,t}) + \beta E_t \left[q_{t+1}u_c(c_{i,t+1}, d_{i,t+1})\right] + \mu_{i,t}\gamma q_t,$$

instead of (5), while the tax/subsidy is compensated by a lump-sum transfer/tax satisfying $T_{i,t} = \tau^d q_t d_{i,t}$.

The size of the Pigouvian-style policy intervention in the market for durables, $\tau^d > 0.006$, is chosen to yield a change in the long-run price of durables that is of the same (long-run) magnitude as under debt market intervention τ^b. The associated price and credit responses are given by the solid blue lines in the Panels (iii) and (iv) of Figures 6 and 7. Ceteris paribus, the taxation of durables causes households to substitute durable goods in favor of non-durable goods. Furthermore, agents who are willing to transfer wealth intertemporally tend to substitute durables in favor of bonds, such that credit supply increases. These direct effects imply that q_t and r_t fall to clear markets, which is shown in the Panels (iii) and (iv) of Figure 6. While the taxes on durables and debt both lower the real interest rate, the responses of the aggregate credit volume substantially differ. A main difference is that the price ratio q/r decreases under the durables tax, which reduces the maximum amount of funds that can borrowed against collateral, whereas the price ratio increases under the symmetric debt tax (see solid blue lines in Panels (i) and (iii) of Figure 7). Correspondingly, the credit volume increases under the symmetric debt tax and decreases under the durables tax, as shown in the Panels (ii) and (iv) of Figure 7.

Like under the symmetric debt tax, the responses of the durables price q_t and the interest rate r_t to a durables tax introduction hardly change when we consider a price-inelastic borrowing constraint (see magenta circles in Panels (i) and (ii) of Figure 6). In contrast, the credit volume responses show remarkable differences: The durables tax leads to a decline in the interest rate, which tends to stimulate borrowing, and to a decline in the durables price, which tends to reduce the borrowing limit under the benchmark (price-elastic) collateral constraint. Under a price-inelastic borrowing constraint, however, a decline in the durables price does not directly affect the borrowing constraint. As a result, the credit volume increases relative to the laissez-faire case due to the decline in the interest rate, whereas it decreases under the price-elastic borrowing constraint (see Panel (iv) of Figure 7).

Recall that we considered values for the durables tax τ^d that induce long-run changes in q_t that are of the same magnitude as those associated a symmetric debt tax $-\tau^b$. In contrast, the response of the interest rate substantially differs under the two tax instruments. Figure 6 shows that the interest rate adjustment is much more pronounced under the borrowing tax τ^b, which directly affects the market for debt. More specifically, a tax on debt of 5% lowers the long-run interest rate by 5.9 percentage points, while a subsidy on durables of 0.6%, which results in the same long-run price of durables, yields an interest rate increase of 0.7 percentage points.

Welfare implications Who benefits from a tax on durables? As shown by the solid blue lines in Figure 11, low-wealth households, which are typically borrowers, benefit from the lower interest rate in almost all income groups, whereas welfare declines for the highest income groups (see yellow bars in the Panels (i) and (ii) of Figure 12). Even constrained households gain despite the drop in the price of durables, which tends to tighten their borrowing constraints. Like symmetric debt tax, the durables tax leads to responses of the interest rate that partially insure borrowers from an ex-ante perspective. Overall, social welfare increases for a durables tax (see Panels (i) and (ii) of Figure 13) in the short-run and in the long-run predominantly due to the decline in the interest rate. It should further be noted

Figure 11: Welfare effects of a tax/subsidy on durables conditional on income and wealth type

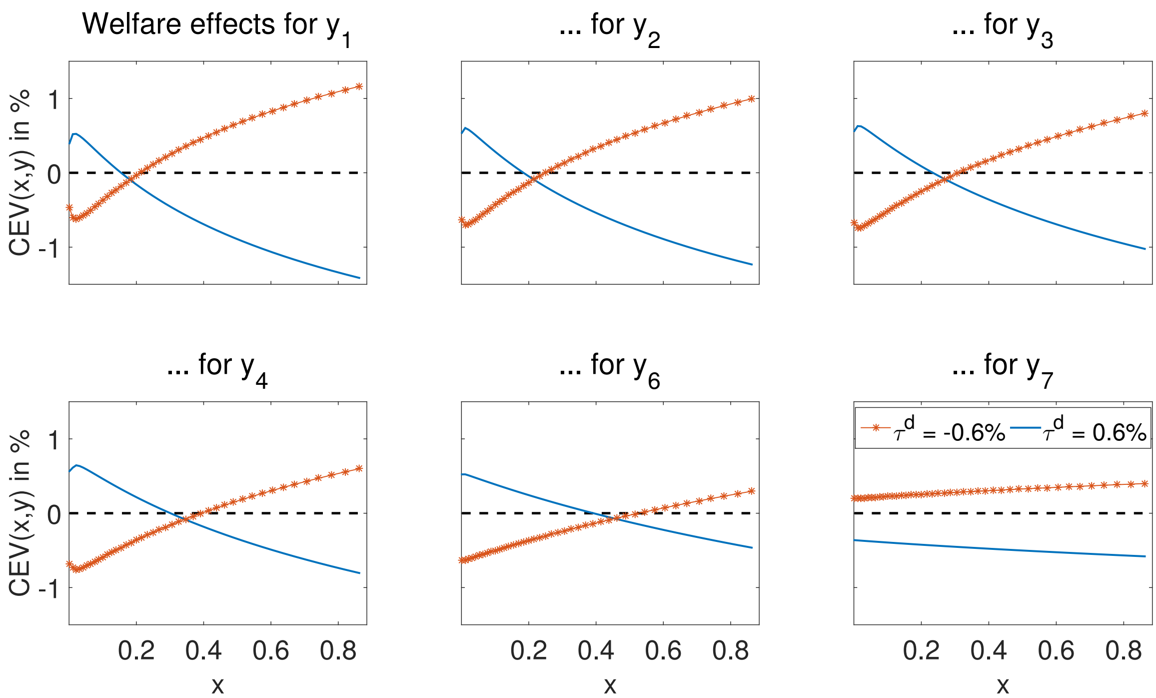
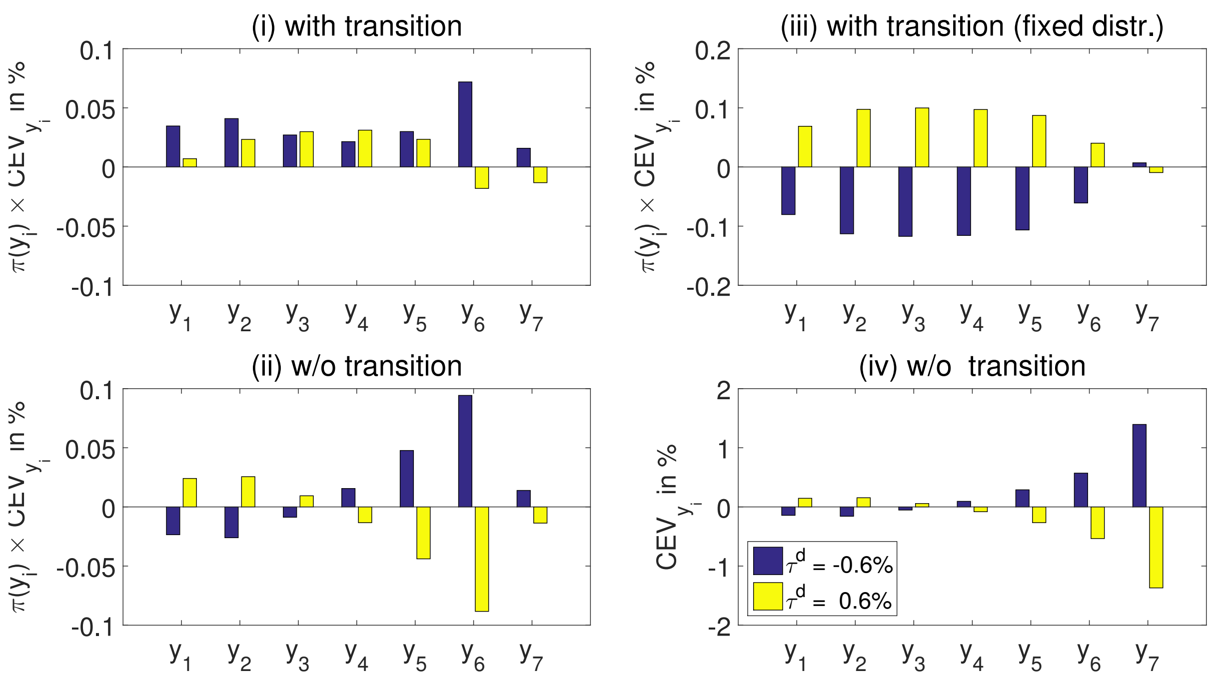


Figure 12: Welfare effects of a tax/subsidy on durables conditional on income state



Notes: Panels (i) to (ii) display welfare conditional on the income state. Panel (iii) shows the measure when the transition period is taken into account but the wealth distribution in the impact period is kept fixed. Panel (iv) displays the measure in Panel (i), weighted by the probability mass of the income states.

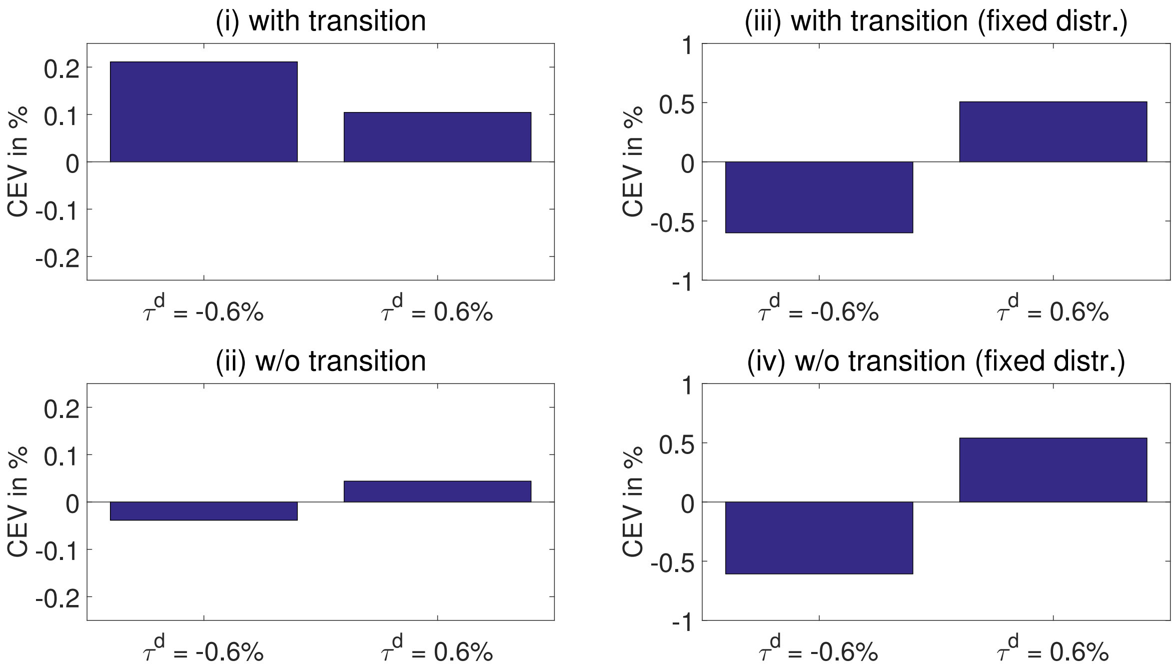
that the decline in the durables price reduces wealth of agents in terms of non-durables, which shifts the wealth distribution such that the mass of agents who gain from lower interest rates increases. Under a price-inelastic borrowing constraint, there are visibly larger social welfare gains (see Panels (iii) and (iv) of Figure 10), which correspond to the difference in the credit volume response (see Figure 7). While this indicates the relevance of collateral effects, it should be noted that it is the decline in the interest rate which is ultimately responsible for the increase in the credit volume and in social welfare.

A subsidy on durables, $\tau^d < 0$, reverses the qualitative responses of prices and the credit volume (see marked orange lines in the Panels (iii) and (iv) Figures 6 and 7). The long-run welfare effects, i.e. those not accounting for the transition dynamics, of a durables subsidy ($\tau^d = -0.006$) are negative and mirror those of the tax on durables with the opposite sign, as shown in the Panel (ii) of Figures 12 and 13. Specifically, savers tend to gain from the increase in the interest rate and the price of durables compared to the laissez-faire case (see marked orange line in Figure 11), where they do not internalize that raising their holdings of durables contributes to the increase in the durables price.[22] However, the overall aggregate welfare effect, which includes the transition phase, is positive (see Panels (i) of Figures 12 and 13).[23] The reason is that the durable subsidy leads to an increase in the durables price q_t, leading to a higher wealth in terms of non-durables of all agents. This effect due to a higher durables price is particularly more pronounced in the short run, where adjustments of the quantities are not yet made. Computing the welfare measures by fixing the wealth distribution prior to the policy change (see Panel (iii) of Figures 12 and 13), shows that welfare then declines in (almost) all income groups, such that aggregate welfare CEV declines as well. Thus, the endogenous change in the wealth distribution contributes to asymmetric welfare effects of taxes and subsidies of durables.

The welfare effects of the durables price increase are non-trivial, since it is beneficial for agents who are net-sellers of durables ($d_{i,t} < d_{i,t-1}$), whereas net-buyers ($d_{i,t} > d_{i,t-1}$) suffer from the price increase. A durables subsidy thereby tends to benefit poor households more than it hurts rich ones. These effects are particularly larger in the transition phase where agents adjust their holdings of durables more than in a stationary equilibrium. The beneficial effects of higher durables prices even compensate agents with low income who would otherwise lose under the durables subsidy (see panel (iii) in Figure 12). As a result, all income groups are better off and social welfare increases for the durables subsidy $\tau^d < 0$ (see Panel (ii) of Figures 12 and 13).[24] Finally, recall that the subsidy on durables and the symmetric debt tax have been scaled to lead to equally-sized long-run changes in the durable prices. Figure 10 however shows that the implied aggregate welfare effects are more than 20-times larger under the debt market intervention. This difference can mainly be attributed to the change in the interest rate, which is more pronounced under the symmetric debt tax. These observations suggest that interest rate responses are more relevant for the overall welfare effects than changes in the collateral price.

[22] This can be seen from the policy functions shown in Figure 15 in Appendix A.2.
[23] Note that CEV does not equal $\sum_{y_i} \pi(y_i) CEV_{y_i}$ by construction.
[24] Within income groups, there might however be some losers, such that there is no strict Pareto improvement.

Figure 13: Aggregate welfare effects of a tax/subsidy on durables



Note: Panels (iii) and (iv) use the wealth distribution prior to the policy shock for the welfare calculation.

4 Conclusion

Pecuniary externalities with regard to the price of collateral can justify financial regulation. This paper examines financial regulation and Pigouvian-style taxes in a incomplete markets economy with collateral constraints and an endogenous wealth distribution. We find that a cap on the loan-to-value ratio positively affects welfare of only income-rich unconstrained borrowers, whereas social welfare decreases. By contrast, a Pigouvian-style symmetric debt tax, which induces a higher collateral price and a lower interest rate, generates welfare gains for (almost) all income groups. Borrowers tend to gain and income-rich lenders tend to lose from the decline in the interest rate, providing a partial insurance for borrowers from an ex-ante perspective. Interventions in the market for durables (collateral) predominantly alter the durables price and exert ambiguous welfare effects due to price-induced shifts in the wealth distribution. The resulting short-run welfare effects can qualitatively overturn the long-run welfare implications, which tend to be positive (negative) for households with a low (high) income in the case of a tax (subsidy) on durables. Overall, the analysis reveals that interest rate responses and distributive effects rather than changes in the durables price and collateral effects are decisive for the total welfare effects. While prudential (ex-ante) policies have been found be beneficial under pecuniary externalities and aggregate risk, our analysis, which focus on idiosyncratic risk and permanent effects, shows that policies interventions that aim at correcting for pecuniary externalities in financial markets enhance social welfare by stimulating rather than dis-incentivizing borrowing.

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A Appendix

A.1 Computational algorithm

This section presents how we solve the quantitative model from Section 3.1. First, we discuss how to solve for the stationary equilibrium of the model economy. Then, we show how to solve for the transition path between two different stationary equilibria.

A.1.1 Calculation of the stationary equilibrium

Solving for the stationary equilibrium involves finding time-invariant values for the real interest rate r and the price of durables q as well as a time-invariant joint distribution of wealth and income implied by the household policy functions such that the markets for durables and bonds clear. The numerical procedure involves the following steps:

I. Choose initial values for r and q.

II. Given r and q, compute the policy functions for non-durable consumption $c(x, y)$, end-of-period bonds $b'(x, y)$, end-of-period durables $d'(x, y)$ and end-of-period wealth $x'(x, y) = b'(x, y) + qd'(x, y)$, using the endogenous grid point method (see Hintermaier and Koeniger, 2010) as outlined below.

III. Given the wealth policy function $x'(x, y)$, compute the implied stationary distribution $\lambda(x, y)$ (see below).

IV. Check whether markets for debt and durables clear. If $|\sum_{x,y} \lambda(x, y)b'(x, y)| < \epsilon^b$ and $|\sum_{x,y} \lambda(x, y)d'(x, y) - \bar{d}| < \epsilon^d$, with $\epsilon^b > 0$ and $\epsilon^d > 0$, stop: r and q are the equilibrium prices. Else, update prices (r, q) and go to Step II.

Solving the household problem via the endogenous grid method The endogenous grid point method used to solve the household problem for r and q involves the following steps:

1. Discretize next period's wealth space $\{x'_1, x'_2, ..., x'_m\}$, $x'_i < x'_{i+1}$. The discretized individual state space then is given by $\{x'_1, x'_2, ..., x'_m\} \times \{y'_1, y'_2, ..., y'_n\}$, where y'_k, $k = 1, ..., n$, are the income states that are possible next period.[25] Select a stopping rule parameter $\epsilon^{egm} > 0$.
2. Initialize the policy functions for non-durable and durable consumption $c_0(x'_i, y'_k)$ and $d'_0(x'_i, y'_k)$, $k \in \{1, ..., n\}$. Our guess is given by $c_0(x'_i, y'_k) = 0.5y'_k$ and $d'_0(x'_i, y'_k) = 0.5\bar{d}$ for all grid point combinations.
3. Update the consumption policy functions (using three auxiliary functions $\hat{c}_0(x'_i, y_k)$, $\hat{x}_0(x'_i, y_k)$ and $\hat{d}'_0(x'_i, y_k)$):
   - First, assume that the borrowing constraint does not bind in any state.

[25] The values for the income grid and the associated transition probabilities are listed in Section A.1.3.

- Use consumption policy functions $c_0(x'_i, y'_k)$ and $d'_0(x'_i, y'_k)$ to compute a guess for current-period non-durable and durable consumption at future wealth x'_i and today's income state y_k, i.e. $\hat{c}_0(x'_i, y_k)$ and $\hat{d}'_0(x'_i, y_k)$, by applying the Euler equations for bonds and durables:

$$\begin{aligned}
u_c(\hat{c}_0(x'_i, y_k), \hat{d}'_0(x'_i, y_k)) =& \beta r \sum_{j=1}^{n} \pi\left(y_j|y_k\right) u_c(c_0(x'_i, y'_j), d'_0(x'_i, y'_j)), \\
u_c(\hat{c}_0(x'_i, y_k), \hat{d}'_0(x'_i, y_k))q =& u_d(\hat{c}_0(x'_i, y_k), \hat{d}'_0(x'_i, y_k)) \\
&+ \beta q \sum_{j=1}^{n} \pi\left(y_j|y_k\right) u_c(c_0(x'_i, y'_j), d'_0(x'_i, y'_j)),
\end{aligned}$$

  which are two equations in the two unknowns $\hat{c}_0(x'_i, y_k)$ and $\hat{d}'_0(x'_i, y_k)$ at given values of x'_i and y_k.

- Now, find the states for which the borrowing constraint is violated. If the borrowing constraint is violated at given grid points x'_i and y_k, i.e. $\hat{d}'_0(x'_i, y_k) > x'_i/(q(1-\gamma))$, we set $\hat{d}'_0(x'_i, y_k) = x'_i/(q(1-\gamma))$. The corresponding value for non-durable consumption $\hat{c}_0(x'_i, y_k)$ can then be calculated via the two Euler equations after having combined them by eliminating the multiplier on the borrowing constraint, which now enters both Euler equations. If the constraint is not binding, i.e. $\hat{d}'_0(x'_i, y_k) \leq x'_i/(q(1-\gamma))$ holds, we keep the values of $\hat{d}'_0(x'_i, y_k)$ and $\hat{c}_0(x'_i, y_k)$ calculated in the step before for this state.

- Use the budget constraint and the auxiliary functions $\hat{c}_0(x'_i, y_k)$ and $\hat{d}'_0(x'_i, y_k)$ to compute current period wealth $\hat{x}$ for x'_i and y_k:

$$\hat{x}_0(x'_i, y_k) = \hat{c}_0(x'_i, y_k) + q\hat{d}'_0(x'_i, y_k) + \left(x'_i - q\hat{d}'_0(x'_i, y_k)\right)/r - y_k.$$

  This implies $\hat{c}_0(x'_i, y_k) = \hat{c}_0(\hat{x}_0(x'_i, y_k), y_k)$ and $\hat{d}'_0(x'_i, y_k) = \hat{d}'_0(\hat{x}_0(x'_i, y_k), y_k)$.

- Calculate updates for the policy functions at $(x'_i, y'_k) \in \{x'_1, x'_2, ..., x'_m\} \times \{y'_1, y'_2, ..., y'_n\}$ by linearly interpolating $\hat{c}_0(\hat{x}_0, y_k)$ and $\hat{d}'_0(\hat{x}_0, y_k)$ at (x'_i, y'_k). This calculation yields the updated consumption policy functions $c_1(x'_i, y'_k)$ and $d'_1(x'_i, y'_k)$.

4. If $||c_1(x'_i, y'_k) - c_0(x'_i, y'_k)||_\infty < \epsilon^{egm}(1 + |c_0(x'_i, y'_k)||_\infty)$ and $||d'_1(x'_i, y'_k) - d'_0(x'_i, y'_k)||_\infty < \epsilon^{egm}(1 + |d'_0(x'_i, y'_k)||_\infty)$, stop and set $c(\cdot) = c_1(\cdot)$ and $d'(\cdot) = d'_1(\cdot)$.
   Else, set $c_0(\cdot) = c_1(\cdot)$ and $d'_0(\cdot) = d'_1(\cdot)$ and go to Step 3.

Computing the stationary distribution For given policy functions, we compute the stationary distribution by calculating the normalized eigenvalue of the Markov transition matrix implied by the policy function for wealth and the income transition probabilities:

1. We add additional grid points for wealth relative the grid used for the calculation of the policy

functions (we go from 10 to 50 thousand grid points for x) and calculate the wealth policy function values for these new states.

2. We calculate the transition probability of being in the state (x_j, y_l) in the next period conditional on currently being in state (x_i, y_k). We denote it as $\Pr((x_j, y_l)|(x_i, y_k))$. This probability is computed as $\Pr((x_j, y_l)|(x_i, y_k)) = \pi(y_l|y_k) \times I(x'(x_i, y_k) = x_j)$, where $I(x'(x_i, y_k) = x_j) = 1$ if $x'(x_i, y_k) = x_j$ and zero otherwise. The Markov transition matrix then consists of the individual transition probabilities $\Pr((x_j, y_l)|(x_i, y_k))$ for all grid point combinations.

3. Compute the eigenvector of this transition matrix that has the largest eigenvalue (which is equal to one). The stationary distribution of the model economy then is obtained by the normalizing this eigenvector.

Updating prices of debt and durables The prices are updated by using two nested bisection algorithms as follows: For a given price of durables q, we calculate the real interest rate r that clears the loan market, i.e. $|\sum_{x,y} \lambda(x, y)b'(x, y)| < \epsilon^b$, using bisection. If the market for durables is also cleared at this combination of q and r, i.e. $|\sum_{x,y} \lambda(x, y)d'(x, y) - \bar{d}| < \epsilon^d$, we can stop. If not, we update the price of durables q and then again calculate the real interest rate r that clears the loan market. The price q is updated by using bisection, too, to get the price that clears the durables market while the corresponding real interest rate at a given q is the value of r that clears the loan market.

A.1.2 Calculation of the transition path to the new stationary equilibrium

In period 0, the economy is in the laissez-faire stationary equilibrium without taxation. In the subsequent period 1, one or both tax rates are unexpectedly and permanently changed to the values τ^b_{new} and τ^d_{new}. Due to this change, the economy departs from the old stationary equilibrium in period 1 and gradually moves to the new stationary equilibrium under the tax rates τ^b_{new} and τ^d_{new}. The transition path to the new long-run equilibrium is computed by using the following steps (see e.g. Rios-Rull, 1999):

- Calculate the stationary equilibria for the laissez-faire economy and the economy with τ^b_{new} and τ^d_{new} as described above and denote the associated stationary distributions as Φ_{old} and Φ_{new}, respectively.
- The beginning-of-period distribution in period 0 is denoted Φ_0 and given by $\Phi_0 = \Phi_{old}$. The distribution of the economy once it has converged to the new stationary equilibrium is denoted as Φ_∞. It is given as $\Phi_\infty = \Phi_{new}$. Note that the beginning-of-period distribution of wealth in period 1 is not the same as in period 0 because the policy change will alter household wealth via durables price q. Since the distributions of bonds and durables at the beginning of period 1 are however not affected and the same as in period 0, we can calculate Φ_1 based on these distributions and price q_1.

- Compute the value function $V_0(x,y)$ in period 0, giving the expected lifetime utility of a household who is in the state (x,y) in period $t=0$, and the value function in the new stationary equilibrium $\mathcal{V}_\infty(\cdot)$.

- Computation of the transition path:

  1. Guess that the transition to the new stationary equilibrium takes $T>0$ periods. This implies that $\Phi_T = \Phi_\infty$ and $V_T = V_\infty$.
  2. Guess a sequence of interest rates $\{\hat{r}_t\}_{t=1}^{T-1}$ as well as durables prices $\{\hat{q}_t\}_{t=1}^{T-1}$. Choose stopping rule parameters $\epsilon^b > 0$, $\epsilon^d > 0$ and $\epsilon^\Phi > 0$.
  3. With the known value $V_T(x,y)$ and guesses $\{\hat{r}_t, \hat{q}_t\}_{t=1}^{T-1}$, we can solve for $\left\{\hat{V}_t, \hat{c}_t, \hat{x}_{t+1}, \hat{d}_{t+1}, \hat{b}_{t+1}\right\}_{t=1}^{T-1}$ via backward induction.
  4. Use the policy functions $\{\hat{x}_{t+1}\}$ and $\Phi_1 = \Phi_0$ to iterate the distribution forward to get $\hat{\Phi}_t$ for $t = 2, ..., T$.
  5. Use the sequence $\left\{\hat{\Phi}_t\right\}_{t=1}^{T}$ to compute excess supply $\hat{A}_t^b = \sum \hat{b}_{t+1} \mathrm{d}\hat{\Phi}_t$ and $\hat{A}_t^d = \sum \hat{d}_{t+1} \mathrm{d}\hat{\Phi}_t - \bar{d}$ for periods $t = 1, ..., T$. If

$$\max_{1 \le t < T} \left|\hat{A}_t^b\right| < \epsilon^b$$
$$\max_{1 \le t < T} \left|\hat{A}_t^d\right| < \epsilon^d,$$

     holds, go to Step 6. Else, adjust the guesses for $\{\hat{r}_t, \hat{q}_t\}_{t=1}^{T-1}$ and go to Step 3.
  6. Check whether $\left\|\hat{\Phi}_T - \Phi_T\right\|_\infty < \epsilon^\Phi$. If it does, the model economy smoothly converges to the new stationary equilibrium and the algorithm ends. If not, go back to Step 1 and start again with a higher value for T.

- The obtained $V_1(\cdot)$ is the value function at time $t=1$ after taxation has changed, such that $V_1(x,y)$ is the expected lifetime utility of a household with income y and beginning-of-period wealth x who has just been hit by the change in taxation. This value hence accounts for the transition of the economy to the new long-run equilibrium.

A.1.3 Transition probabilities and income values

The individual income transition probabilities are obtained as discussed in Section 3.1. The transition matrix is given as

$$\Pi = \begin{pmatrix} 0.9132 & 0.0867 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0001 \\ 0.0867 & 0.7870 & 0.1200 & 0.0001 & 0.0000 & 0.0000 & 0.0001 \\ 0.0000 & 0.1260 & 0.7355 & 0.1382 & 0.0001 & 0.0000 & 0.0001 \\ 0.0000 & 0.0001 & 0.1382 & 0.7355 & 0.1260 & 0.0000 & 0.0001 \\ 0.0000 & 0.0000 & 0.0001 & 0.1260 & 0.7870 & 0.0867 & 0.0001 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0867 & 0.9132 & 0.0001 \\ 0.0021 & 0.0021 & 0.0021 & 0.0021 & 0.0021 & 0.0021 & 0.9876 \end{pmatrix},$$

and the income grid values $(y_1, y_2, ..., y_7)$ are

$$(0.0123, 0.0250, 0.0376, 0.0544, 0.0819, 0.1667, 1)\,.$$

Let i denote the row index and j the column index of matrix Π. The entry $\Pi(i,j) \equiv \pi\left(y_j|y_i\right)$ is the probability that next period's income y_{t+1} equals y_j, conditional on current income $y_t = y_i$.

A.2 Additional figures

Figure 14: Bond holdings and welfare for y_6 (effective change in loan-to-value ratio)

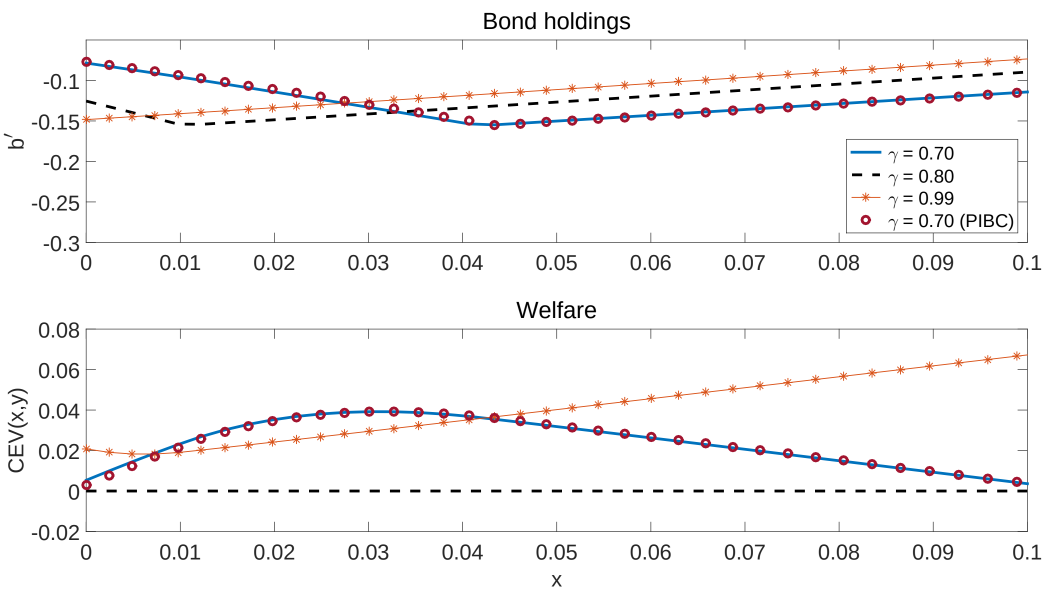

Figure 15: Durable holdings and welfare for y_6 (tax on durables))