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Financial stability, growth and macroprudential policy☆

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ABSTRACT

This paper studies the effect of optimal macroprudential policy in a small open economy model where growth is endogenous. By introducing endogenous growth, this model is able to capture the persistent effect of financial crises on output, which is different from previous literature but consistent with the data. Furthermore, there is a new policy trade-off between cyclical and trend consumption growth. In a calibrated version of the baseline model, I find that the impact of the optimal macroprudential policy on growth and welfare is quantitatively small even if it significantly increases financial stability. I consider two extensions of the model in which the optimal macroprudential policy has a larger impact on growth and welfare: one in which macroprudential policy is jointly used with a growth subsidy that helps reduce the cost of financial crises; and another extension with a direct growth externality.

1. Introduction

In the wake of the Global Financial Crisis in 2008-2009, the use of macroprudential policy to manage boom-bust cycles came to the forefront of macroeconomic research (see Lorenzoni (2008), Benigno et al. (2013), and Dávila and Korinek (2017)). By limiting excessive capital inflows, the goal of macroprudential policy is to mitigate the risk of financial crises and the resulting highly persistent output losses.[1] However, financial crises in current models of macroprudential policy have a temporary effect on output.[2] This raises the question of how the optimal macroprudential policy changes in these models when financial crises have a permanent effect on the output level.

The main contributions of this paper are twofold. First, I provide a new framework such that financial crises have a persistent effect on output level. To achieve this goal, I introduce endogenous growth into a small open economy (SOE) model with occasionally binding collateral constraints that has been widely used in the literature (see Jeanne and Korinek (2018) and Benigno et al. (2016)). In a quantitative exercise, I show that my model is able to match the output dynamics during the crises episodes. Second, I analyze the impact of macroprudential policy on financial stability and growth in the new framework. Unlike the existing literature, there is a new policy trade-off between the cyclical and trend consumption growth. By constraining external borrowing to reduce financial instability, the optimal macroprudential policy hurts trend growth in good times but reduces the permanent output losses from crises. A quantitative exercise suggests that the optimal macroprudential policy significantly enhances financial stability (reducing the probability of crises by two thirds) at the cost of lowering average growth by a small amount.

The key feature of my model is an endogenous productivity process, which can be affected by the occasionally binding collateral constraints. In each period, private agents can use resources to invest in a technology that increases productivity. In a crisis, when the collateral constraint binds, they are forced to cut spending and thus investment in the technology. As a result, crises are associated with lower productivity growth.

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[1] There is strong evidence that financial crises have very persistent effects on output. See Cerra and Saxena (2008), Reinhart and Reinhart (2009), Rogoff and Reinhart (2009), and Ball (2014).

[2] In the existing literature, productivity growth is by assumption exogenous. See Jeanne and Korinek (2018) and Benigno et al. (2013).

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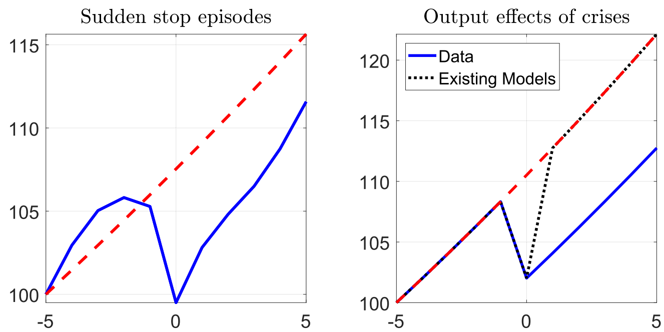

Fig. 1. Output dynamics in existing models and data. *Note:* The red dashed line is a linear projection, and 0 means the time of a crisis. The left panel of the figure is constructed using sudden stop episodes identified by Calvo et al. (2006). The blue solid line is the real GDP per capita, normalized to 100 at five years before crises. The right panel of the figure is only suggestive and constructed using artificial data.

Importantly, growth rates only converge to the long-run average level after crises, which captures the persistent effect of financial crises. Unlike existing models in the literature, output in my model follows a trajectory that is parallel to its pre-crisis trend after financial crises, consistent with the data (see Fig. 1).

This new framework is appropriate to analyze the impact of macroprudential policy on growth. Unsurprisingly, there is room in my model for policy intervention to address over-borrowing. Like other papers (e.g., Jeanne and Korinek (2018)), I analyze the role of macroprudential policy by considering a social planner with an instrument to manage capital flows, i.e. macroprudential capital controls.[3] Unlike the existing literature, however, I do so in an environment that allows me to evaluate the policy's impact on average growth. There is a new policy trade-off between the cyclical and trend consumption growth. Specifically, the macroprudential policy reduces the permanent output losses from crises at the cost of lowering trend growth in good times.

In general, the impact of macroprudential policy on average growth is ambiguous. On one hand, the macroprudential policy increases growth during crises because it reduces financial vulnerabilities. On the other hand, it also lowers growth during normal periods because it reduces external borrowing and thus the expenditures to increase productivity. The calibrated version of my model reveals that optimal macroprudential policy reduces the probability of crises from 6.2 percent to 1.9 percent (about two-thirds), at the cost of lowering average growth by 0.01 percentage point. Therefore, the growth cost of policy intervention is quantitatively small. This result is robust to many alternative specifications of the model and due to the absence of direct growth externality in the setting. In one extension of the model, I show that macroprudential policy can have a larger impact on growth rate once introducing growth externality.

Furthermore, I find that the welfare gains from the optimal macroprudential policy are equivalent to a 0.06 percent permanent increase in annual consumption. Like in the existing literature, the optimal macroprudential policy increases welfare by limiting the likelihood and severity of financial crises, thereby helping agents to smooth consumption. In fact, in the model, that effect is stronger with endogenous growth. However, macroprudential policy also reduces growth in normal times. The cost of lowering trend growth has significant welfare consequences, which explains why the optimal policy only lowers average growth by a small amount. Furthermore, even if the welfare gains from smoothing the cyclical consumption growth have been enhanced by endogenous growth, the probability of crises has been driven down considerably by this optimal policy. Overall, the size of the welfare gains from macroprudential policy are similar to models with exogenous productivity (see Jeanne and Korinek (2018)).

However, the macroprudential policy can have a much larger welfare impact once it is jointly used with an additional instrument that helps reduce the cost of financial crises ex post. I analyze two such instruments in my economy. One instrument is an asset price subsidy that can be used to increase the price of collateral in a crisis like in Benigno et al. (2016). The second instrument, which is new to the literature and is made possible by the endogenous growth, is a tax/subsidy on the productivity investment (growth subsidy for brevity) that can be used to change the composition of spending. Both instruments can enhance the welfare impact of macroprudential policy since they help to relax the borrowing constraint. In the end, the optimal policy mix consists of both an ex-ante and ex-post intervention, which can generate larger welfare benefits than using the ex-ante macroprudential policy alone (see Jeanne and Korinek (forthcoming) and Benigno et al. (2013)).

1.1. Relation to literature

This paper is related to the literature on the relationship between growth and stability, in which empirical evidence often leads to mixed results. There are papers on the cross-country relationship between average growth and the volatility of growth. For example, Ramey and Ramey (1995) find a negative relationship between average growth and volatility of growth, while Rancière et al. (2008) argue that countries experiencing more crises (more volatile growth) have higher average growth (see Levine (2005) for a summary). Moreover, there are also papers on the impact of policy on growth and financial stability. For example, Sánchez and Gori (2016) find that certain growth-promoting policies can have negative side-effects on financial stability, while Boar et al. (2017) find that macroprudential policy can increase both financial stability and long-run economic growth. This paper finds a negative relationship between average growth and financial stability for macroprudential policy, consistent with Rancière et al. (2008) and Sánchez and Gori (2016). However, this relationship depends on calibrations and might become positive in some cases, which is consistent with the findings in Ramey and Ramey (1995) and Boar et al. (2017).

This paper is also related to the literature on short-run fluctuations and growth. There are two existing approaches in the literature to introduce endogenous growth into a standard DSGE framework: One approach models growth following Romer (1990), such as Comin and Gertler (2006), Queraltó (2019), and Guerron-Quintana and Jinnai (2014). The other approach models growth following Aghion and Howitt (1992), such as Ates and Saffie (2016) and Benigno and Fornaro (2017). My way of modeling growth is similar to the first approach, which preserves the representative-agent framework. However, unlike the existing literature, which focuses on a positive analysis, my paper is interested in the characterization of optimal policy and the policy's impact on growth and welfare.

Finally, this paper belongs to the literature on optimal macroprudential policy and capital flow management. The theoretical rationale for macroprudential policy includes pecuniary externalities (see Lorenzoni (2008), Jeanne and Korinek (2010), and Dávila and Korinek (2017)) and aggregate demand externalities (see Farhi and Werning (2016) and Korinek and Simsek (2016)). The general takeaway from the theories is that ex-ante policy intervention can be welfare-improving, since it addresses over-borrowing in the credit market and thus reduces financial instability. However, the literature has been silent on the effect of the ex-ante intervention on economic growth, which is the central focus of this paper. Specifically, this paper introduces endogenous growth into a standard SOE-DSGE model with occasional binding constraints (see Jeanne and Korinek (2018), Bianchi (2011) and Bianchi and Mendoza (2018)). Unlike in other literature, crises have persistent output-level effects in this model, consistent with the empirical evidence.

The organization of this paper is as follows: Section 2 presents a benchmark model; Section 3 presents the calibration procedure and

[3] This policy is prudential capital control. See Korinek (2011), Jeanne, 2012, Jeanne et al. (2012), and IMF (2012) for a detailed overview. For a survey on the recent development of the literature on macroprudential capital controls, see Erten et al. (2019) and Rebucci and Ma (2019).

model performance; Section 4 presents a normative analysis for macroprudential policy; Section 5 presents quantitative analysis of the policy; Section 6 presents the robustness of the results to alternative specifications of the model; Section 7 presents two extensions to the baseline analysis; and Section 8 concludes.

2. Model economy

This section introduces an analytical framework that incorporates endogenous growth into an SOE model as in Jeanne and Korinek (2018). One feature of the model is an occasionally binding collateral constraint, which can capture financial crises and justifies the policy intervention (see Benigno et al. (2013) and Dávila and Korinek (2017)). In the model, normal periods are when the constraint is slack, and crisis periods are when the constraint binds. In order to capture the persistent effect of financial crises, I make two departures from the standard literature. First, I introduce a technology that allows agents to change the productivity level. By doing so, crises can have an impact on growth. Second, I make a modification to utility functions such that growth rates fall at a level that is consistent with the data. As I will explain later, this modification can be interpreted as one form of internal habit. Its role is to increase the local concavity of the utility functions (see Campbell and Cochrane (1999)).

2.1. Analytical framework

In my model, the economy is populated by a continuum of identical households that have access to an international capital market and a technology that increases productivity. Due to friction in the financial market, there exist collateral borrowing constraints, and the maximum amount of external borrowing cannot exceed the value of collateral. In normal periods, when the constraints are slack, households can finance their desired levels of expenditure through external borrowing. The economy thus grows at a normal rate. In crises, when the collateral constraints bind, households cannot finance enough expenditures for the technology. As a result, the growth rate drops.

Preferences: Households have the following Constant Relative Risk Aversion (CRRA) preferences with one modification:

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_t - \mathscr{H}_t) \equiv E_0 \sum_{t=0}^{\infty} \beta^t \frac{(c_t - \mathscr{H}_t)^{1-\gamma}}{1-\gamma} \tag{1}$$

where $\beta \in (0,1)$ is the discount factor, γ is the coefficient of risk aversion, c_t is consumption, and $\mathscr{H}_t$ is the modification. Given that the economy is growing, I assume that $\mathscr{H}_t$ depends on the level of endogenous productivity (trend) z_t and takes the functional form as follows (see Christiano (1989)):[4]

$$\mathscr{H}_t = hz_t \tag{2}$$

Interpretation of $\mathscr{H}_t$: One interpretation of $\mathscr{H}_t$ is a form of internal habit. The stock of habit depends on a pre-determined economic trend z_t. As I will explain later, households can spend on a technology to change the trend from z_t to z_{t+1} at period t, which will affect the term $\mathscr{H}_{t+1}$. Importantly, the private agent internalizes this effect. Therefore, this is a form of internal habit. Rather than modelling $\mathscr{H}_t$ as a function of past consumption, I assume that it depends on past trend, which reduces the number of endogenous state variables and thus the computational burden. The other interpretation of $\mathscr{H}_t$ is a form of subsistence level of consumption as in the Stone-Geary functional form (see Geary (1950) and Stone (1954)). A subsistence level of consumption has been introduced before in the literature on growth in open economies (see Rebelo (1992) and Steger (2000)). I assume that the subsistence level of consumption increases with the economy. As argued by Ravn et al. (2008), "Luxuries in a poor society, such as tap water, inside plumbing, and health care, are considered necessities in developed countries."

[4] $h > 0$ is a constant.

Role of $\mathscr{H}_t$: The main role of $\mathscr{H}_t$ is to increase the local concavity of utility functions as in the habit formation literature (see Campbell and Cochrane (1999)). Without $\mathscr{H}_t$, private agents find it costly to cut z_{t+1}, since that implies a permanent future loss in output.[5] Instead, private agents cut consumption spending. As a result, the endogenous growth rate, $\frac{z_{t+1}}{z_t}$, barely falls when there is a negative shock. Therefore, crises only have a temporary impact on output level in the model even after introducing endogenous growth. To have a large decrease in growth, one need to raise the cost of cutting consumption for private agents, which is achieved here by increasing the local concavity of the utility functions as in the habit formation literature.[6]

Production Function: Production only requires a productive asset n_t as an input and takes the following form:

$$y_t = A_t n_t^{\alpha} \tag{3}$$

where A_t represents the productivity level in the economy and $\alpha \in (0,1)$. Productive asset n_t is an endowment to households and is normalized to 1. It corresponds to an asset in fixed supply, such as land. In each period, households trade the productive asset n_t at a market-determined price q_t.

Endogenous Productivity: The level of productivity A_t takes the following form:

$$A_t = \theta_t z_t \tag{4}$$

where θ_t is a stationary exogenous productivity shock, and z_t is non-stationary endogenous productivity chosen by private agents.

Source of Growth: Growth in the economy comes from the endogenous productivity z_t that households can choose. Specifically, there is a technology that costs $\Psi(z_{t+1}, z_t)$ units of consumption to elevate endogenous productivity from z_t to z_{t+1}. I call $\Psi(z_{t+1}, z_t)$ "growth-enhancing expenditures," which include all the expenditures that facilitate long-term economic growth. Here I do not take a stand on any particular form of endogenous growth, but use a generic form that includes many models in the growth literature.[7] For example, $\Psi(z_{t+1}, z_t)$ includes physical capital investment in the AK growth framework as in Romer (1986), human capital investment as in Lucas (1988), R&D expenditure as in Romer (1990) and Aghion and Howitt (1992), etc. The only restriction is that there are no externalities in the process of choosing z_{t+1}. When private agents choose z_{t+1}, they internalize its impact on not only the future term $\mathscr{H}_{t+1}$ in the utility function but also the future cost function, $\Psi(z_{t+2}, z_{t+1})$. This restriction thus shuts down any externalities in endogenous growth.[8] This departs from the literature on short-run fluctuations and growth, where economic growth is typically suboptimal (see Comin and Gertler (2006) and Kung and Schmid (2015)).

Financial Friction: I introduce a collateral constraint on external borrowing following Jeanne and Korinek (2018). Specifically, households can purchase b_{t+1} units of a one-period bond from the international market in each period, and these bonds promise a gross interest rate $1 + r$ in the next period. The domestic economy is atomistic in the international world and takes the interest rate as given.

[5] As I will explain below, future output y_{t+1} depends on productivity z_{t+1}.

[6] One might also want to increase the risk-aversion coefficient of utility functions or introduce Epstein-Zin preference. However, neither of these modifications leads to a large decrease in growth following a crisis.

[7] Admittedly, it is important to understand the source of growth. However, the main focus of this paper is to understand the policy's impact on growth. Therefore, I adopt a reduced-form function of endogenous growth so as to match the output dynamics during the crisis episodes.

[8] As I will explain in the next section, there are pecuniary externalities in the economy that justify an optimal policy. However, both externalities in growth and pecuniary externalities typically call for policy interventions. If both of them are present in the economy, it is hard to disentangle their effects. Furthermore, externalities in endogenous growth tend to dominate pecuniary externalities. See Section 7 which analyzes the economy with two externalities.

Furthermore, bonds are supplied with infinite elasticity. However, there is a source of financial friction in the market: Private agents need to post their productive assets as collateral for external borrowing, and the maximum amount of external borrowing cannot exceed a fraction $\phi \in (0,1)$ of the collateral value q_t.[9] Therefore, the collateral constraint can be written as[10]

$$-b_{t+1} \leq \phi q_t \tag{5}$$

Budget Constraint: In each period, households make expenditure plans for consumption c_t, growth-enhancing expenditures $\Psi(z_{t+1}, z_t)$, productive assets $q_t n_{t+1}$, and bond holdings b_{t+1}. Their incomes come from the output y_t, sale of productive assets $q_t n_t$, and existing bond holdings $(1 + r)b_t$. As a result, the budget constraint can be written as follows:

$$c_t + \Psi(z_{t+1}, z_t) + q_t n_{t+1} + b_{t+1} = y_t + q_t n_t + (1+r)b_t, \tag{6}$$

Market Clearing: There are two markets in the economy: the final goods market and the productive asset market. Given that the productive asset is in fixed supply and owned by the households, the equilibrium condition implies that

$$n_t = 1, \quad \forall t \tag{7}$$

The final goods market can be pinned down by aggregating the budget constraint for each household and applying the equilibrium condition (7) in the productive asset market.

$$c_t + \Psi(z_{t+1}, z_t) + b_{t+1} = y_t + (1+r)b_t, \tag{8}$$

2.2. Competitive equilibrium (CE)

Competitive Equilibrium: In this economy, a competitive equilibrium consists of a stochastic process $\{c_t, z_{t+1}, n_{t+1}, b_{t+1}\}_{t=0}^{\infty}$ chosen by the households and an asset price $\{q_t\}_{t=0}^{\infty}$, given initial values $\{b_0, z_0\}$ and the exogenous shock $\{\theta_t\}_{t=0}^{\infty}$ such that utility (1) is maximized, constraints (5) and (6) are satisfied, and the productive assets and goods market clear, i.e., conditions (7) and (8) are satisfied.

Recursive Formulation: It is convenient to define net consumption by $c_t^h = c_t - \mathscr{H}_t$ and write the problem in a recursive formulation. State variables at time t include the endogenous variables $\{z_t, n_t, b_t\}$ and the exogenous variable θ_t. I can write the optimization problem as follows:

$$\begin{aligned} V_t^{CE}(z_t, n_t, b_t, \theta_t) \quad &= \max_{c_t^h, z_{t+1}, n_{t+1}, b_{t+1}} u\left(c_t^h\right) + \beta E\left[V_{t+1}^{CE}(z_{t+1}, n_{t+1}, b_{t+1}, \theta_{t+1})\right] \\ \text{s.t.} \quad & c_t^h + hz_t + \Psi(z_{t+1}, z_t) + q_t n_{t+1} + b_{t+1} = \theta_t z_t n_t^{\alpha} + q_t n_t + (1+r)b_t, \\ & -b_{t+1} \leq \phi q_t. \end{aligned}$$

The maximization problem yields the following optimality conditions for each period:

$$\lambda_t^{CE} = u'\left(c_t^h\right) \tag{9}$$

$$\lambda_t^{CE}\Psi_{1,t} = \beta E_t\left[\lambda_{t+1}^{CE}(\theta_{t+1} - h - \Psi_{2,t+1})\right] \tag{10}$$

$$\lambda_t^{CE} q_t = \beta E_t\left[\lambda_{t+1}^{CE}(\alpha\theta_{t+1} z_{t+1} + q_{t+1})\right] \tag{11}$$

$$\lambda_t^{CE} = \mu_t^{CE} + \beta(1+r)E_t\left[\lambda_{t+1}^{CE}\right] \tag{12}$$

where $\Psi_{1,t} = \dfrac{\partial\Psi(z_{t+1}, z_t)}{\partial z_{t+1}}$ and $\Psi_{2,t+1} = \dfrac{\partial\Psi(z_{t+2}, z_{t+1})}{\partial z_{t+1}}$. λ_t^{CE} and μ_t^{CE} are Lagrangian multipliers associated with the budget constraint and collateral constraint, respectively.

Condition (9) is the marginal valuation of household wealth. Condition (10) is the key equation for growth in this model, where private agents equate the marginal cost of choosing z_{t+1} with the marginal benefit. The cost is reflected in the partial derivative of the technology function $\Psi_{1,t}$, while the benefit includes a future output θ_{t+1}, excluding the normalized future habit term (or subsistence level of consumption term), h and the partial derivative of future technology function, $\Psi_{2,t+1}$. The marginal cost and marginal benefit are evaluated at the marginal valuation of wealth in periods t and $t+1$ respectively. The third condition (11) is a standard asset pricing function, where holding productive asset n_{t+1} yields a dividend income $\alpha\theta_{t+1}z_{t+1}$ and capital gains q_{t+1}. The last condition (12) is the Euler equation for holding bonds. The additional term μ_t^{CE} captures the effect of collateral constraint on the external borrowing. When the collateral constraint (5) binds, the marginal benefit of borrowing to increase consumption exceeds the expected marginal cost by an amount equal to the shadow price of relaxing collateral constraint μ_t^{CE}.

Normalized Economy: To solve for a stationary equilibrium, I normalize all the endogenous variables by z_t and denote this by variables with hats. Specifically, I denote $\hat{x}_t = \dfrac{x_t}{z_t}$, where $x_t = \{c_t^h, b_t, q_t, V_t^{CE}, \cdots\}$, and endogenous growth rate $g_{t+1} = \dfrac{z_{t+1}}{z_t}$. The normalized equilibrium conditions are given in Appendix C.

3. Calibration

This section first describes empirical evidence on the persistent effect of crises, i.e. an 11-year event window that the model targets. It then shows parameter values and the model's ability to fit the data.

3.1. Targeted event window

One key feature of the model is its generation of such persistent output-level effects of financial crises as found in the data (see Cerra and Saxena (2008), Rogoff and Reinhart (2009), and Ball (2014)). To quantify the magnitude of output cost for later calibration, I construct an 11-year event window of output growth rates centering on one specific type of financial crisis in emerging markets, i.e., sudden stop episodes.[11] These episodes occur when there is a sudden slowdown in private capital inflows to emerging market economies and a corresponding sharp reversal in current account balances. For the identification of sudden stops I use the episodes in Calvo et al. (2006) ("Calvo episodes"), whose criterion is based on a sharp reversal in current account balances and a spike in spreads. For robustness, I also use episodes identified in Korinek and Mendoza (2014) ("KM episodes") and report the results in Appendix B.

The left panel of Fig. 2 shows that the growth rate of real GDP per capita is a stationary process and falls to −5.65 percent at the time of crises. I also construct an event window for "Total Factor Productivity (TFP)" in the right panel of Fig. 2 and find that productivity displays a similar pattern to output, consistent with the predictions of my model.

[9] One rationale for the collateral constraint is as follows: There is a moral hazard problem between domestic households and international investors (see Jeanne and Korinek (2018)). Households have the option to invest in a scam that prevents international investors from seizing future productive assets. This implies that households can default on their debts without any punishment. The investors, however, cannot coordinate to punish the households by excluding them from the market. The only recourse is to take legal action before the scam is completed. By doing so, they can only seize a fraction ϕ of productive assets and sell them to other households at the prevailing market price q_t. As a result, rational international investors will restrict the amount of external borrowing up to ϕq_t.

[10] One can also specify the collateral constraint in the form of $-b_{t+1} \leq \phi q_t n_t$ or $-b_{t+1} \leq \phi q_t n_{t+1}$. I check these alternative formulations and find that the quantitative results are similar to the current setting (see Section 6.1). Following Jeanne and Korinek (2018), I adopt the form as in (5) since it makes the math simpler.

[11] The source of real GDP per capita is explained in Appendix A.

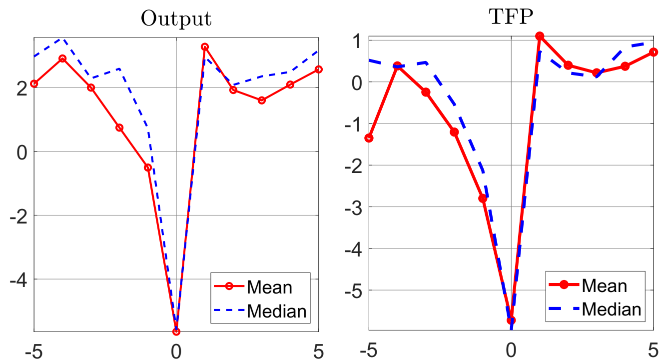

Fig. 2. Growth rates in sudden stop episodes (%). *Note:* The series are constructed using an 11-year window centering on the sudden stop episodes.

3.2. Parameter values

I calibrate the model to annual frequency using 55 countries' data from between 1961 and 2015 (see Appendix A for details). The model can be solved using a variant of the endogenous gridpoint method, as in Carroll (2006) (see Appendix H for details). There is only one shock in the economy: the exogenous technology shock θ_t, which follows the process below. I discretize the process using Rouwenhorst method as in Kopecky and Suen (2010).

$$\log\theta_t = \rho\ \log\theta_{t-1} + \varepsilon_t, \quad \text{where}\ \ \varepsilon_t \sim N(0, \sigma^2)$$

where ρ and σ are persistence and volatility of the shock, and ε_t is a random variable following a normal distribution.

It is important to have the shock θ_t in the model to capture the fall of output growth during crises, as seen in Fig. 2. Without a fall in θ_t, one cannot explain the negative output growth rate in crises, since output y_t depends on the predetermined productivity z_t and the exogenous productivity θ_t.[12] Furthermore, the endogenous response of productivity z_{t+1} prevents the output growth rate after crises from being higher than its long-run average, consistent with the event window.[13]

Assumption 1. *Cost function* $\Psi(z_{t+1}, z_t)$ *is quadratic and takes the following form:*

$$\Psi(z_{t+1}, z_t) = \left[\left(\frac{z_{t+1}}{z_t} - \psi\right) + \kappa\left(\frac{z_{t+1}}{z_t} - \psi\right)^2\right] z_t,$$

where $\psi > 0$ *and* $\frac{z_{t+1}}{z_t} \geq \psi$.

I impose a simple quadratic form on $\Psi(z_{t+1}, z_t)$ so as to calibrate my model. Given that this way of modeling growth is generic, I calibrate the function's parameter values using references to moments in the data. For example, κ is a scale parameter and is used to match the average share of consumption in GDP. The parameter ψ is the minimum level of endogenous growth g_{t+1} in the model and is used to match the output growth rate after crises in the targeted event window.

I need to assign values to 10 parameters in the model: $\{\beta, r, \gamma, h, \psi, \kappa, \alpha, \rho, \sigma, \phi\}$. The calibration proceeds in two steps. First, some parameter values are standard in the literature. For example, I choose the interest rate r to be 6 percent and the coefficient of risk aversion parameter γ to be 2. The parameter α equals productive asset income's share of total income, and I choose 0.2 following Jeanne and Korinek (2018). Second, given these parameter values, I jointly choose the remaining parameters to match relevant moments in the data and the targeted event window in Fig. 2.

Specifically, I use the following parameters to match data moments. Parameter β determines the incentive to borrow and is chosen to match the long-run Net Foreign Asset (NFA) to GDP ratio (−30 percent). Parameter ρ is chosen to match the correlation between the current account and output at −0.25, since I focus on the relationship between capital flows and output growth.[14] Parameter ϕ determines the maximum value of borrowing in the economy and thus the probability of crises.[15] In the model, I define crisis episodes as periods when constraints bind and the magnitude of current account reversal exceeds 1 standard deviation of its long-run average (see Bianchi (2011)). The parameter ϕ is chosen to match the probability of crises at 5.5 percent, a standard value in the literature (see Bianchi (2011) and Eichengreen et al. (2008)). Furthermore, parameters h and κ are jointly chosen to match the average growth rate, 2.3 percent and the share of consumption in GDP, 77.6 percent. Specifically, h and κ must satisfy the normalized resource constraint (8) and the Euler equation of z_{t+1} (10) as follows:

$$\underbrace{\hat{c}_{ss}}_{77.6\%} + \hat{\Psi}(\underbrace{g_{ss}}_{1+2.3\%}) = 1 + \frac{1 + r - g_{ss}}{g_{ss}} \underbrace{\hat{b}_{ss} g_{ss}}_{-30\%}$$

$$\Psi_1(g_{ss}) = \beta g_{ss}^{-\gamma}(1 - h - \Psi_2(g_{ss}))$$

where the average value of θ_t is normalized at 1, and the value of h and κ depend on the value of β and ψ.[16]

As explained before, I also want to match the event window in Fig. 2. The volatility σ governs the minimum level of the exogenous shock θ_t and thus the decline in the output growth rate during crises. Parameter ψ determines the minimum level of the endogenous growth rate g_{t+1} and thus the decline in the output growth rate one year after crises. Therefore, I choose σ and ψ to jointly match the output growth rate during crises (−5.65 percent) and one period after crises (3.28 percent) in the event window.

In sum, given the values of $\{r, \gamma, \alpha, \eta\}$, I pick values of $\{\beta, \psi, \rho, \sigma\}$, which determine values of $\{\phi, \kappa, h\}$. I then simulate the model, calculate moments of the simulated data, construct an event window as in Fig. 2, and then compare the simulation results with the actual data moments and the targeted event window.[17] The values of all parameters are reported in Table 1.

3.3. Model performance

Table 2 reports model and data moments. One can see that the model matches targeted moments in the data. As with other models with occasionally binding collateral constraints, crisis episodes are rare

[12] Admittedly, other shocks, such as financial shocks and interest rate shocks, are important for understanding financial crises. However, these shocks alone cannot lead to a drop of output growth in crises in the model, since the productivity z_t is predetermined.

[13] One could also have an exogenous trend shock, as in Aguiar and Gopinath (2007). Introducing an exogenous trend shock, however, does not allow me to analyze the policy's impact on growth.

[14] Aguiar and Gopinath (2007) find that the persistence of shocks governs the correlation between the current account and output. The correlation is constructed by first detrending the output series with a HP filter and then calculating the correlation between the current account to GDP ratio and the cyclical component of output.

[15] I calibrate the model such that the collateral constraint marginally binds in the long run and the following relationship holds in the steady states:

$$\underbrace{-\hat{b}g_{ss}}_{30\%} = \phi\hat{q}$$

$$\hat{q} = \frac{\beta g_{ss}^{1-\gamma}}{1 - \beta g_{ss}^{1-\gamma}} \alpha$$

[16] Here, I calibrate the economy so that in the long run it is unconstrained and the collateral constraint marginally binds.

[17] Specifically, I simulate the model for 11,000 periods and throw away the first 1000 periods. Data moments are calculated based on the remaining 10,000 periods of simulated data. Furthermore, I identify crisis episodes in the simulated data and calculate the output growth rate during crises and one period after crises.

Table 1
Calibration.

	Value	Source/target
Parameter in production function	$\alpha = 0.2$	Jeanne and Korinek (2018)
Risk-free interest rate	$r = 6\%$	Benigno et al. (2013)
Risk aversion	$\gamma = 2$	Standard in the literature
Volatility of technology shock	$\sigma = 0.04$	Output growth rate at time of crises = −5.65 %
Parameter in Ψ functions	$\psi = 0.95$	Output growth rate one year after crises =3.28%
Parameter in Ψ functions	$\kappa = 26.29$	Consumption-GDP ratio =77.6%
Parameter in the utility function	$h = 0.51$	Average GDP growth =2.3%
Discount rate	$\beta = 0.968$	Probability of crises =5.5%
Persistence of technology shock	$\rho = 0.83$	Correlation between current account and output = −0.25
Collateral constraint parameter	$\phi = 0.0852$	NFA-GDP ratio = −30%

events in my model and occur with a probability of 6.2 percent in the simulation.

Unlike existing models in the literature, my model can generate the growth rate dynamics in Fig. 2. To see this, I simulate the model, identify crisis episodes and construct an 11-period event window for different variables in Fig. 3. Not surprisingly, crises occur when there is a large drop in the exogenous shock θ_t. The current account experiences a large reversal because the borrowing constraints bind and private agents have to cut their external borrowing, i.e., an increase in $\hat{b}_{t+1}$. Furthermore, these events are accompanied by a decline in spending such as consumption $\hat{c}_t$ and growth-enhancing expenditures (reflected in a decline in the endogenous growth rate g_{t+1}). The asset price $\hat{q}_t$ also drops, which leads to an amplification effect through collateral constraints. Fortunately, my model captures the empirical regularity of crises. Importantly, it can capture the persistent output-level effects of crises as in the data: Output growth rates fall during crises with a decline in θ_t and only go back to the long-run average level after crises. This occurs because the endogenous growth rate g_{t+1} decreases during crises.

4. Optimal macroprudential policy

Consistent with the literature, there is a role for macroprudential policy in the economy due to the presence of pecuniary externalities (see Lorenzoni (2008) and Dávila and Korinek (2017)).[18] These pecuniary externalities are related to a vicious cycle associated with the collateral borrowing constraints. Intuitively, private agents need to cut spending when a negative shock hits and the constraints bind. However, asset prices fall with a decline in spending and private agents need to cut spending further due to lower collateral values and tighter borrowing constraints. Therefore, the initial shock is endogenously amplified through the constraints. Importantly, private agents, taking the asset price as given, fail to internalize their contributions to this vicious cycle, which represents pecuniary externalities in the economy. As a result, they over-borrow in normal periods. The optimal macroprudential policy is designed to correct this over-borrowing in the credit market.

Following the literature, I first define the social planner's problem and then choose macroprudential policy to implement the allocation (see Jeanne and Korinek (2018), Bianchi (2011), and Bianchi and Mendoza (2018)). This is similar to the "primal approach" in optimal policy analysis (originally from Stiglitz (1982)), in which the social planner can choose allocations subject to resource, implementability, and collateral constraints. This formulation allows me to see the wedge between the social planner and private agents in choosing allocations and understand the inefficiencies in the economy. To implement the social planner's allocation, I consider what tax or subsidy with lump-sum transfers is needed to close the wedge. In this case, a tax on capital flows is needed.

Specifically, I consider the social planner who chooses allocations on behalf of the representative household to be subject to the same constraints as private agents, but who lacks the ability to commit to future policies. Importantly, I assume that the asset price q_t remains market determined and that the Euler equation of asset price (11) enters the social planner's problem as an implementability constraint. The implicit rationale is that the social planner cannot directly intervene with respect to the asset price but internalizes how the allocations affect it and thus the collateral constraint.[19,20]

Furthermore, I assume that endogenous productivity z_{t+1} is chosen by private agents and that the Euler equation of productivity (10) also enters the social planner's problem as an additional implementability constraint. This is because I use macroprudential policy to decentralize this social planner's allocation and the policy is designed to correct the wedge only in the bond holdings.

I call the social planner with macroprudential policy a *macroprudential social planner* and denote her allocation with a superscript "MP". As described before, the maximization problem can be written as

$$
\begin{aligned}
V_t^{MP}(z_t, b_t, \theta_t) \quad &= \max_{c_t^h, z_{t+1}, b_{t+1}, q_t} u\left(c_t^h\right) + \beta E\left[V_{t+1}^{MP}(z_{t+1}, b_{t+1}, \theta_{t+1})\right] \\
\text{s.t.} \quad & c_t^h + hz_t + \Psi(z_{t+1}, z_t) + b_{t+1} = \theta_t z_t + (1+r)b_t, \\
& -b_{t+1} \le \phi q_t,
\end{aligned}
$$

$$
u'\left(c_t^h\right)q_t = \underbrace{\beta E_t\left[u'\left(c_{t+1}^h\right)(\alpha\theta_{t+1}z_{t+1} + q_{t+1})\right]}_{G(z_{t+1}, b_{t+1})}, \tag{13}
$$

$$
u'\left(c_t^h\right)\Psi_{1,t} = \underbrace{\beta E_t\left[u'\left(c_{t+1}^h\right)(\theta_{t+1} - h - \Psi_{2,t+1})\right]}_{I(z_{t+1}, b_{t+1})}. \tag{14}
$$

where Eqs. (13) and (14) are two implementation constraints, i.e., the Euler equations of choosing productive assets and productivity. I write implementation constraints as functions of future endogenous state variables z_{t+1} and b_{t+1}, since I want to solve for time-consistent policy functions as in Jeanne and Korinek (2018) and Bianchi and Mendoza (2018).[21]

Given the definition of the macroprudential social planner, it is straightforward to define constrained inefficiency as follows:

Table 2
Moments: data and model.

Targeted moments	Data	Model
Average GDP growth (%)	2.30	2.31
Probability of crises (%)	5.50	6.23
NFA-GDP ratio (%)	−30.00	−27.18
Consumption-GDP ratio (%)	77.6	77.53
Correlation between current account and output	−0.25	−0.22

[18] Pecuniary externalities refer to externalities associated with prices. In an economy with incomplete markets, allocations with pecuniary externalities are generically suboptimal. For a detailed proof, see early contributions by Geanakoplos and Polemarchakis (1986) and Greenwald and Stiglitz (1986).

[19] I do not allow the social planner to trade assets on behalf of private agents. One rationale is that private agents are better than the planner at observing fundamental payoffs of financial assets (see Jeanne and Korinek (2018)).

[20] This corresponds to the notion of "constrained efficiency" in the welfare analysis (see Stiglitz (1982), Kehoe and Levine (1993) and Benigno et al. (2013)).

[21] There exists a time-consistency issue in the social planning problem. In our time-consistent setting, the planner can only affect the future by changing the endogenous state variables z_{t+1} and b_{t+1}. In other words, the planner does not have the ability to commit and has to take the future social planner's action as given. If the planner had the power to commit, she could raise the asset price and thus relax the borrowing constraint at time t by promising a lower consumption at time $t+1$. However, this commitment is not credible since it is optimal to consume more at time $t+1$.

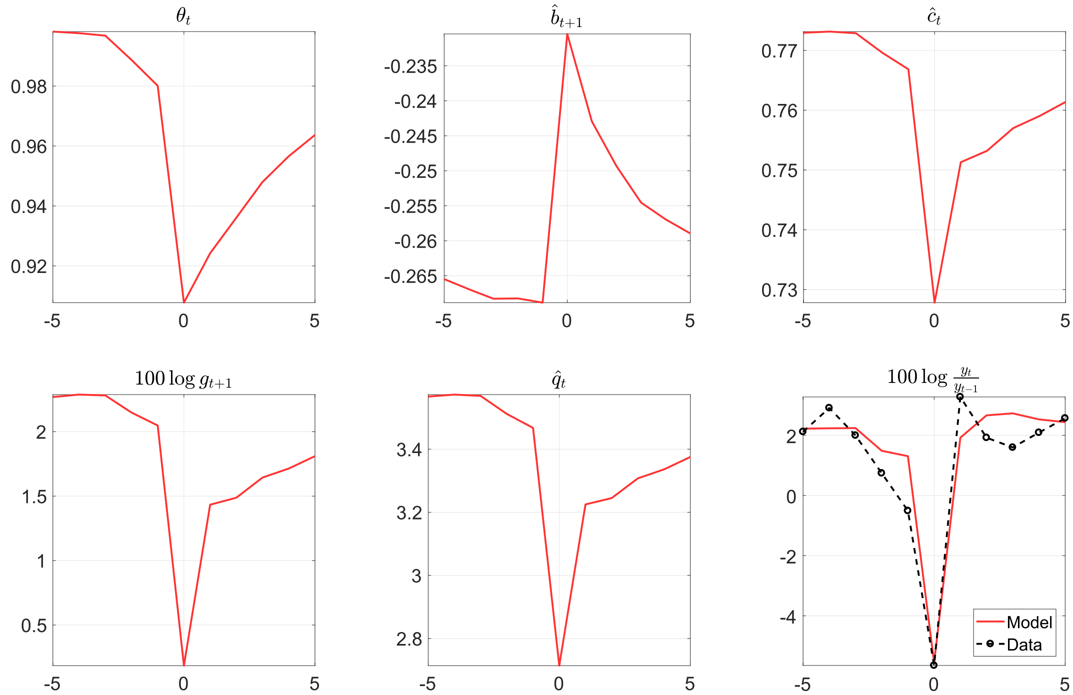

Fig. 3. Event window: model and data.

Definition 1. *Constrained inefficiency*

The competitive equilibrium displays constrained inefficiency if it differs from the allocation chosen by the macroprudential social planner.

To understand the difference between private agents and the macroprudential social planner, I derive the optimality conditions of MP as follows:

$$\lambda_t^{MP} = u'\left(c_t^h\right) - \xi_t^{MP} u''\left(c_t^h\right) q_t - \nu_t^{MP} u''\left(c_t^h\right)\Psi_{1,t} \quad (15)$$

$$\lambda_t^{MP}\Psi_{1,t} - \xi_t^{MP} G_{1,t} - \nu_t^{MP}\left[I_{1,t} - u'\left(c_t^h\right)\Psi_{11,t}\right]$$

$$= \beta E_t\left[\lambda_{t+1}^{MP}\left(\theta_{t+1} - h - \Psi_{2,t+1}\right) - \nu_{t+1}^{MP} u'\left(c_{t+1}^h\right)\Psi_{12,t+1}\right] \quad (16)$$

$$\phi\mu_t^{MP} = \xi_t^{MP} u'\left(c_t^h\right) \quad (17)$$

$$\lambda_t^{MP} = \mu_t^{MP} + \xi_t^{MP} G_{2,t} + \nu_t^{MP} I_{2,t} + \beta(1+r)E_t\left[\lambda_{t+1}^{MP}\right] \quad (18)$$

where $\Psi_{11,t} = \frac{\partial^2\Psi(z_{t+1}, z_t)}{\partial z_{t+1}^2}$, $\Psi_{12,t+1} = \frac{\partial^2\Psi(z_{t+2}, z_{t+1})}{\partial z_{t+2}\partial z_{t+1}}$, $G_{1,t} = \frac{\partial G(z_{t+1}, b_{t+1})}{\partial z_{t+1}}$, $G_{2,t} = \frac{\partial G(z_{t+1}, b_{t+1})}{\partial b_{t+1}}$, $I_{1,t} = \frac{\partial I(z_{t+1}, b_{t+1})}{\partial z_{t+1}}$, and $I_{2,t} = \frac{\partial I(z_{t+1}, b_{t+1})}{\partial b_{t+1}}$. λ_t^{MP}, μ_t^{MP}, ξ_t^{MP}, and ν_t^{MP} are Lagrangian multipliers associated with the budget constraint, collateral constraint, and two implementation constraints, respectively.

Wedge in Marginal Valuation of Wealth: The main difference between CE and MP is reflected in the marginal valuation of wealth, λ_t^{CE} and λ_t^{MP}. One can see that the wedge includes two terms due to the presence of implementation constraints: The first term is $-\xi_t^{MP}u''(c_t^h)q_t$, which captures pecuniary externalities in the economy, and the second term is $-\nu_t^{MP}u''(c_t^h)\Psi_{1,t}$, which captures the inability of the social planner to change z_{t+1}. Consistent with results in the literature, the first term is positive due to condition (17). Uniquely, I also have the second term with ν_t^{MP}, which is the shadow price of implementation constraint (14). The value of ν_t^{MP} is given by the optimality condition (16). Quantitatively, it is small. Hence, the wedge $-\xi_t^{MP}u''(c_t^h)q_t - \nu_t^{MP}u''(c_t^h)\Psi_{1,t}$ is positive.

Due to this wedge, the competitive equilibrium is constrained inefficient, and the social planner chooses a different allocation than do private agents. However, the difference appears only when the constraint is slack. The reason is that the social planner cannot change the allocation when the constraint binds. In the period when the collateral constraint is slack, i.e., $\mu_t^{MP} = 0$, the social planner chooses a higher level of bond holding than do private agents due to a higher valuation of future wealth $E_t[\lambda_{t+1}^{MP}]$ (see the optimality conditions of bond holding in CE and MP, (12) and (18)).[22] Hence, there is an over-borrowing issue in competitive equilibrium, consistent with the literature.

A New Policy Trade-off: Unlike previous literature, there is a new policy trade-off between the trend and cyclical consumption growth for the macroprudential social planner. Intuitively, the social planner internalizes the pecuniary externalities and addresses the over-borrowing issue in the decentralized economy. By constraining the external borrowing during normal periods, she increases welfare by reducing the frequency of crises and the resulting output losses. As a result, the volatility of cyclical consumption growth is reduced. However, this comes at a cost of lowering trend growth during normal periods since the marginal cost of choosing z_{t+1} increases with lower borrowing. In the quantitative exercise below, I show that each channel has a significant welfare consequence.

Implementation: I assume that the planner has access to a macroprudential tax $\tau_t^{MP,b}$ on capital flows and a lump-sum transfer T_t^{MP}. The budget constraint for private agents becomes

$$c_t^h + hz_t + \Psi(z_{t+1}, z_t) + q_t n_{t+1} + \left(1 - \tau_t^{MP,b}\right) b_{t+1}$$
$$= y_t + q_t n_t + (1+r)b_t + T_t^{MP}$$

where $T_t^{MP} = -\tau_t^{MP,b} b_{t+1}$.

Proposition 1. *Decentralization with macroprudential policy*

[22] Quantitatively, the term $\nu_t^{MP}u''(c_t^h)\Psi_{1,t} + \nu_t^{MP}I_{2,t}$ is small.

The macroprudential social planner's allocation can be implemented by a macroprudential tax $\tau_t^{MP,b}$ on capital flows that is rebated to private agents with a lump-sum transfer T_t^{MP}. Furthermore, the tax $\tau_t^{MP,b}$ is given by

$$\tau_t^{MP,b} = \frac{\beta g_{t+1}^{-\gamma}(1+r)E_t\left[\gamma\phi\hat{\mu}_{t+1}^{MP}\hat{q}_{t+1}\left(\hat{c}_{t+1}^h\right)^{-1}+\gamma\hat{\nu}_{t+1}^{MP}\left(\hat{c}_{t+1}^h\right)^{-\gamma-1}\Psi_{1,t+1}\right]}{\left(\hat{c}_t^h\right)^{-\gamma}} - \frac{\gamma\phi\hat{\mu}_t^{MP}\hat{q}_t\left(\hat{c}_t^h\right)^{-1}+\gamma\hat{\nu}_t^{MP}\left(\hat{c}_t^h\right)^{-\gamma-1}\Psi_{1,t}-\phi\hat{\mu}_t^{MP}g_{t+1}^{-\gamma}\hat{G}_{2,t}\left(\hat{c}_t^h\right)^{\gamma}-\hat{\nu}_t^{MP}g_{t+1}^{-1-\gamma}\hat{I}_{2,t}}{\left(\hat{c}_t^h\right)^{-\gamma}}$$

Proof. See Appendix D.1.

Consistent with the literature, a macroprudential tax $\tau_t^{MP,b}$ is used to correct the wedge between λ_t^{MP} and λ_t^{CE}. It is positive in the quantitative exercise, since the Lagrangian multiplier ν_t^{MP} is small. Hence macroprudential policy is also used to correct the over-borrowing issue in the economy.

5. Quantitative results

In this section, I first compare the allocations of private agents and of the macroprudential social planner, and then analyze policy impacts on average growth. I also calculate welfare gains from macroprudential policy and compare these values with the literature. Lastly, I analyze the size of macroprudential taxes. In Appendix E, I conduct a sensitivity analysis with respect to the results.

5.1. Comparing CE and MP allocations

The difference between the macroprudential social planner and private agents is captured by policy functions. Fig. 4 plots consumption $\hat{c}_t^h$, endogenous growth rate g_{t+1}, asset price $\hat{q}_t$, and bond holding $\hat{b}_{t+1}$ for the competitive equilibrium (red solid line) and the macroprudential social planner (green dashed line) over the bond holding $\hat{b}_t$ when θ_t is 2 standard deviations below its long-run average.[23]

There are kinks in all policy functions due to the presence of the collateral constraint. When the economy starts from a lower bond holding $\hat{b}_t$ (a higher debt to repay), the collateral constraint binds, and private agents must cut external borrowing and total spending. As a result, both consumption and growth are reduced.

Consistent with the literature, there is an over-borrowing phenomenon in the competitive equilibrium because the social planner chooses a higher bond holding $\hat{b}_{t+1}$ than do private agents. Unlike in the literature, the over-borrowing also has an implication for the endogenous growth rate. Due to the new policy trade-off, the social planner chooses a lower g_{t+1} when the constraint is slack. Trend growth is lower with this policy, but the economy becomes more resilient.

Fig. 5 displays the ergodic distributions of bond holding $\hat{b}_{t+1}$ and endogenous growth rate g_{t+1}. Compared with private agents, the macroprudential social planner borrows less and thus chooses more mass in the range of higher bond holdings. In terms of the ergodic distribution for g_{t+1}, the social planner has less mass at both extremely low and normal (around 2 percent) growth levels. One can see that the dispersion of growth for MP has been marginally reduced. However, it is unclear whether average growth has been increased or decreased.

To see the impact of macroprudential policy on average growth and the probability of crises, Table 3 reports model moments for the social planner and private agents. With macroprudential policy, external borrowing is reduced from 27.18 percent to 25.78 percent, which lowers average growth from 2.315 percent to 2.307 percent. However, the policy also reduces the probability of crises from 6.23 percent to 1.89 percent. Hence, the economy becomes more resilient.

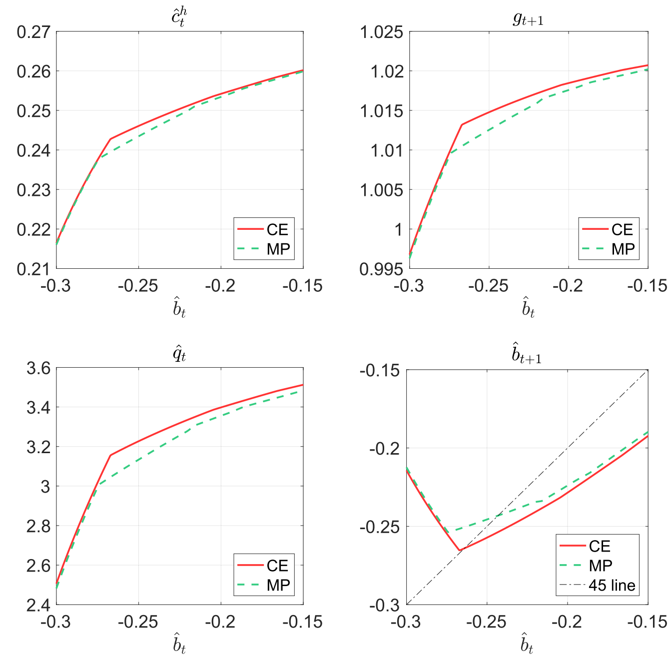

Fig. 4. Policy functions: CE and MP.

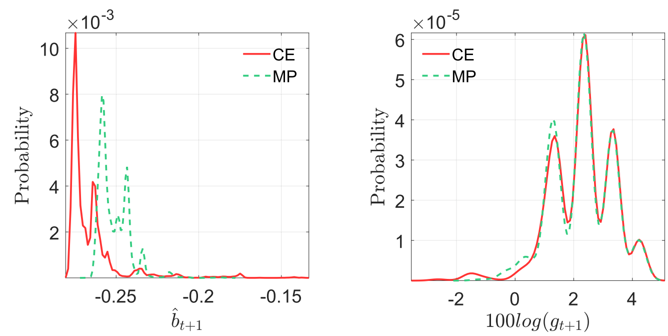

Fig. 5. Ergodic distributions: CE and MP.

Fig. 6 reports the event window as before but also plots the dynamics of variables for the social planner given the same exogenous shock θ_t. One can see that the probability of crises has been reduced by the social planner in the last panel of Fig. 6. Furthermore, the planner chooses a higher bond holding in normal periods and thus suffers less when a very large shock hits at time 0. As a result, the social planner cuts consumption and growth-enhancing expenditures less during crises.

However, macroprudential policy also reduces borrowing and thus the endogenous growth in normal periods. To show its impact, Fig. 7 plots the transition dynamics from competitive equilibrium to the equilibrium chosen by the social planner.[24] On the whole, the macroprudential social planner borrows less than private agents, which reduces both consumption and endogenous growth. However, the economy becomes more resilient and has a lower probability of crises. Therefore, consumption converges on a higher level. But the

[23] I choose θ_t to be at 2 standard deviations below its long-run average because the economy in competitive equilibrium converges to a marginally unconstrained steady state in the absence of future shocks in θ_t. Hence, any small shock to θ_t pushes the economy into a constrained state, i.e., a crisis episode.

[24] The transition dynamics is constructed by first running 1,000 simulations of 1,020 periods for competitive equilibrium and then introducing the social planner from period 1,001.

Table 3
Moments: CE and MP.

Moments	CE	MP
Average GDP growth (%)	2.315	2.307
Probability of crises (%)	6.23	1.89
NFA-GDP ratio (%)	−27.18	−25.78
Consumption-GDP ratio (%)	77.53	77.65
Correlation between current account and output	−0.22	−0.37

endogenous growth rate g_{t+1} only converges to a lower level because the economy borrows less in the long run.

5.2. Policy impacts on average growth

This model allows for an analysis of policy impacts on average growth. Clearly macroprudential policy increases the endogenous growth rate g_{t+1} during crises but reduces it in normal periods. Even though the policy lowers the volatility of growth unambiguously, its impacts on average growth are theoretically ambiguous.

In the baseline calibration, there is a negative relationship between average growth and financial stability for macroprudential policy. A more general question is which parameters govern this relationship? To answer this question, I simplify the model so it can be solved mostly analytically.

Instead of using the existing log AR(1) process for θ_t, I assume that $\theta_t = 1$ for all t, and that it falls to 0.9 in the second period, with a probability $p \in [0,1]$. Furthermore, the economy is unconstrained in a steady state, and I need to change β such that $\beta(1+r)g_{ss}^{-\gamma} = 1$, where $g_{ss} = 1.023$, as in the baseline calibration. I keep other parameter values the same as before. Hence, crisis occurs in the economy when $\theta_2 = 0.9$ and the collateral constraint binds.

I plot the average growth chosen by the private agents and by the social planner in Fig. 8.[25] Whether the social planner increases or decreases average growth depends on two parameters: The probability of negative shock p and the tightness of the collateral constraint ϕ. Intuitively, the macroprudential social planner can increase average growth because she reduces the cost of crisis and thus raises the growth rate during a crisis. However, a crisis occurs with probability p, and its cost depends on the tightness of the collateral constraint. When p is higher or ϕ is lower, macroprudential policy is very beneficial, since the expected cost of crisis is relatively large. Hence, the policy can increase average growth in these scenarios.

I also find that the magnitude of the impacts is small (see Fig. 8 and Table 3). This is because there is an optimal rate of growth defined by the technology $\Psi(z_{t+1}, z_t)$.[26] Macroprudential policy does not change this function directly but only changes the marginal valuation of wealth. Furthermore, any changes in the growth rate have non-trivial effects on welfare (see Lucas (1987) and Barlevy (2004)). Hence, if the optimal policy must affect growth negatively in order to increase financial stability, a planner will tend to choose a policy that changes growth only by a small amount. Otherwise, it is too costly for social welfare.

[25] I run 100-period simulations in two separate states to calculate average growth: $\theta_2 = 0.9$ in state L and $\theta_2 = 1$ in state H. The growth rate for each simulation is calculated as follows:
$G^i = (\Pi_{t=1}^{100} g_{t+1})^{\frac{1}{100}}$, where $i \in \{H, L\}$
Therefore, average growth is $p * G^L + (1-p) * G^H$.

[26] In other words, there is no direct growth externality in the framework. Macroprudential policy can have a larger growth impact once introducing growth externality (see Section 7).

5.3. Welfare gains

To calculate the welfare gains from macroprudential policy, I define a variable $\Delta^{MP}(\hat{b}_t, \theta_t)$, which compares two utilities and converts their difference into consumption equivalents:

$$\Delta^{MP}\left(\hat{b}_t, \theta_t\right) = 100\left[\left(\frac{\hat{V}^{MP}\left(\hat{b}_t, \theta_t\right)}{\hat{V}^{CE}\left(\hat{b}_t, \theta_t\right)}\right)^{\frac{1}{1-\gamma}} - 1\right] \tag{19}$$

where $\hat{V}^i(\hat{b}_t, \theta_t)$ is a normalized value function and $i \in \{CE, MP\}$.

$\Delta^{MP}(\hat{b}_t, \theta_t)$ depends on state variables $\{\hat{b}_t, \theta_t\}$, and I plot it in Fig. 9.[27] Consistent with the literature, it peaks in the region where the magnitude of externalities is at its maximum. It becomes smaller when the economy has a higher amount of bond holding, since the probability of future crisis is lower. It also becomes smaller when the economy has a lower amount of bond holding, i.e. when the constraint binds. The macroprudential social planner chooses the same allocation as the private agents in these regions. Hence, the welfare gains are small.

To understand the average benefit of macroprudential policy, I also define a variable EV^{MP} as follows:

$$EV^{MP} = E\left[\Delta^{MP}\left(\hat{b}_t, \theta_t\right)\right] \tag{20}$$

where the expectation is taken using the ergodic distribution of $\hat{b}_t$ and θ_t in competitive equilibrium.

The unconditional welfare gains from the macroprudential social planner EV^{MP} are equivalent to a 0.06 percent permanent increase in annual consumption, the same range as in the literature. Hence, endogenous growth does not fundamentally change the benefit of macroprudential policy. The benefit of the policy is a lower frequency of crises as well as a smaller drop in consumption and growth during crises. As I will show later, the welfare benefit from reducing the magnitude of crises is enhanced with endogenous growth. However, crisis is a rare event and its frequency is further reduced by the policy. Furthermore, there is policy trade-off between the trend and cyclical consumption growth. The welfare cost of lowering the trend growth in normal periods is also significant with endogenous growth. Overall, the macroprudential policy still increases welfare. Its magnitude is comparable to that in the previous literature.

Welfare Impact of the Policy Trade-off: To understand the welfare channel of the new policy trade-off, I split the overall welfare gains into two channels: One is a cyclical component of consumption $\hat{c}_t^h$, a traditional channel as in the literature, and the other is a trend component of consumption, i.e., productivity z_t, a new channel with endogenous growth. Specifically, utilities depend on the net consumption series $\{c_t^h\}_{t=0}^{\infty}$, which in turn is the product of the cyclical component of consumption $\{\hat{c}_t^h\}_{t=0}^{\infty}$ and the trend component of consumption $\{z_t\}_{t=0}^{\infty}$. I will compare these two series for private agents and the social planner in order to understand the welfare impact of the policy trade-off.

To accomplish this, I run 1,000 simulations and get both cyclical and trend components of consumption for the competitive equilibrium and the social planner. To control for the trend (cyclical) component of the consumption channel, I multiply the trend (cyclical) component of consumption in competitive equilibrium by the cyclical (trend) component of consumption under the social planner to construct a counter-factual consumption. I then compare the utility of this counter-factual consumption with the utility of consumption in competitive equilibrium.

[27] Like the policy functions, $\Delta^{MP}(\hat{b}_t, \theta_t)$ is plotted over the bond space $\hat{b}_t$ when the shock θ_t is 2 standard deviations below its long-run average.

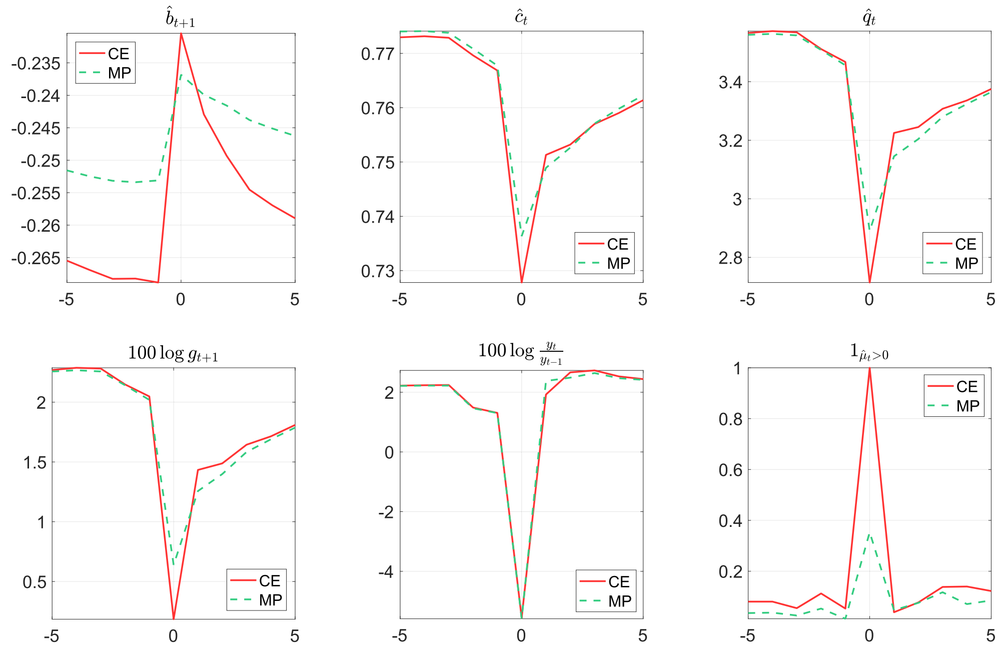

Fig. 6. Event window: CE and MP.

The difference between these two is considered as gains through the cyclical (trend) component of consumption channel.

Table 4 reports the results. Indeed, gains through the cyclical component of consumption channel are reinforced by endogenous growth: a 0.40 percent permanent increase in annual consumption, which is much larger than those found in the literature. However, there are welfare losses through the trend component of the consumption channel, since the policy reduces average growth. Even if the magnitude of reduction is small, 0.01 percentage point, the cost in terms of welfare is large, a 0.34 percent permanent decrease in annual consumption. Overall, macroprudential policy is still desirable, but due to the new policy trade-off, the gains are no larger than those in the models with exogenous growth.

5.4. Policy instruments

Fig. 10 shows the macroprudential tax on capital flows $\tau_t^{MP,b}$.[28] The tax rate varies from 0 to 5 percent, depending on the state variable $\hat{b}_t$, and I find that it is 1.28 percent on average. As explained before, the macroprudential social planner cannot change the allocation when the constraint binds, and I set the tax rate at zero in these regions. Consistent with the literature, the tax rate peaks in the region where the magnitude of externalities is at its maximum. The tax approaches zero when the economy has sufficient bond holdings $\hat{b}_t$.

6. Robustness

This section provides several modifications to our benchmark model and shows the robustness of our main results. In the first subsection, I provide different specifications of the collateral constraints. In the second subsection, I relax Assumption 1 on the quadratic form of Ψ function and introduce a higher curvature. In the third subsection, I adopt the notion of "conditional efficiency" to characterize the social planning problem (see Benigno et al. (2013)). I find that the main quantitative results are robust to these modifications.[29]

6.1. Alternative specifications of collateral constraints

The collateral constraint (5) in the benchmark model follows Jeanne and Korinek (2018) who assume that the aggregate asset holdings serve as collateral. Alternatively, one could introduce a setting where the individual asset holding serves as collateral. There are two ways to introduce the individual asset holdings. One could assume that the collateral value depends on n_t as in (21), i.e. the asset holdings at the beginning of period t, or n_{t+1} as in (22), i.e. the asset holdings at the end of period t.[30] I check the robustness of these two specifications by numerically solving the equilibrium and comparing their quantitative results with our benchmark model.

$$-b_{t+1} \le \phi q_t n_t \tag{21}$$

$$-b_{t+1} \le \phi q_t n_{t+1} \tag{22}$$

These two different types of constraints lead to a higher demand for the productive assets since the assets help relax the borrowing constraints either today (in form (22)) or tomorrow (in form (21)). However, the supply of productive asset is fixed in aggregate. As a result, the higher demand transfers into a higher asset price. The quantitative results are virtually the same as in the benchmark model since the collateral constraint is only marginally binding in the long run equilibrium (see Tables 5 and 6).

The literature has also explored the collateral constraints that depend on future asset prices, i.e. $-b_{t+1} \le \phi E_t q_{t+1}$. For example, in Kiyotaki and Moore (1997), the financial amplification effects arise from a feedback loop between falling borrowing capacity today, falling investment today and falling asset prices tomorrow. However, these amplification effects require incorporating an additional investment channel and thus state variable into the analysis. In our model, this setting would not lead to financial amplification effects since the borrowing constraint does not directly affect the asset price tomorrow (see the discussion in the online appendix of Jeanne and Korinek (2018)). Mathematically speaking, one can normalize the borrowing constraint by z_{t+1} and get $-\hat{b}_{t+1} \le \phi E_t \hat{q}_{t+1}$. This constraint does not imply an

[28] As before, I plot it over the bond holding $\hat{b}_t$ when the shock θ_t is 2 standard deviations below its long-run average.

[29] To facilitate comparison, I adopt the same parameter values as in the benchmark model.

[30] See the online appendix in Jeanne and Korinek (2018) where they conduct robustness check using these two specifications of collateral constraints.

[31] The normalized asset price $\hat{q}_t$ is typically an increasing function of $\hat{b}_t$ as in Figure 6.

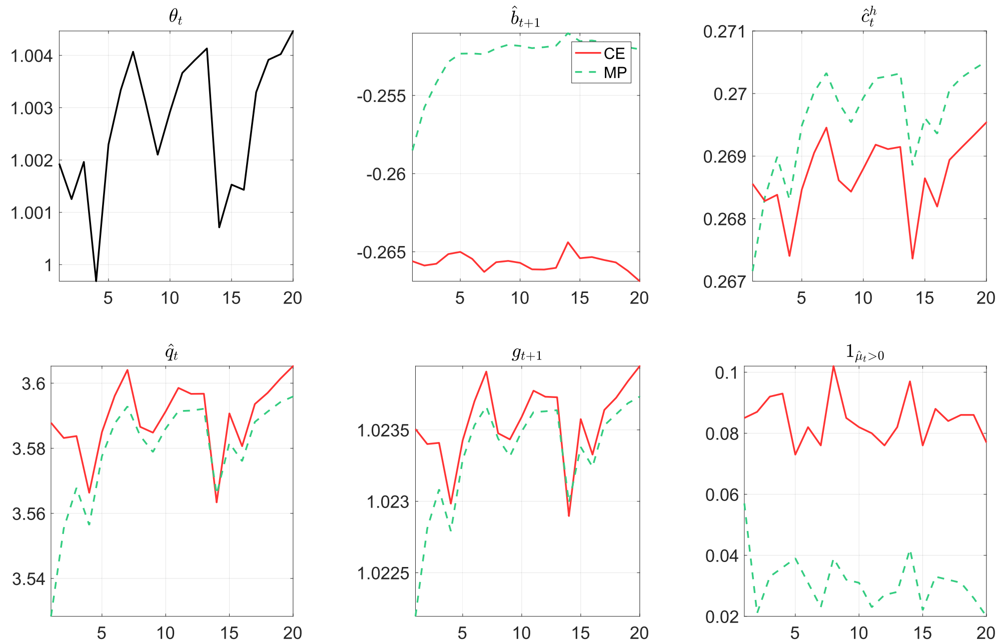

Fig. 7. Transition dynamics: CE and MP.

amplification effect—when the constraint binds, the borrowing $-\hat{b}_{t+1}$ declines, which increases the future asset prices $E_t[\hat{q}_{t+1}]$ and thus relaxes the collateral constraint.[31] However, in our benchmark model, the collateral constraint can be normalized as $-\hat{b}_{t+1}g_{t+1} \le \phi\hat{q}_t$. There is an amplification effect—when it binds, a decline in $-\hat{b}_{t+1}$ is accompanied by a decline in all the expenditure and also the asset price $\hat{q}_t$. Therefore, being constrained today can directly tighten the collateral constraint.

6.2. Different forms of Ψ function

In our benchmark model, I choose a quadratic functional form in the Ψ function. Generally speaking, it can be written as

$$\Psi(z_{t+1}, z_t) = \left[\left(\frac{z_{t+1}}{z_t} - \psi\right) + \kappa\left(\frac{z_{t+1}}{z_t} - \psi\right)^{\eta}\right] z_t, \tag{23}$$

The benchmark model corresponds to the case where $\eta = 2$. I check the robustness of my results by looking at a higher degree of curvature, i.e. $\eta = 3$ and $\eta = 4$. The quantitative results are presented in Tables 7 and 8. With a higher η, both the growth and welfare impact of policy intervention become even smaller. Furthermore, the economy in competitive equilibrium borrows less and thus ends up with a lower probability of crises.

Intuitively, a higher curvature increases the adjustment cost of changing z_{t+1} and thus endogenous growth rate g_{t+1}. Therefore, private agents are more risk averse to volatilities in growth rate g_{t+1} and consumption $\hat{c}_t$. To avoid such volatilities, they increase their precautionary savings to self-insure, which weakens the case for policy intervention. As a result, the policy has a smaller impact on both the welfare and growth rate with a higher η.

6.3. Conditional efficiency

In our benchmark model, I adopt the "constrained efficiency" notion of policy analysis (see Stiglitz (1982), Kehoe and Levine (1993) and Benigno et al. (2013)), i.e. the asset pricing function and the Euler equation of productivity serve as implementation constraints in the social planner's problem. For robustness, I use the idea of "conditional efficiency", in which the social planner's problem is constrained by the competitive equilibrium pricing function $(q_t = \mathcal{Q}(z_t, b_t, \theta_t))$ and the Euler equation of productivity. Specifically, the social planner's problem is defined as follows. To differentiate, I use the notion "Con" to denote

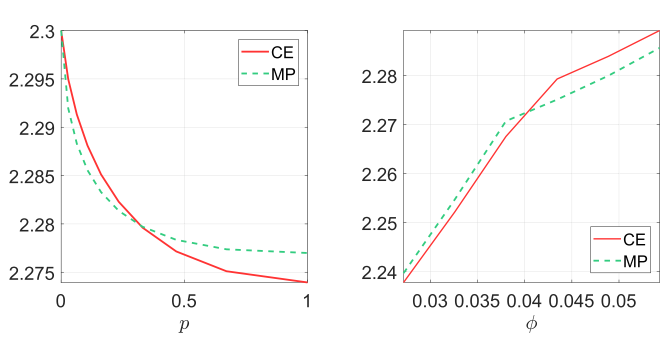

Fig. 8. Policy impacts on average growth: CE and MP.

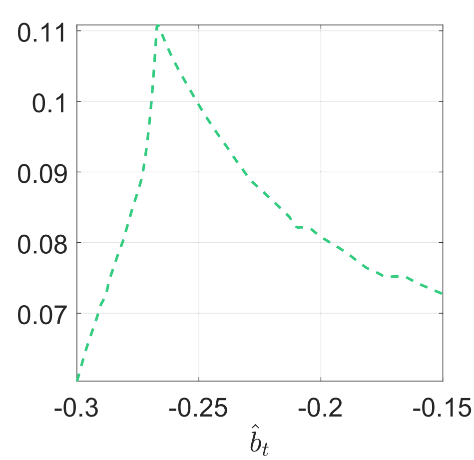

Fig. 9. Welfare gains (%): MP.

Table 4
Source of welfare gains (%).

	Overall	Trend consumption channel	Cyclical consumption channel
MP	0.06	−0.34	0.40

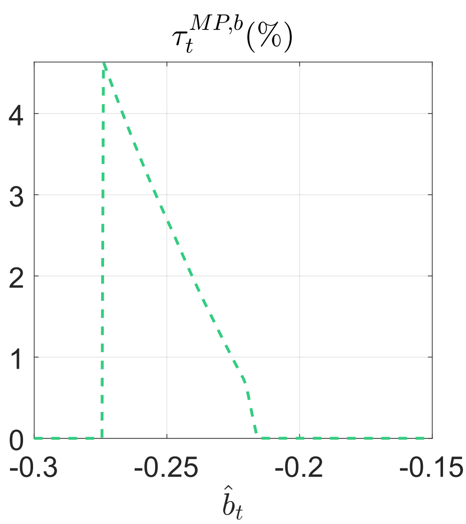

Fig. 10. Macroprudential tax on capital flows.

Table 5
Moments: alternative collateral constraints.

	Baseline model		$-b_{t+1} \leq \phi q_t n_t$		$-b_{t+1} \leq \phi q_t n_{t+1}$	
Moments	CE	MP	CE	MP	CE	MP
Average GDP growth (%)	2.315	2.307	2.316	2.306	2.314	2.307
Probability of crises (%)	6.23	1.89	6.00	1.89	6.85	1.89
NFA-GDP ratio (%)	−27.18	−25.78	−27.61	−25.90	−27.94	−26.50
Consumption-GDP ratio (%)	77.53	77.65	77.51	77.64	77.51	77.62
Correlation between current account and output	−0.22	−0.37	−0.22	−0.37	−0.23	−0.37

Table 6
Welfare gains and taxes (%): alternative collateral constraints.

	Taxes	Overall gains	Trend consumption	Cyclical consumption
Baseline model	1.28	0.06	−0.34	0.40
$-b_{t+1} \leq \phi q_t n_t$	1.36	0.06	−0.40	0.46
$-b_{t+1} \leq \phi q_t n_{t+1}$	1.14	0.04	−0.33	0.36

Table 7
Moments: different curvatures in Ψ function.

	Baseline model ($\eta = 2$)		$\eta = 3$		$\eta = 4$	
Moments	CE	MP	CE	MP	CE	MP
Average GDP growth (%)	2.315	2.307	2.301	2.297	2.298	2.297
Probability of crises (%)	6.23	1.89	3.42	1.86	5.14	1.84
NFA-GDP ratio (%)	−27.18	−25.78	−25.11	−23.34	−25.00	−23.84
Consumption-GDP ratio (%)	77.53	77.65	77.65	77.77	77.70	77.77
Correlation between current account and	−0.22	−0.37	0.01	0.15	0.07	0.17

Table 8
Welfare gains and taxes (%): different curvatures in Ψ function.

	Taxes	Overall gains	Trend consumption	Cyclical consumption
Baseline model ($\eta = 2$)	1.28	0.06	−0.34	0.40
$\eta = 3$	1.29	0.05	−0.21	0.26
$\eta = 4$	1.01	0.02	−0.08	0.09

this social planner's allocation.

$$\begin{aligned} V_t^{Con}(z_t, b_t, \theta_t) \quad &= \max_{c_t^h, z_{t+1}, b_{t+1}} u\left(c_t^h\right) + \beta E\left[V_{t+1}^{Con}(z_{t+1}, b_{t+1}, \theta_{t+1})\right] \\ \text{s.t.} \quad & c_t^h + hz_t + \Psi(z_{t+1}, z_t) + b_{t+1} = \theta_t z_t + (1+r) b_t, \\ & -b_{t+1} \leq \phi \mathcal{Q}(z_t, b_t, \theta_t), \\ & u'\left(c_t^h\right)\Psi_{1,t} = \underbrace{\beta E_t\left[u'\left(c_{t+1}^h\right)\left(\theta_{t+1} - h - \Psi_{2,t+1}\right)\right]}_{\mathcal{F}(z_{t+1}, b_{t+1})}. \end{aligned}$$

where $\mathcal{Q}(z_t, b_t, \theta_t)$ is the policy function in competitive equilibrium.

The difference between this new social planner and the macroprudential social planner in our benchmark model is the way they internalize the pecuniary externality through the asset price. Unable to affect the current asset price q_t (since it depends on the current state variables $\{z_t, b_t, \theta_t\}$), the new social planner realizes that her choice of b_{t+1} will affect the future asset price. In this way, she behaves differently from the private agents. In addition to this channel, the macroprudential social planner also realizes that her choice of b_{t+1} will affect the asset price today (since it depends on the asset pricing equation (11)). But the ability for her to improve upon the competitive equilibrium through this channel is also limited—the allocation is the same for the social planner and competitive equilibrium when the constraint binds.[32] For this reason, the quantitative results in these two social planners are virtually the same (see Tables 9 and 10).[33]

7. Extensions

I discuss two extensions of the baseline analysis. In the first one, I introduce growth externality. In the second one, I introduce alternative instruments. In both exercises, I show that the welfare and growth effects of policy intervention can become larger than our benchmark model under certain scenarios.

7.1. Growth externality

The benchmark model assumes no direct growth externality. In this subsection, I introduce a new functional form of Ψ as follows to allow for growth externality.[34] Specifically, the function depends on both the individual and aggregate level of endogenous productivity. When private agents choose their individual level of productivity z_{t+1}, they do not internalize their collective choice of Z_{t+1} will have an impact

[32] Both allocations $\{c_t^h, z_{t+1}, b_{t+1}, q_t\}$ are pinned down by the budget constraint, collateral constraint, the Euler equation for productivity and asset pricing equations.

[33] In the footnote 11 of Benigno et al. (2016), they find that the constrained and conditional efficiency definition yield the same allocation in the endowment economy.

[34] There is a literature that introduces growth externality and analyzes the impact of foreign reserve accumulation on welfare and growth. See Benigno and Fornaro (2012) and Korinek and Serven (2016) for a detailed analysis.

Table 9
Moments: conditional efficiency.

Moments	CE	MP	Conditional Efficiency
Average GDP growth (%)	2.315	2.307	2.309
Probability of crises (%)	6.23	1.89	1.89
NFA-GDP ratio (%)	−27.18	−25.78	−25.84
Consumption-GDP ratio (%)	77.53	77.65	77.63
Correlation between current account and output	−0.22	−0.37	−0.37

on the future Ψ function, which is a growth externality.

$$\Psi(z_{t+1}, z_t, Z_t) = \left[\left(\frac{z_{t+1}}{z_t^{m_1} Z_t^{1-m_1}} - \psi\right) + \kappa\left(\frac{z_{t+1}}{z_t^{m_1} Z_t^{1-m_1}} - \psi\right)^2\right] z_t^{m_2} Z_t^{1-m_2} \tag{24}$$

where $m_1, m_2 \in [0,1]$.

In this new form, both the parameters m_1 and m_2 capture the degree of growth externality. It is easy to see that our benchmark model corresponds to the case where $(m_1,m_2) = (1,1)$. In terms of economic interpretation, m_1 captures the degree of positive growth externality like in the Romer type's endogenous growth model (i.e. Romer (1990)). When $m_1 < 1$ and $m_2 = 1$, private agents fail to internalize that their choice of z_{t+1} will collectively reduce future growth-enhancing expenditure. As a result, they tend to choose an inefficiently low level of z_{t+1} and thus growth rate. Similarly, m_2 captures the degree of negative growth externality like in the creative destruction type's endogenous growth model (i.e. Aghion and Howitt (1992)). When $m_1 = 1$ and $m_2 < 1$, private agents fail to internalize that their choice of z_{t+1} will collectively increase future growth-enhancing expenditure. As a result, they choose an inefficiently high level of z_{t+1} and thus growth rate.

The presence of growth externality will have an impact on the pecuniary externality. To understand their relative importance in changing our baseline results, I use the same parameter values as in our benchmark model and choose different sets of parameter values for (m_1,m_2). For a given degree of growth externality, I compare the allocation under competitive equilibrium with three different allocations. The first allocation is chosen by a social planner who internalizes the pecuniary externality but has to respect the Euler equation of productivity chosen by private agents. In other words, it is an allocation with growth externality but not pecuniary externality. To implement this allocation, one needs to use the macroprudential policy as in our benchmark model. The second allocation is the competitive equilibrium with $(m_1,m_2) = (1,1)$, i.e. the competitive equilibrium in the benchmark model. As explained in our main text, it is an allocation without growth externality but with pecuniary externality. To implement this allocation, one need to use a tax/subsidy on growth-enhancing expenditure (growth subsidy for brevity). The last allocation is the allocation chosen by the macroprudential social planner in our benchmark model. It is an allocation without pecuniary externality nor growth externality. To implement this allocation, both the growth subsidy and the macroprudential policy are needed.[35]

Tables 11 and 12 present the quantitative results with different degrees of growth externality. Consistent with the analysis above, the growth rate is inefficiently high when $m_1 = 1$ and $m_2 < 1$. Higher growth rate also increases the private agents' incentive to borrow, which leads to a higher probability of crises. Therefore, the case for correcting pecuniary externality should increase with a lower m_2.

[35] Specifically, the budget constraint of private agents with two policies changes into $c_t^h + hz_t + \Psi(z_{t+1}, z_t, Z_t)(1-\tau_t^z) + q_t n_{t+1} + b_{t+1}(1-\tau_t^{MP,b}) = y_t + q_t n_t + (1+r)b_t + T_t$ where $T_t = -\tau_t^z \Psi(z_{t+1}, z_t, Z_t) - \tau_t^{MP,b} b_{t+1}$. These two instruments can be used to close the gaps between two allocations.

Table 10
Welfare gains and taxes (%): conditional efficiency.

	Taxes	Overall gains	Trend consumption	Cyclical consumption
MP	1.28	0.06	−0.34	0.40
Conditional efficiency	1.36	0.07	−0.29	0.36

Indeed, the quantitative results show that the welfare benefit from macroprudential policy increases when m_2 decreases although the magnitude of the gains remains the same as in the benchmark model.[36] Furthermore, the macroprudential policy only lowers the growth rate by a small amount, consistent with the benchmark model.

However, the macroprudential policy can have a significantly larger impact on welfare and growth rate once it is used with the growth subsidy.[37] By correcting the growth externality, the policy intervention lowers average growth rate by a significant amount. The reduction in growth rate also helps correct the pecuniary externality since it reduces the incentive to borrow. As a result, these two policies can generate a much larger welfare gain than the benchmark model and the gains increase with a lower m_2. Furthermore, the majority of welfare gains come from correcting the growth externality. One can see this by comparing the competitive equilibrium allocation with allocations in CE and MP under $(m_1,m_2) = (1,1)$ (i.e. CE and MP in our benchmark model).

When there is a positive growth externality, i.e. $m_1 < 1$ and $m_2 = 1$, the growth rate will be inefficiently low, as is the incentive to borrow. As a result, there might be "underborrowing" with pecuniary externality as opposed to "overborrowing" when m_1 is lower enough (see Benigno et al. (2013) for the case of "underborrowing"). In this case, correcting pecuniary externality can also generate some welfare gains but the magnitude is at the same range as in the benchmark model. Furthermore, its impact on growth is small.

Consistent with the findings above, the macroprudential policy can have a larger impact on both welfare and growth rate once it is used jointly with the growth subsidy. With two policies, the growth rate is higher and the probability of crises is lower.[38] Therefore, the optimal policy mix can generate much larger welfare gains than the benchmark model. Furthermore, the gains increase with a lower m_1 and most of them come from correcting the growth externality.[39,40]

Introducing growth externality can change the welfare and growth impacts of the macroprudential policy. In particular, the policy can generate a much larger impact when it is used with the growth subsidy that corrects the growth externality. When it is the only policy instrument, its impact is limited. In other words, this extension implies a dominant role of the growth externality over the pecuniary externality.[41] Given that the main purpose of this paper is to analyze the impact of financial frictions on growth, I have made a more conservative modeling assumption in the benchmark framework by assuming that there is no direct growth externality.

[36] One can see this by comparing CE and MP with the same parameter values for (m_1,m_2).
[37] One can see this by comparing CE with the allocation in MP under $(m_1,m_2) = (1,1)$.
[38] One casn see this by comparing the MP under $(m_1,m_2) = (1,1)$ with CE under $(m_1 < 1, m_2 = 1)$.
[39] One can compare the welfare gains in correcting growth externality and both externalities.
[40] Different from correcting the negative growth externality, two policies correcting the positive growth externality enhance social welfare through the trend consumption channel as opposed to the cyclical consumption channel.
[41] This is consistent with the general policy implication that growth should be the main focus of policies in Lucas (1987).

Table 11
Moments: growth externality.

(m_1,m_2)	Baseline model: (1,1)		(1,0.95)		(1, 0.9)		(0.995, 1)		(0.992, 1)	
Moments	CE	MP	CE	MP	CE	MP	CE	MP	CE	MP
Average GDP growth (%)	2.315	2.307	2.395	2.387	2.478	2.469	2.130	2.123	2.018	2.014
Probability of crises (%)	6.23	1.89	6.99	1.89	7.46	1.89	2.28	1.89	2.45	1.89
NFA-GDP ratio (%)	−27.18	−25.78	−27.19	−25.65	−27.18	−25.53	−26.87	−26.17	−26.18	−26.41
Consumption-GDP ratio (%)	77.53	77.65	77.16	77.28	76.77	76.90	78.39	78.47	78.93	78.94
Correlation between current account and output	−0.22	−0.37	−0.25	−0.37	−0.27	−0.36	−0.14	−0.38	−0.05	−0.39

Table 12
Welfare gains (%): growth externality.

	Both externalities			Growth externality			Pecuniary externality		
	Overall	Trend	Cyclical	Overall	Trend	Cyclical	Overall	Trend	Cyclical
Benchmark $(m_1,m_2)=(1,1)$	0.06	−0.34	0.40	n.a.	n.a.	n.a.	0.06	−0.34	0.40
$(m_1,m_2)=(1,0.95)$	0.13	−1.66	1.81	0.07	−1.33	1.41	0.07	−0.35	0.42
$(m_1,m_2)=(1,0.9)$	0.25	−2.97	3.31	0.19	−2.64	2.91	0.08	−0.36	0.44
$(m_1,m_2)=(0.995,1)$	0.11	2.88	−2.67	0.04	3.23	−3.09	0.06	-0.24	0.30
$(m_1,m_2)=(0.992,1)$	0.24	5.01	−4.54	0.18	5.36	−4.93	0.04	−0.05	0.09

7.2. Alternative policy instruments

In the benchmark model, I only consider the use of macroprudential policy, i.e. the tax/subsidy ($\tau_t^{MP,b}$) on bond holdings b_{t+1}. In this section, I consider two alternative instruments in our economy. The first one is a tax/subsidy (τ_t^n) on the productive asset n_{t+1} (asset price subsidy for brevity).[42] It is an interesting policy instrument since it can be used to change the asset price q_t and thus relax the borrowing constraint. As shown in Benigno et al. (2016), such a policy instrument can eliminate the effect of collateral constraint and generate a large welfare gain. Following their analysis, I consider the cases when τ_t^n can be used in a costless manner (with lump-sum transfer) and in a distortionary way (without lump-sum transfer). The second instrument is a tax/subsidy τ_t^z on the growth-enhancing expenditure Ψ (growth subsidy for brevity).[43] This instrument is specific to our setting since there are multiple margins that pecuniary externality can distort decisions. As shown above, τ_t^z can have a larger impact on growth and welfare when there is a growth externality. To understand its role in our benchmark model, I analyze the cases when it is used alone and jointly with the macroprudential policy.

7.2.1. Asset price subsidy (τ_t^n) with lump-sum transfer

Similarly to Benigno et al. (2016), asset price subsidy provides a tool to directly affect the asset price in competitive equilibrium. This can be interpreted as an ex-post intervention (crisis management).[44] When the asset price subsidy τ_t^n and a lump-sum transfer is available, the asset pricing function changes into

$$q_t=\frac{\beta E_t\left[u'\left(c_{t+1}^h\right)\left(\alpha\theta_{1+1}z_{t+1}+q_{t+1}\right)\right]}{u'\left(c_t^h\right)\left(1-\tau_t^n\right)} \tag{25}$$

By choosing τ_t^n, one can increase q_t to the level where the collateral constraint never binds. As a result, this policy can implement an economy without collateral constraint. I denote the allocation in this economy by "unconstrained equilibrium" ("UE" for brevity). Even though one does not need to impose a collateral constraint, a natural borrowing limit is needed to ensure a well-behaved distribution of bond holdings in the economy. To this end, I impose the following constraint.[45] In this case, τ_t^n is chosen to increase q_t to the level of $\frac{\bar{B}z_{t+1}}{\phi}$ and thus implement the unconstrained equilibrium.

$$-b_{t+1}\leq\bar{B}z_{t+1} \tag{26}$$

Tables 13 and 14 present the long-run moments and welfare impacts of τ_t^n. Consistent with Benigno et al. (2016), this policy instrument, when used in a costless manner, can generate a large welfare gain, 14 percent permanent increase in annual consumption. This large gain comes from both a higher level of growth rate and a lower probability of crises.[46]

7.2.2. Asset price subsidy (τ_t^n) and macroprudential policy (distortionary financing)

As noted in Benigno et al. (2016), it is typically unrealistic to use a crisis management policy like τ_t^n in a costless manner. One realistic assumption is to impose a distortionary financing cost, i.e. when the lump-sum transfer is not available. In particular, it is interesting to assume that the asset price subsidy has to be financed by the macroprudential policy tax. In this case, the government budget constraint becomes

$$\tau_t^n q_t=-\tau_t^{MP,b}b_{t+1} \tag{27}$$

In this case, there is a limitation from using τ_t^n to support asset prices when the constraint is binding—on the one hand, the asset price subsidy

[42] With τ_t^n, the budget constraint of private agents changes into
$c_t^h+hz_t+\Psi(z_{t+1},z_t)+q_tn_{t+1}(1-\tau_t^n)+b_{t+1}=y_t+q_tn_t+(1+r)b_t+T_t^n$
where $T_t^n=-\tau_t^nq_t$ when it can be financed in a costless manner.

[43] With τ_t^z, the budget constraint of private agents changes into
$c_t^h+hz_t+\Psi(z_{t+1},z_t)(1-\tau_t^z)+q_tn_{t+1}+b_{t+1}=y_t+q_tn_t+(1+r)b_t+T_t^z$
where $T_t^z=-\tau_t^z\Psi(z_{t+1},z_t)$.

[44] Its impact on asset price does not matter when the collateral constraint is slack. However, it matters when the constraint binds since it can change the asset prices and thus allocation.

[45] Since the economy is growing, the borrowing capacity is assumed to be proportional to z_{t+1}. $\bar{B}$ is interpreted as the "natural borrowing limit", which is equal to the level of bond holding when the shocks are at the minimum level and the consumption and growth rate converge to the lowest level.

[46] The growth rate is higher both because the economy is smoother and also the private agents want to invest more in the growth-enhancing expenditure in order to increase the borrowing capacity, $\bar{B}z_{t+1}$.

Table 13
Moments: alternative policy instruments.

Moments	CE	MP	GS	MI	OP	UE
Average GDP growth (%)	2.315	2.307	2.303	2.288	2.307	3.45
Probability of crises (%)	6.23	1.89	5.95	14.23	1.89	0
NFA-GDP ratio (%)	−27.18	−25.78	−27.54	−28.98	−26.72	−316.31
Consumption-GDP ratio (%)	77.53	77.65	77.56	77.58	77.61	65.51
Correlation between current account and output	−0.22	−0.37	−0.21	−0.54	−0.37	−0.12

Table 14
Welfare gains and taxes (%): alternative policy instruments.

	$\tau_t^{MP,b}$	τ_t^z	τ_t^n	Overall gains	Trend consumption	Cyclical consumption
MP	1.28	n.a.	n.a.	0.06	−0.34	0.40
GS	n.a.	0.19	n.a.	0.00	−0.14	0.15
MI	1.12	1.00	n.a.	0.24	−0.14	0.39
OP	1.57	n.a.	0.13	0.13	−0.19	0.33
UE	n.a.	n.a.	n.a.	14.15	40.57	−24.79

helps to increase the asset price and thus relaxes the constraint; on the other hand, the asset price subsidy is financed through a higher macroprudential tax which increases the cost of borrowing.[47] In the end, the effect of these policies in relaxing the constraint is restricted. Nevertheless, this policy combination is still beneficial since it combines an ex-ante macroprudential policy to address the pecuniary externality and an ex-post crisis management policy to reduce the cost of crises. Therefore, it is expected that this policy combination can generate a larger gain compared to using macroprudential policy alone (see Jeanne and Korinek (forthcoming) and Benigno et al. (2012)).

The full characterization of the Ramsey problem is in Appendix F. Specifically, the social planner chooses the tax instruments $\{\tau_t^n, \tau_t^{MP,\,b}\}$ that maximize the utility function subject to the budget constraint, collateral constraint, private agents' first-order conditions and the distortionary financing constraint (27). To differentiate, I denote the allocation by "OP."[48]

Tables 13 and 14 present the quantitative results. As expected, two policy instruments can generate a much larger welfare benefit than the macroprudential policy alone—the number is around 0.13 percent permanent increase in annual consumption, 2 times larger than the benchmark results. With the asset price subsidy to intervene when the constraint binds, the cost of crises is reduced and so is the precautionary motive. Indeed, the external borrowing is higher than the case with only macroprudential policy (allocation in "MP"). However, there is still a higher precautionary motive than the competitive equilibrium since the asset price subsidy, constrained by the distortionary financing, is unable to completely eliminate the effect of the collateral constraint. As a result, the economy borrows less than the competitive equilibrium and ends up with a lower probability of crises.[49]

Furthermore, the average growth rate is also lower than the competitive equilibrium, about the same magnitude as in the case with only macroprudential policy. It suggests that the policymaker still faces the trade-off between the trend and cyclical consumption growth when the asset price subsidy is financed in a distortionary way.[50]

7.2.3. Growth subsidy (τ_t^z)

The growth subsidy τ_t^z can be used to change the dynamics of productivity and thus growth rate in the economy. As shown in the previous analysis, this policy instrument can be used to correct the growth externality. Given that the economy has multiple margins that the pecuniary externality can distort decisions, it is useful to understand whether this policy can help correct the pecuniary externality when the growth externality is absent as in our benchmark model. Specifically, the growth subsidy changes the Euler equation of productivity into

$$u'\left(c_t^h\right)\Psi_{1,t}(1-\tau_t^z) = \beta E_t\left[u'\left(c_{t+1}^h\right)\left(\theta_{t+1}-h-(1-\tau_{t+1}^z)\Psi_{2,t+1}\right)\right] \quad (28)$$

To see the effectiveness of growth subsidy in correcting the pecuniary externality, I introduce a social planner like the macroprudential social planner who maximizes the utility function subject to the budget constraint, collateral constraint, and two implementation constraints. The first implementation constraint is the asset pricing function and the second one is the Euler equation for bond holding. Therefore, one can use the growth subsidy to implement this social planner's allocation. To differentiate, I denote her allocation by "GS." The complete characterization of the problem is given in Appendix F.

Tables 13 and 14 present the quantitative results. With the growth subsidy, both the average growth rate and the probability of crises are lower than the competitive equilibrium. However, the external borrowing is higher. This occurs since the growth subsidy is used to reduce the cost of crises when the constraint binds. One can see that from the policy function of the growth subsidy in Fig. G.2—the growth subsidy shifts the spending from the growth-enhancing expenditure to consumption when the constraint binds, which will lead to a higher asset price and thus relax the constraint. This ex-post intervention is beneficial for correcting the pecuniary externality since it reduces the tightness of the constraint. However, the precautionary motive is also reduced with a declining cost of the binding constraint, which worsens the pecuniary externality in the economy.[51] At the margin, the growth subsidy does not generate a large welfare benefit. In the quantitative exercise, the gains are negligible compared to the benchmark model. Furthermore, the growth impact is quantitatively small.

7.2.4. Growth subsidy (τ_t^z) and macroprudential policy

As explained above, the growth subsidy is used to reduce the cost of crises, like an "ex-post" intervention. It could potentially complement the role of macroprudential policy (see Jeanne and Korinek (forthcoming) and Benigno et al. (2013)). To this end, I introduce a social planner who has access to both the growth subsidy τ_t^z and the macroprudential policy $\tau_t^{MP,b}$. To differentiate from the macroprudential social planner, I call her a *multi-instrument social planner* ("MI" for brevity). Like the macroprudential social planner, the multi-instrument social planner chooses allocation on behalf of private agents subject to the resource constraint and the collateral constraint. Differently, she only has the asset pricing equation as an implementation constraint. The full characterization of the problem is given in Appendix F.

In the quantitative results of Tables 13 and 14, one can see that the welfare benefits from τ_t^z and $\tau_t^{MP,\,b}$ are considerably larger than the benchmark model, 0.24 percent permanent increase in annual consumption. These welfare benefits mainly come from a reduction in the cost of financial crises and an increase in borrowing. In the policy function of instruments in Fig. G.2, one can see that both policies are used in

[47] One can see this from the event window in Fig. G.3. When the constraint binds in competitive equilibrium, both the asset price τ_t^n and $\tau_t^{MP,\,b}$ are positive.

[48] It is computationally challenging to solve a Ramsey problem as in this setting. Following Benigno et al. (2012, 2016), I use value function iteration to numerically solve for a Markov-Perfect optimal policy equilibrium.

[49] One can also see this from the transition path as in Fig. G.4.

[50] In the case where the asset price subsidy can be used without cost, policymakers do not face the trade-off: the average growth is higher than the competitive equilibrium and the probability of crises is driven to zero. Therefore, policy intervention can have a much larger impact on both growth and welfare.

[51] One can see this from the transition dynamics in Fig. G.4 where the debt level converges to a higher level once introducing the GS social planner.

a way to relax the constraint during crises— τ_t^z is used to shift the spending from the growth-enhancing expenditure to consumption while $\tau_t^{MP,b}$ is used to increase borrowing. As a result, the cost of crises is reduced, and the economy is able to borrow more even with a binding constraint.[52] Furthermore, the precautionary motive is reduced when the constraint is slack. But this does not worsen the pecuniary externality as in the case with just growth subsidy since the macroprudential policy is used to address this distortion. In the end, the economy is able to borrow more than the competitive equilibrium and there is a short run boom in consumption and growth (see the transition dynamics in Fig. G.4). In the long run, both consumption and growth rate converges to a lower level because all the expenditures are used to finance a higher level of debt. Since the private agents are impatient, the short run benefit dominates the long run loss.[53]

To sum up, the welfare and growth impact of policy intervention can be significantly larger once introducing different sets of instruments. Consistent with Benigno et al. (2016), there exists a policy instrument (an asset price subsidy in this case) that can completely remove the effect of collateral constraints and generate a much larger welfare benefit. In this case, macroprudential policy is inferior to this policy. However, one can still generate a larger welfare benefit by combining the macroprudential policy with an additional policy instrument that can help relax the borrowing constraint, such as the asset price subsidy or the growth subsidy.

8. Conclusion

This paper introduces endogenous growth into a model with occasionally binding collateral constraints of the type that has been used previously in the literature on macroprudential policy. In the previous literature, binding constraints did not have a long-run impact on output. By contrast, in my model, they do, which increases their cost and presumably might reinforce the case for macroprudential policy. My model thus lends itself to analyzing the role of macroprudential policy in the context of a trade-off between growth and financial stability.

The impact of macroprudential policy on average growth is, in general, ambiguous. Macroprudential policy reduces the frequency of crises and their impact on growth but comes at the cost of reducing borrowing and growth in good times. To resolve this ambiguity, I look at a calibrated version of the model.

In the quantitative analysis, I find that optimal macroprudential policy substantially reduces the frequency of crises but has a very small negative effect on average growth. As is shown in the literature, changes in average growth have a very large welfare impact (see Lucas (1987) and Barlevy (2004)). Given that optimal macroprudential policy must lower average growth to increase financial stability, it does not change growth by a large amount, because even a small reduction in growth is very costly in terms of welfare. Quantitatively, a 0.01 percentage point reduction in average growth leads to a welfare loss equivalent to a 0.34 percent permanent decrease in annual consumption.

Nevertheless, macroprudential policy is still desirable because it reduces the probability of crises and smooths consumption. The benefits from consumption smoothing actually outweigh the welfare loss from the reduction in average growth. Overall, the welfare gains from the optimal policy are equivalent to a permanent increase in consumption by less than 0.1 percent, which is the same order of magnitude as in the existing literature with exogenous growth.

This paper provides a framework to think about the trade-off between average growth and financial stability faced by macroprudential policymakers. One takeaway is that macroprudential policy only marginally lowers average growth to enhance financial stability. Therefore, it is still desirable to use macroprudential policy, even considering its negative impact on average growth.

To the best of my knowledge, this is the first paper to analyze the impact of macroprudential policy on growth. Hence, there are many unsolved, interesting questions that I leave for future research. First and foremost, my paper is about the role of macroprudential policy in capital flows. However, many countries, including advanced economies, adopted macroprudential policies towards other financial markets after the 2008-09 Global Financial Crisis. It would be interesting to continue this line of research by looking at the effects of other macroprudential policies (leverage ratio, capital requirement, etc.). Second, my paper does not consider the other type of risk-taking behavior in the economy. In the model, there is an excessive risk-taking behavior due to the pecuniary externality. The macroprudential policy is used to restrict the amount of funding to productive projects. However, private agents might respond to the policy by taking on riskier projects, a different type of risk-taking behavior that is absent in the current model. Such behavior might be socially inefficient, even if it is privately optimal. In the end, the excessive risk-taking behavior might further lower average growth. Therefore, it may be interesting to see whether average growth is further driven down by this optimal policy.

Declarations of Competing Interest

None.

Appendix A. Data source

The sample includes the following 55 countries:

Algeria	Argentina	Australia	Austria	Belgium
Brazil	Canada	Chile	China	Colombia
Cote d'Ivoire	Croatia	Czech Republic	Denmark	Dominican Republic
Ecuador	Egypt, Arab Rep.	El Salvador	Finland	France
Germany	Greece	Hungary	Iceland	Indonesia
Ireland	Italy	Japan	Korea, Rep.	Lebanon
Malaysia	Mexico	Morocco	Netherlands	New Zealand
Nigeria	Norway	Pakistan	Panama	Peru
Philippines	Poland	Portugal	Russian Federation	South Africa
Spain	Sweden	Thailand	Tunisia	Turkey
Ukraine	United Kingdom	United States	Uruguay	Venezuela, RB

[52] See the policy functions in Fig. G.1.

[53] Due to a higher incentive to borrow and a lower cost of crises, the economy ends up with a higher probability of crises and lower growth. Nevertheless, this economy is superior to the competitive equilibrium due to a short run boom in consumption and growth.

The sources are as follows:
GDP Per Capita Growth: GDP per capita from World Development Indicators (WDI);
TFP: Pen World Table;
Consumption Share of GDP: calculated using final consumption expenditure and GDP data in WDI;
Net Foreign Asset to GDP Ratio: an updated dataset in Lane and Milesi-Ferretti (2007) (see `http://www.philiplane.org/EWN.html`).

Appendix B. Empirical results for KM episodes

I use sudden stop episodes as in Korinek and Mendoza (2014) to show the persistent output-level effects of crises. One can see that this effect is robust to identification of crises. Furthermore, TFP displays a similar pattern to output, as in Fig. 2.

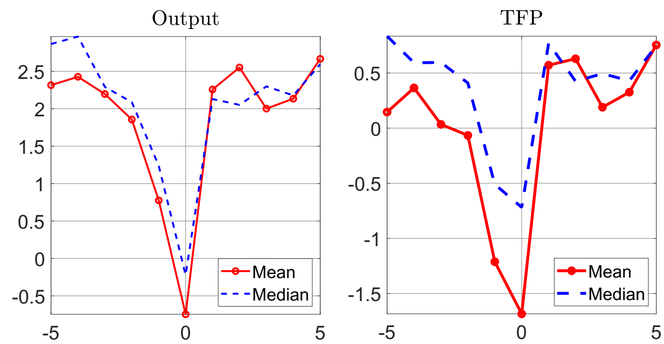

Fig. B.1. Growth rates in KM episodes (%). *Note:* The series are constructed using an 11-year window centering on the sudden stop episodes.

Appendix C. Normalized economy

I normalize the economy by the endogenous variable z_t and denote normalized variables by a hat. The normalized competitive equilibrium conditions are given by

$$\left(\hat{c}_t^h\right)^{-\gamma}\Psi_{1,t}=\beta g_{t+1}^{-\gamma}E_t\left[\left(\hat{c}_{t+1}^h\right)^{-\gamma}(\theta_{t+1}-h-\Psi_{2,t+1})\right]$$
$$\left(\hat{c}_t^h\right)^{-\gamma}\hat{q}_t=\beta g_{t+1}^{1-\gamma}E_t\left[\left(\hat{c}_{t+1}^h\right)^{-\gamma}(\alpha\theta_{t+1}+\hat{q}_{t+1})\right]$$
$$\left(\hat{c}_t^h\right)^{-\gamma}=\hat{\mu}_t^{CE}+\beta g_{t+1}^{-\gamma}(1+r)E_t\left[\left(\hat{c}_{t+1}^h\right)^{-\gamma}\right]$$
$$\hat{c}_t^h+\hat{\Psi}(g_{t+1})+\hat{b}_{t+1}g_{t+1}=\theta_t-h+(1+r)\hat{b}_t$$
$$\hat{\mu}_t^{CE}\left(\hat{b}_{t+1}g_{t+1}+\phi\hat{q}_t\right)=0,\text{ with }\hat{\mu}_t^{CE}\geq 0.$$

For the macroprudential social planner, the normalized equilibrium conditions are

$$\hat{\lambda}_t^{MP}=\left(\hat{c}_t^h\right)^{-\gamma}+\frac{\gamma\phi\hat{\mu}_t^{MP}\hat{q}_t}{\hat{c}_t^h}+\gamma\hat{\nu}_t^{MP}\left(\hat{c}_t^h\right)^{-\gamma-1}\Psi_{1,t}$$
$$\hat{\lambda}_t^{MP}\Psi_{1,t}-\frac{\phi\hat{\mu}_t^{MP}g_{t+1}^{-\gamma}\hat{G}_{1,t}}{\left(\hat{c}_t^h\right)^{-\gamma}}-\hat{\nu}_t^{MP}\left[g_{t+1}^{-1-\gamma}\hat{I}_{1,t}-\left(\hat{c}_t^h\right)^{-\gamma}\hat{\Psi}_{11,t}\right]$$
$$=\beta g_{t+1}^{-\gamma}E_t\left[\hat{\lambda}_{t+1}^{MP}(\theta_{t+1}-h-\Psi_{2,t+1})-\hat{\nu}_{t+1}^{MP}\left(\hat{c}_{t+1}^h\right)^{-\gamma}\hat{\Psi}_{12,t+1}\right]$$
$$\hat{\lambda}_t^{MP}=\hat{\mu}_t^{MP}+\frac{\phi\hat{\mu}_t^{MP}g_{t+1}^{-\gamma}\hat{G}_{2,t}}{\left(\hat{c}_t^h\right)^{-\gamma}}+\hat{\nu}_t^{MP}g_{t+1}^{-1-\gamma}\hat{I}_{2,t}+\beta(1+r)g_{t+1}^{-\gamma}E_t\left[\hat{\lambda}_{t+1}^{MP}\right]$$

where

$$I(z_{t+1},b_{t+1})=z_{t+1}^{-\gamma}\hat{I}\left(\hat{b}_{t+1}\right),$$
$$I_{1,t}=(-\gamma)z_{t+1}^{-\gamma-1}\hat{I}\left(\hat{b}_{t+1}\right)+z_{t+1}^{-\gamma}\hat{I}'\left(\hat{b}_{t+1}\right)\frac{-b_{t+1}}{z_{t+1}^2}=-z_{t+1}^{-\gamma-1}\left[\gamma\hat{I}+\hat{I}'\hat{b}_{t+1}\right],$$
$$I_{2,t}=z_{t+1}^{-\gamma-1}\hat{I}'.$$

and

$$G(z_{t+1}, b_{t+1}) = z_{t+1}^{1-\gamma}\hat{G}\left(\hat{b}_{t+1}\right),$$
$$G_{1,t} = (1-\gamma)z_{t+1}^{-\gamma}\hat{G}\left(\hat{b}_{t+1}\right) + z_{t+1}^{1-\gamma}\hat{G}'\left(\hat{b}_{t+1}\right)\frac{-b_{t+1}}{z_{t+1}^2} = z_{t+1}^{-\gamma}\left[(1-\gamma)\hat{G} - \hat{G}'\hat{b}_{t+1}\right],$$
$$G_{2,t} = z_{t+1}^{-\gamma}\hat{G}'.$$

Appendix D. Proofs

D.1. Proof of Proposition 1

Proof. To implement the macroprudential social planner's allocation, I compare the normalized optimality conditions of private agents and of the macroprudential social planner (see Appendix C) and find that

$$\tau_t^{MP,b} = \frac{\beta g_{t+1}^{-\gamma}(1+r)E_t\left[\gamma\phi\hat{\mu}_{t+1}^{MP}\hat{q}_{t+1}\left(\hat{c}_{t+1}^h\right)^{-1} + \gamma\hat{\nu}_{t+1}^{MP}\left(\hat{c}_{t+1}^h\right)^{-\gamma-1}\Psi_{1,t+1}\right]}{\left(\hat{c}_t^h\right)^{-\gamma}} - \frac{\gamma\phi\hat{\mu}_t^{MP}\hat{q}_t\left(\hat{c}_t^h\right)^{-1} + \gamma\hat{\nu}_t^{MP}\left(\hat{c}_t^h\right)^{-\gamma-1}\Psi_{1,t} - \phi\hat{\mu}_t^{MP}g_{t+1}^{-\gamma}\hat{G}_{2,t}\left(\hat{c}_t^h\right)^{\gamma} - \hat{\nu}_t^{MP}g_{t+1}^{-1-\gamma}\hat{I}_{2,t}}{\left(\hat{c}_t^h\right)^{-\gamma}}$$

Appendix E. Sensitivity analysis

I conduct sensitivity analysis for different parameters in the model. As with the baseline calibration, I first give values for seven parameters, i.e., $\{\beta, \psi, r, \gamma, \alpha, \rho, \sigma\}$: I only change the value of one parameter while keeping the other parameter values the same, as in the baseline calibration. Given these values, I choose $\{\kappa, h, \phi\}$ to match average growth, the consumption to GDP ratio, and the NFA-GDP ratio. I follow this strategy because I want the model to match average growth, which is affected by consumption's share of GDP and by the NFA-GDP ratio. The sensitivity analysis results are presented in Table E.1, and I discuss the robustness of my results with respect to the parameters. One can see that the results do not change with α, since in the calibration, I assume that the collateral constraint binds in steady state, and that ϕ changes with α.

Table E.1
Sensitivity analysis.

	Welfare gains (%)			Tax on capital flows (%)	Prob. of crisis (%)		Average GDP growth (%)	
	MP (overall)	MP (growth)	MP (consumption)	MP	CE	MP	CE	MP
Baseline	0.06	−0.34	0.40	1.28	6.23	1.89	2.315	2.307
$\beta = 0.93$	0.01	−0.04	0.05	1.51	13.24	12.39	2.315	2.312
$\beta = 0.95$	0.03	−0.17	0.20	1.67	10.83	9.52	2.318	2.312
$\psi = 0.94$	0.12	−0.48	0.59	1.65	2.86	1.89	2.323	2.311
$\psi = 0.96$	0.03	−0.16	0.18	1.04	7.32	2.06	2.308	2.305
$\phi = 0.07$	0.01	−0.12	0.13	0.81	7.27	6.66	2.308	2.306
$\phi = 0.08$	0.02	−0.17	0.20	0.94	7.43	2.34	2.311	2.307
$r = 3\%$	0.12	−0.56	0.69	2.59	7.84	6.26	2.336	2.312
$r = 4\%$	0.10	−0.41	0.51	1.92	7.35	2.49	2.323	2.310
$\gamma = 3$	0.21	−1.13	1.40	2.38	10.49	7.00	2.363	2.352
$\gamma = 4$	0.43	−1.77	2.19	3.03	12.12	10.65	2.392	2.382
$\alpha = 0.3$	0.06	−0.34	0.40	1.28	6.23	1.89	2.315	2.307
$\alpha = 0.4$	0.06	−0.34	0.40	1.28	6.23	1.89	2.315	2.307
$\rho = 0.80$	0.05	−0.34	0.40	1.37	5.93	2.22	2.295	2.287
$\rho = 0.90$	0.03	−0.31	0.33	1.35	4.72	2.20	2.287	2.278
$\sigma = 0.02$	0.02	−0.08	0.10	0.93	10.91	8.29	2.297	2.296
$\sigma = 0.03$	0.03	−0.19	0.22	1.22	7.38	6.75	2.303	2.300

Note: Welfare gains and taxes on debt are calculated by simulating the economy for 10,000 periods. Crises are defined as periods when the collateral constraint binds and the current account reversal exceeds 1 standard deviation of its long-run average.

Impacts on Growth: The negative relationship between average growth and financial stability for the macroprudential social planner is very robust to all the parameter values. Furthermore, the growth cost of the policy is very small.

Welfare Gains: The results on welfare gains are robust to various parameters. In particular, I find that the macroprudential social planner can generate welfare gains equivalent to a 0.06 percent permanent increase in annual consumption. In particular, the size of gains increases with parameters that affect the size of externalities, such as ϕ. The gains also increase with parameters that make growth more sensitive to shocks, such as $\{\psi, \gamma\}$. Given that the social planners smooth the economy, welfare gains also increase with parameters that govern risk, such as $\{\rho, \sigma\}$.[54] The welfare gains are supposed to decrease with the discount rate β and the interest rate r, since they decide private agents' impatience condition, given by $\beta(1+r)g^{-\gamma}$. Intuitively, when agents are more impatient, i.e., there is a lower β or r, the economy borrows more and ends up with more crises. Policy interventions should have more benefits, since they mitigate the frequency and severity of crises. Indeed, I find larger gains with a lower interest rate.

[54] Here, lower ρ implies a higher risk for the economy, since it is more likely to enter a bad state tomorrow conditional on a good state today.

However, I also find that welfare gains increase with β. This is because β decides the Euler equation of productivity. High β means that private agents care more about the reduction of growth during crisis. Hence, policy interventions can generate larger benefits by reducing this reduction.

Size of Interventions: In the baseline results, I find that the macroprudential social planner imposes a 1.28 percent capital flows tax. Generally speaking, the magnitude of the macroprudential capital flows tax varies with different parameters and depends on the size of externalities and the ergodic distribution of debt.

Appendix F. Social planner's problem for alternative policy instrument

Asset Price Subsidy with Macroprudential Policy: Following Benigno et al. (2016), I consider the case where the lump-sum transfer is not available and the government budget is balanced with distortionary financing. In this case, it is costly to manipulate the asset prices using taxes on the productive asset since it has to be financed by a tax/subsidy on bond holdings. Specifically, the Ramsey problem is characterized as follows.

$$\begin{aligned}
V_t^{OP}(z_t, b_t, \theta_t) &= \max_{c_t^h, b_{t+1}, z_{t+1}, \tau_t^n, \tau_t^b, \mu_t, q_t} u\left(c_t^h\right) + \beta E\left[V_{t+1}^{OP}(z_{t+1}, b_{t+1}, \theta_{t+1})\right] \\
\text{s.t.} \quad & c_t^h + hz_t + \Psi(z_{t+1}, z_t) + \left(1-\tau_t^b\right)b_{t+1} + (1-\tau_t^n)q_t n_{t+1} = \theta_t z_t n_t^\alpha + q_t n_t + (1+r)b_t, \\
& -b_{t+1} \leq j q_t, \\
& u'\left(c_t^h\right)\Psi_{1,t} = \underbrace{\beta E_t\left[u'\left(c_{t+1}^h\right)(\theta_{t+1} - h - \Psi_{2,t+1})\right]}_{I(z_{t+1}, b_{t+1})}, \\
& u'\left(c_t^h\right)q_t(1-\tau_t^n) = \underbrace{\beta E_t\left[u'\left(c_{t+1}^h\right)(\alpha\theta_{t+1} + q_{t+1})\right]}_{G(z_{t+1}, b_{t+1})}, \\
& u'\left(c_t^h\right)\left(1-\tau_t^b\right) = \mu_t + \underbrace{\beta(1+r)E_t\left[u'\left(c_{t+1}^h\right)\right]}_{L(z_{t+1}, b_{t+1})}, \\
& -\tau_t^n q_t = \tau_t^b b_{t+1}, \\
& \mu_t(b_{t+1} + \phi q_t) = 0.
\end{aligned}$$

Growth-enhancing Subsidy: I consider a social planner who has only access to the growth-enhancing subsidy τ_t^z with a lump-sum transfer. Equivalently, one can define a social planner who maximizes the utility function and is subject to the budget constraint, borrowing constraint and two implementation constraints as follows. To simplify notation, I denote her allocation as "GS."

$$\begin{aligned}
V_t^{GS}(z_t, b_t, \theta_t) &= \max_{c_t^h, z_{t+1}, b_{t+1}, q_t} u\left(c_t^h\right) + \beta E\left[V_{t+1}^{GS}(z_{t+1}, b_{t+1}, \theta_{t+1})\right] \\
\text{s.t.} \quad & c_t^h + hz_t + \Psi(z_{t+1}, z_t) + b_{t+1} = \theta_t z_t + (1+r)b_t, \\
& -b_{t+1} \leq \phi q_t, \\
& u'\left(c_t^h\right)q_t = \underbrace{\beta E_t\left[u'\left(c_{t+1}^h\right)(\alpha\theta_{t+1}z_{t+1} + q_{t+1})\right]}_{G(z_{t+1}, b_{t+1})}, \\
& u'\left(c_t^h\right) = \mu_t + \underbrace{\beta(1+r)E_t\left[u'\left(c_{t+1}^h\right)\right]}_{L(z_{t+1}, b_{t+1})}
\end{aligned}$$

where the last two constraints are the Euler equation of choosing a productive asset and bond holdings.

Multi-Instrument Social Planner: The maximization problem can be written as

$$\begin{aligned}
V_t^{MI}(z_t, b_t, \theta_t) &= \max_{c_t^h, z_{t+1}, b_{t+1}, q_t} u\left(c_t^h\right) + \beta E\left[V_{t+1}^{MI}(z_{t+1}, b_{t+1}, \theta_{t+1})\right] \\
\text{s.t.} \quad & c_t^h + hz_t + \Psi(z_{t+1}, z_t) + b_{t+1} = \theta_t z_t + (1+r)b_t, \\
& -b_{t+1} \leq \phi q_t, \\
& u'\left(c_t^h\right)q_t = \underbrace{\beta E_t\left[u'\left(c_{t+1}^h\right)(\alpha\theta_{t+1}z_{t+1} + q_{t+1})\right]}_{G(z_{t+1}, b_{t+1})}.
\end{aligned}$$

where the last constraint is the Euler equation of choosing a productive asset.

Appendix G. Quantitative results with alternative policy instruments

This section presents policy functions and event window analysis for alternative policy instruments.[55] For the policy functions, they are conditional on the same exogenous shock θ_t as in the benchmark model. For the event window and transition dynamics, they are constructed in the same way as in the benchmark model.

[55] I did not report the case with "unconstrained equilibrium" since its behavior is different from other cases.

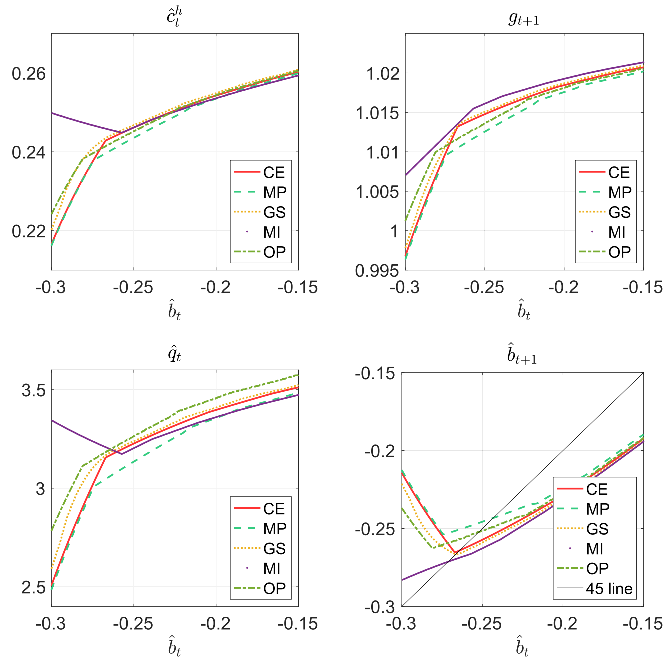

Fig. G.1. Policy functions: alternative policy instruments.

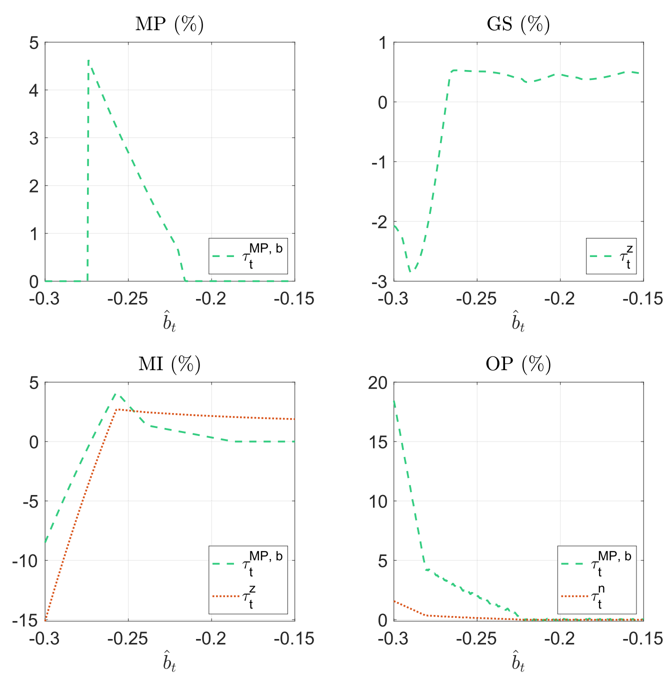

Fig. G.2. Alternative policy instruments.

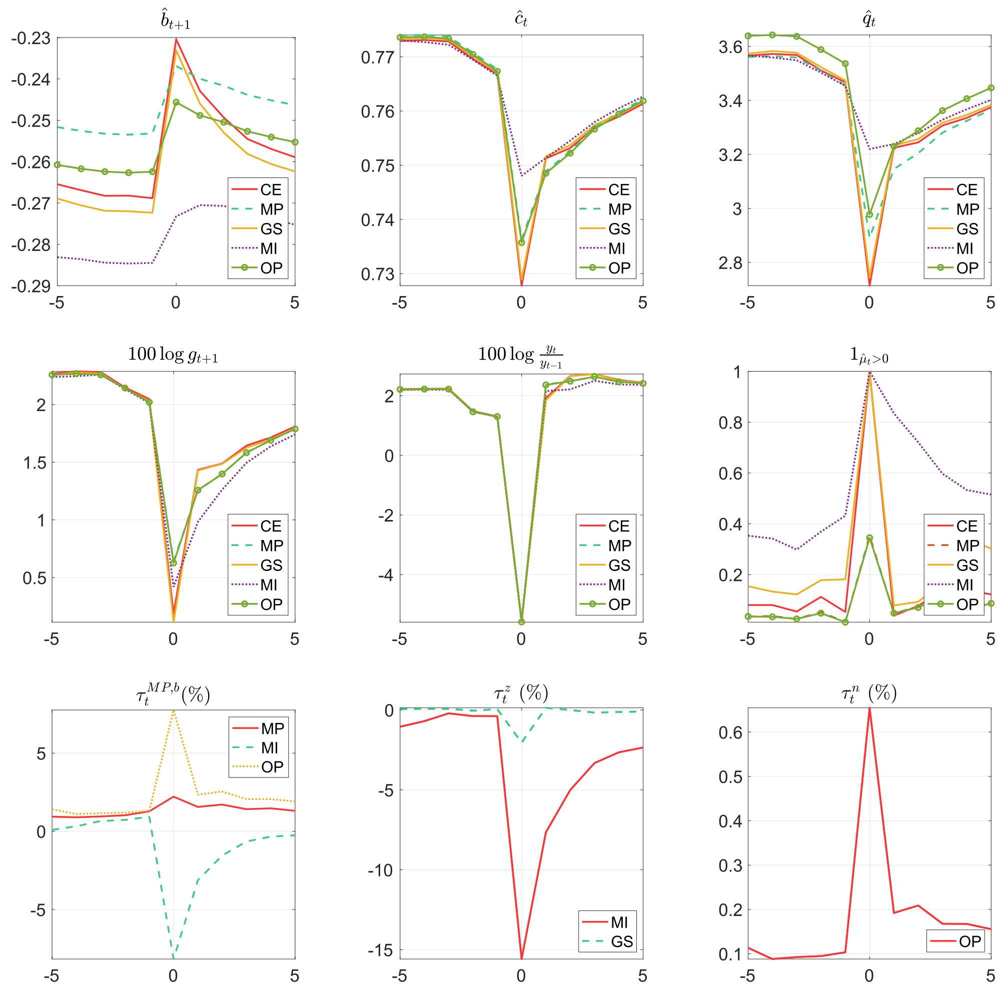

Fig. G.3. Event window: alternative policy instruments.

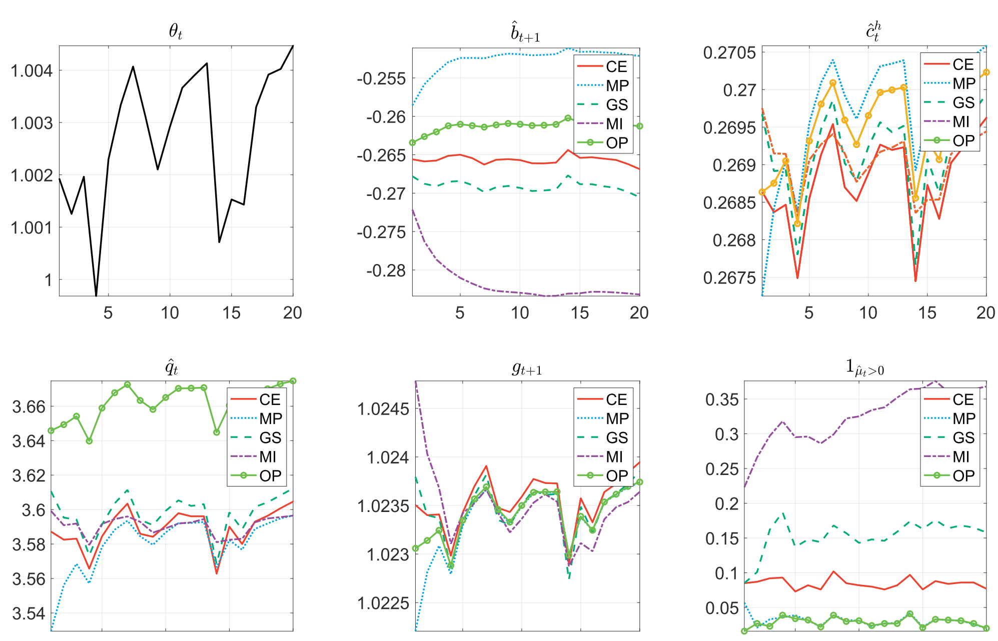

Fig. G.4. Transition dynamics: alternative policy instruments.

Appendix H. Numerical methods for solving policy functions

I first create a grid space $\mathcal{G}_b = \{\hat{b}^0, \hat{b}^1, \cdots\}$ for the bond holding $\hat{b}_t$ and a grid space $\Theta = \{\theta_1, \cdots, \theta_5\}$ for the exogenous technology shock θ_t. The discretization method for the log AR (1) process of θ_t follows the Rouwenhorst method, as in Kopecky and Suen (2010). I apply the endogenous gridpoint method as in Carroll (2006) to iterate first-order conditions in CE and MP, and the iteration stops until policy functions converge. Policy functions in competitive equilibrium include consumption $\mathcal{C}(\hat{b}_t, \theta_t)$, endogenous growth $\mathcal{G}(\hat{b}_t, \theta_t)$, asset price $\mathcal{Q}(\hat{b}_t, \theta_t)$, and bond holding $\mathscr{B}(\hat{b}_t, \theta_t)$. Denote the iteration step by j and start from arbitrary policy functions $\mathcal{C}^0(\hat{b}_t, \theta_t)$, $\mathcal{G}^0(\hat{b}_t, \theta_t)$, $\mathcal{Q}^0(\hat{b}_t, \theta_t)$, and $\mathscr{B}^0(\hat{b}_t, \theta_t)$, where 0 means the iteration step $j = 0$. Given policy functions in iteration step j, I solve policy functions for iteration $j + 1$ as follows:

1. For any $\theta_t \in \Theta$ and $\hat{b}_{t+1} \in \mathcal{G}_b$, I can solve $\{\hat{c}_t^h, g_{t+1}, \hat{q}_t\}$ using equilibrium conditions. Using the budget constraint, these allocations imply a level of $\hat{b}_t$.[56] Then I have a combination of $\{\hat{b}_t\}$ and corresponding allocations $\{\hat{c}_t^h, g_{t+1}, \hat{q}_t, \hat{b}_{t+1}\}$. I can update policy functions using these combinations. In this process, I need to deal with the collateral constraint. Specifically, I assume that the constraint is slack and then check whether this condition is satisfied.
2. I first assume that the constraint is slack and allocations $g_{t+1}, \hat{c}_t^h, \hat{q}_t$ can be solved using the following conditions:

$$\Psi_t(g_{t+1}) = \frac{E_t\left[\left(\mathcal{C}^j\left(\hat{b}_{t+1}, \theta_{1+1}\right)\right)^{-\gamma}\left(\theta_{t+1} - h - \Psi_2\left(\mathcal{G}^j\left(\hat{b}_{t+1}, \theta_{t+1}\right)\right)\right)\right]}{(1+r)E_t\left[\left(\mathcal{C}^j\left(\hat{b}_{t+1}, \theta_{1+1}\right)\right)^{-\gamma}\right]}$$
$$\hat{c}_t^h = g_{t+1}\left[\beta(1+r)E_t\left[\left(\mathcal{C}^j\left(\hat{b}_{t+1}, \theta_{1+1}\right)\right)^{-\gamma}\right]\right]^{-\frac{1}{\gamma}}$$
$$\hat{q}_t = \left(\hat{c}_t^h\right)^{\gamma}\beta g_{t+1}^{1-\gamma}E_t\left[\left(\mathcal{C}^j\left(\hat{b}_{t+1}, \theta_{1+1}\right)\right)^{-\gamma}\left(\alpha\theta_{t+1} + \mathcal{Q}\left(\hat{b}_{t+1}, \theta_{t+1}\right)\right)\right]$$

3. If the collateral constraint $-\hat{b}_{t+1}g_{t+1} \le \phi\hat{q}_t$ is satisfied, I proceed to solve $\hat{b}_t$ using the budget constraint:

$$\hat{b}_t = \frac{\hat{c}_t^h + h + \hat{\Psi}(g_{t+1}) + \hat{b}_{t+1}g_{t+1} - \theta_t}{1+r}$$

4. For all the combinations of $\{\hat{b}_{t+1}, \hat{c}_t^h, g_{t+1}, \hat{b}_t, \hat{q}_t\}$ that satisfy the collateral constraint, using the interpolation methods to find the level of current bond holding $\overline{b}$ such that the constraint is marginally binding. I will use the combinations of $\{\hat{b}_{t+1}, \hat{c}_t^h, g_{t+1}, \hat{b}_t, \hat{q}_t\}$ to update policy functions $\mathcal{C}^{j+1}(\hat{b}_t, \theta_t), \mathcal{G}^{j+1}(\hat{b}_t, \theta_t), \mathcal{Q}^{j+1}(\hat{b}_t, \theta_t), \mathscr{B}^{j+1}(\hat{b}_t, \theta_t)$ for $\hat{b}_t \ge \overline{b}$.
5. If the constraint is violated, I can solve allocations $\{\hat{q}_t, \hat{c}_t^h, g_{t+1}\}$ using the following equations:

$$\left(\hat{c}_t^h\right)^{-\gamma}\Psi_t(g_{t+1}) = \beta g_{t+1}^{-\gamma}E_t\left[\left(\mathcal{C}^j\left(\hat{b}_{t+1}, \theta_{1+1}\right)\right)^{-\gamma}\left(\theta_{t+1} - h - \Psi_2\left(\mathcal{G}^j\left(\hat{b}_{t+1}, \theta_{t+1}\right)\right)\right)\right]$$
$$-\hat{b}_{t+1}g_{t+1} = \phi\hat{q}_t$$
$$\hat{q}_t = \left(\hat{c}_t^h\right)^{\gamma}\beta g_{t+1}^{1-\gamma}E_t\left[\left(\mathcal{C}^j\left(\hat{b}_{t+1}, \theta_{1+1}\right)\right)^{-\gamma}\left(\alpha\theta_{t+1} + \mathcal{Q}\left(\hat{b}_{t+1}, \theta_{t+1}\right)\right)\right]$$

6. For these combinations to satisfy the equilibrium conditions, it has to the case where $\hat{b}_t \le \overline{b}$. I can update $\mathcal{C}^{j+1}(\hat{b}_t, \theta_t), \mathcal{G}^{j+1}(\hat{b}_t, \theta_t), \mathcal{Q}^{j+1}(\hat{b}_t, \theta_t), \mathscr{B}^{j+1}(\hat{b}_t, \theta_t)$ for $\hat{b}_t \le \overline{b}$ using the combinations of $\hat{b}_t \le \overline{b}$ and $\{g_{t+1}, \hat{c}_t^h, \hat{q}_t, \hat{b}_{t+1}\}$.
7. I keep iterating until policy functions in two consecutive iterations are close enough.

To solve policy functions for the social planner, I need to solve additional policy functions of Lagrangian multipliers, i.e. $\mu(\hat{b}_t, \theta_t)$ and $\nu(\hat{b}_t, \theta_t)$, using equilibrium conditions described in Appendix C. Otherwise, the procedure is the same as above.

[56] As will be explained later, one $\hat{b}_{t+1}$ is associated with two $\hat{b}_t$. One is consistent with a slack collateral constraint and the other is consistent with a binding constraint.

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