Optimal Time-Consistent Macroprudential Policy

Javier Bianchi

Federal Reserve Bank of Minneapolis and National Bureau of Economic Research

Enrique G. Mendoza

University of Pennsylvania, National Bureau of Economic Research, and Penn Institute for Economic Research

Collateral constraints widely used in models of financial crises feature a pecuniary externality: Agents do not internalize how borrowing decisions made in "good times" affect collateral prices during a crisis. We show that under commitment the optimal financial regulator's plans are time inconsistent and study time-consistent policy. Quantitatively, this policy reduces sharply the frequency and magnitude of crises, removes fat tails from the distribution of asset returns, and increases social welfare. In contrast, constant debt taxes are ineffective and can be welfare reducing, while an optimized "macroprudential Taylor rule" is effective but less so than the optimal time-consistent policy.

I. Introduction

Following the 2008 Global Financial Crisis, the realization that credit booms are infrequent but perilous events that often end in similar crises (see, e.g., Mendoza and Terrones 2008; Reinhart and Rogoff 2009) has

We are grateful for the support of the National Science Foundation under awards 1325122 (Mendoza) and 1324395 (Bianchi). Mendoza also acknowledges the support of the Bank for International Settlements under a 2014 Research Fellowship and the Jacobs Levy Center for Quantitative Financial Research of the Wharton School under a 2014–15 research grant. We thank Fernando Alvarez, Gianluca Benigno, John Cochrane, Alessandro Dovis, Charles Engel, Lars Hansen, Olivier Jeanne, Tasos Karantounias, Anton Korinek,

Electronically published March 14, 2018
[*Journal of Political Economy*, 2018, vol. 126, no. 2]

resulted in a strong push for a new "macroprudential" form of financial regulation. The objective of this new regulation is to adopt a macroeconomic perspective of credit dynamics, with a view to defusing credit booms in their early stages as a prudential measure to prevent them from turning into crises (see, e.g., Borio 2003; Bernanke 2010). Efforts to move financial regulation in this direction, however, have moved faster and further than our understanding of how financial policies influence the transmission mechanism driving financial crises, particularly in the context of quantitative models that can be used to design and evaluate these policies.

This paper aims to fill this gap by answering three key questions: First, can credit frictions affecting individual borrowers produce strong financial amplification effects that result in macroeconomic crises? Second, if the answer to the first question is yes, what is the optimal design of macroprudential policy, particularly when commitment and credibility are issues at stake? Third, how effective is this policy at affecting private borrowing incentives in a prudential manner, reducing the magnitude and frequency of crises, and improving social welfare?

This paper provides answers to these questions derived from the theoretical and quantitative analysis of a dynamic stochastic general equilibrium model with a collateral constraint linking borrowing capacity to the market value of collateral assets. We start by developing a normative theory of the optimal macroprudential policy with and without commitment. Then we calibrate the model to data from industrial countries and solve it numerically to show that, in the absence of macroprudential policy, the model embodies a strong financial amplification mechanism that produces financial crises. Then we solve for the optimal, time-consistent macroprudential policy of a regulator who cannot commit to future policies and compute a state-contingent schedule of debt taxes that supports the optimal allocations as a competitive equilibrium. We evaluate the effectiveness of this policy for reducing the probability and magnitude of crises and increasing social welfare and compare it with the effectiveness of simpler policy rules.

The collateral constraint is occasionally binding and limits total debt (one-period debt plus within-period working capital) to a fraction of the market value of physical assets that can be posted as collateral, which are in fixed supply. This constraint is the engine of the model's financial amplification mechanism. When the constraint binds, Irving Fisher's classic debt-deflation effect is set in motion: Agents fire-sale assets to meet

Zheng Liu, Guido Lorenzoni, Tom Sargent, Harald Uhlig (the editor), and three anonymous referees for helpful comments and discussions. We also acknowledge comments by audiences at several seminar and conference presentations since 2010. Some material included here circulated earlier under the title "Overborrowing, Financial Crises and Macroprudential Policy," NBER Working Paper no. 16091, June 2010. Data are provided as supplementary material online

their obligations forcing price declines that tighten further the constraint and trigger further asset fire sales. The result is a financial crisis driven by a nonlinear feedback loop between asset fire sales and borrowing capacity.

Focusing on financial frictions models with collateral constraints is important because of the prevalence of secured lending worldwide. The relevance of collateral in residential mortgage markets is self-evident, but in addition, evidence cited by Gan (2007) shows that roughly 70 percent of all commercial and industrial loans are secured with collateral in the United States, the United Kingdom, and Germany and that real estate is a dominant form of collateral for firm financing in these three countries and in 58 emerging economies. In line with this evidence, Chaney, Sraer, and Thesmar (2012) found that movements in US local real estate prices are statistically significant for explaining cross-sectional variations in US corporate investment. Moreover, there is also evidence showing that a sizable share of working capital financing requires collateral and that it plays an important role in the drop in economic activity during financial crises. The Federal Reserve's 2013 Survey of Terms of Business Lending shows that 40 percent of commercial and industrial loans with less than a year of maturity used collateral. Amiti and Weinstein (2011) provide empirical evidence showing that trade credit is a key determinant of firm-level exports during financial crises.

The normative theory we study highlights a pecuniary externality similar to those used in the related literature on credit booms and macroprudential policy (e.g., Lorenzoni 2008; Korinek 2009; Bianchi 2011; Stein 2012): Individual agents facing a collateral constraint taking prices as given do not internalize how their borrowing decisions in "good times" affect collateral prices, and hence aggregate borrowing capacity, in "bad times" in which the collateral constraint binds. This creates a market failure that results in equilibria that can be improved on by a financial regulator who faces the same credit constraint but internalizes the externality.

In our setup, this pecuniary externality implies that private agents fail to internalize the Fisherian debt-deflation effect that crashes asset prices and causes a crisis when the constraint binds. Moreover, when this happens production plans are also affected, because working capital loans pay for a fraction of the cost of inputs, and these loans are also subject to the collateral constraint. This results in a sudden increase in effective factor costs and a fall in output when the constraint binds. In turn, this affects expected dividend streams and therefore asset prices and introduces an additional vehicle for the pecuniary externality to operate.

We study the optimal policy problem of a financial regulator who chooses the level of credit to maximize private utility subject to resource, collateral, and implementability constraints. This regulator internalizes the pecuniary externality and cannot commit to future policies. The inability to commit is modeled explicitly by solving for optimal time-consistent macroprudential policy as a Markov perfect equilibrium, in which the effects of the regulator's optimal plans on future regulators' plans are taken into account. We followed this approach because we show that, under commitment, the regulator promises lower future consumption to prop up asset prices when the collateral constraint binds, but reneging is optimal ex post. Hence, in the absence of effective commitment devices, the optimal macroprudential policy under commitment is not credible.

We provide theoretical results showing that the regulator can decentralize its equilibrium allocations as a competitive equilibrium with optimal state-contingent debt taxes. A key element of these taxes is what we label a *macroprudential debt tax*, which is levied in good times when collateral constraints do not bind at date t but can bind with positive probability at $t + 1$, and we show that this tax is always positive. When the constraint binds at t, the optimal taxes include two other components, which combined can be positive or negative: One captures the regulator's "ex post" incentives to influence asset prices to prop up credit when collateral constraints are already binding, and the other captures its incentives to influence the optimal plans of future regulators due to the lack of commitment.

The quantitative results show that the optimal policy reduces sharply the frequency and severity of financial crises. The probability of crises is 4 percent in the unregulated decentralized equilibrium versus close to zero in the equilibrium attained by the regulator. When a crisis occurs, asset prices drop 43.7 percent and the equity premium rises to 4.8 percent in the former versus 5.4 and 0.7 percent, respectively, in the latter. Without regulation, the output drop is about 28 percent larger and the distribution of asset returns features an endogenous "fat tail." In terms of welfare, the optimal policy yields a sizable average gain of one-third of a percent computed as the standard Lucas-style compensating variation in consumption that equates expected lifetime utility with and without policy. The optimal macroprudential debt tax is about 3.6 percent on average, fluctuates roughly half as much as GDP, and has a correlation of .7 with leverage.

We also evaluate the effectiveness of policy rules simpler than the optimal policy. Fixed debt taxes are ineffective at best, and at worst they can be welfare reducing. In contrast, a macroprudential Taylor rule that makes the tax an isoelastic function of the debt position relative to a target performs better. Optimizing the elasticity of this rule to maximize the average welfare gain, we construct a welfare-increasing rule that is effective at reducing the probability and magnitude of crises, albeit less so than the optimal policy.

This paper contributes to the growing quantitative macro-finance literature by developing a nonlinear quantitative framework suitable for the normative analysis of macroprudential policy. Most of this literature, including this article, follows in the steps of the work on financial accelerators initiated by Bernanke and Gertler (1989) and Kiyotaki and Moore (1997) (see, e.g., Perri and Quadrini 2011; Arellano, Bai, and Kehoe 2012; Jermann and Quadrini 2012; Boissay, Collard, and Smets 2016). In particular, we follow Mendoza (2010) in analyzing the nonlinear dynamics of an occasionally binding collateral constraint. He showed that a small-open-economy business cycle model with a constraint of this kind produces financial crises that match the key features of emerging market crises, but his work abstracted from normative issues, which are the main focus of this study.

There are also quantitative studies of pecuniary externalities due to collateral constraints. In particular, Bianchi (2011) studies the effects of a debt tax in a setting in which the borrowing capacity is linked to the relative price of nontradable goods to tradable goods. Benigno et al. (2013) show in a similar setup that there can be a role for ex post policies to reallocate labor from the nontradables sector to the tradables sector and show how this reduces precautionary savings. This paper differs from these studies in that it focuses on assets as collateral and on asset prices as a key factor driving debt dynamics and the pecuniary externality, instead of the relative price of nontradable goods. This is important because private debt contracts commonly use assets as collateral and also because the forward-looking nature of asset prices introduces effects that are absent otherwise. In particular, expectations of future crises affect the discount rates applied to future dividends and distort asset prices even in periods of financial tranquility. This also drives the time consistency issues that we tackle in this study and that were absent from previous work. Our model also differs in that we introduce working capital financing subject to the collateral constraint, which implies that the asset fire sales also affect adversely production, factor allocations, and dividend rates.

This paper is also related to the work of Jeanne and Korinek (2010), who studied a model in which assets serve as collateral. In their model, however, aggregate, not individual, assets are collateral for private borrowing, output follows an exogenous Markov-switching process, and debt is limited to the sum of a fraction of the value of collateral plus an exogenous constant. In addition, in their setup the planner faces asset prices that are predetermined in states in which the collateral constraint binds, while we study a time-consistent Markov perfect equilibrium in which the planner internalizes how borrowing choices made when the constraint binds affect prices contemporaneously via changes in current consumption and in the optimal plans of future regulators.[1] With this approach,

[1] See sec. K of the appendix, available online, for a detailed comparison. Korinek and Mendoza (2014, 325) also compare the two social planning problems.

we can prove that the optimal macroprudential tax is positive, while Jeanne and Korinek obtain a tax that depends on equilibrium objects with a potentially ambiguous sign. The two studies also differ in their quantitative implications. In their work, the constant term in the credit limit is much larger than the fraction of the value of assets that serve as collateral, and the probability of crises equals the exogenous probability of a low-output regime. As a result, debt taxes cannot affect the frequency of crises and have small effects on their magnitude. In contrast, in our model both the probability of crises and output dynamics are endogenous, and the optimal policy reduces sharply the incidence and magnitude of crises.

Our analysis is also related to other studies on inefficient borrowing and its policy implications. In particular, Schmitt-Grohé and Uribe (2014) and Farhi and Werning (2016) examine the scope for macroprudential policy as a tool for smoothing aggregate demand in the presence of nominal rigidities. In earlier work, Uribe (2006) examined an economy with an aggregate borrowing limit and compared the borrowing decisions with those of an economy in which the borrowing limit applies to individual agents.

The rest of the paper is organized as follows: Section II presents the theoretical analysis. Section III conducts the quantitative analysis. Section IV provides conclusions. In addition, an extended online appendix provides further details on various aspects of the theoretical and quantitative analyses.

II. A Model of Financial Crises and Macroprudential Policy

In this section we study a small-open-economy model of financial crises driven by an occasionally binding collateral constraint. We characterize first a decentralized competitive equilibrium (DE) without regulation, following an approach similar to that used in Mendoza (2010), in which a representative firm-household (the "agent") makes both production and consumption-savings plans for simplicity.[2] Then we analyze the optimal policy problem of a constrained-efficient social planner (SP) who is unable to commit to future policies and demonstrate that the SP's allocations can be supported as a competitive equilibrium with state-contingent debt taxes. Finally, we compare the results with those obtained under commitment.

[2] Section C of the online appendix shows that the competitive equilibrium is the same if we separate the optimization problems of households and firms (assuming a frictionless equity market).

A. *Firm-Household Optimization Problem*

The representative agent has an infinite life horizon and preferences given by

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(c_t - G(h_t)). \tag{1}$$

In this expression, $\mathbb{E}(\cdot)$ is the expectations operator, β is the subjective discount factor, c_t is consumption, and h_t is labor supply (we follow the standard convention of using lowercase letters for individual variables and uppercase letters for aggregate variables). The utility function $u(\cdot)$ is a standard concave, twice continuously differentiable function that satisfies the Inada condition. The argument of $u(\cdot)$ is the composite commodity $c_t - G(h_t)$ defined by Greenwood, Hercowitz, and Huffman (1988). The term $G(h)$ is a convex, strictly increasing, and continuously differentiable function that measures the disutility of labor. This formulation of preferences removes the wealth effect on labor supply, which prevents a counterfactual increase in labor supply during crises.

The agent combines physical assets, intermediate goods (v_t), and labor (h_t) to produce final goods using a production technology such that $y = z_t F(k_t, h_t, v_t)$, where F is a twice continuously differentiable, concave production function and z_t is a productivity shock. This shock has compact support and follows a finite-state, stationary Markov process. Intermediate goods are traded in competitive world markets at a constant exogenous price p_v in terms of domestic final goods (i.e., p_v can be interpreted as the terms of trade taken as given by the small open economy and is also the marginal rate of transformation between final goods and intermediate goods). The profits of the agent are given by $z_t F(k_t, h_t, v_t) - p_v v_t$.

The agent's budget constraint is

$$q_t k_{t+1} + c_t + \frac{b_{t+1}}{R_t} = q_t k_t + b_t + [z_t F(k_t, h_t, v_t) - p_v v_t], \tag{2}$$

where b_t and k_t are holdings of one-period non-state-contingent foreign bonds and domestic physical assets, respectively; q_t is the market price of assets; and R_t is the world-determined gross real interest rate also taken as given by the small open economy.[3] Since assets are in fixed unit supply, the market-clearing condition in the asset market is simply $k_t = 1$. The interest rate R_t is stochastic, and like the productivity shocks, it follows a finite-state, stationary Markov process with compact support. Assuming that R_t is stationary is conservative, because in the pre-2008 crisis boom

[3] An equivalent formulation is to assume deep-pockets, risk-neutral lenders that discount utility at rate $\beta^* = 1/R$. They are unaffected by domestic financial policies because their return on savings remains the same.

years, real interest rates displayed a protracted decline, and introducing this drop strengthens our results by enhancing the overborrowing effect of the pecuniary externality.

The assumption that the economy is small and open relative to world financial markets fits well the advanced economies we targeted to calibrate the model in Section III. Even in the United States, interest rates have become increasingly dependent on external factors as a result of financial globalization. Mendoza and Quadrini (2010) document that about one-half of the surge in net credit in the US economy since the mid-1980s was financed by foreign capital inflows, and by 2010 more than half of the stock of Treasury bills was owned by foreign agents. Still, section I of the online appendix shows how our quantitative findings vary if we replace the exogenous R_t process with an inverse supply-of-funds curve, which allows the real interest rate to increase as debt rises.

The firm-household also faces a working capital constraint that requires a fraction $\theta \leq 1$ of the cost of inputs $p_v v_t$ to be paid in advance of production using foreign credit. This credit is a within-period loan that effectively carries a zero interest rate. In contrast, in the conventional working capital setup, the marginal cost of inputs carries a financing cost determined by R_t and thus responds to interest rate shocks (e.g., Uribe and Yue 2006). Our formulation isolates the effect of working capital due to the need to provide collateral for these funds, as explained below, which is present even without the effect of R_t on marginal factor costs.

The agent faces a collateral constraint that limits total debt not to exceed a fraction κ_t of the market value of beginning-of-period asset holdings (i.e., κ_t imposes a ceiling on the leverage ratio):

$$-\frac{b_{t+1}}{R_t} + \theta p_v v_t \;\leq\; \kappa_t q_t k_t. \tag{3}$$

We show in section A.5 of the online appendix that this constraint can be derived as an implication of incentive-compatibility constraints on borrowers if limited enforcement prevents lenders from collecting more than a fraction κ_t of the value of the assets owned by a defaulting debtor. Note also that, while bonds and working capital are explicitly modeled as credit from abroad, this credit could also be provided by a domestic financial system that has unrestricted access to world capital markets and faces the same enforcement friction.

The model allows for shocks to κ_t, which can be viewed as financial shocks that lead creditors to adjust collateral requirements on borrowers (e.g., Jermann and Quadrini 2012; Boz and Mendoza 2014). It is important to note, however, that neither the nature of the financial amplification mechanism nor the normative arguments we develop later rely on κ_t being stochastic. In fact, models with constant κ have been shown to be able to produce crises dynamics with realistic features in response to productivity shocks of standard magnitudes (see Mendoza 2010).

The agent maximizes (1) subject to (2) and (3) taking prices as given. This maximization problem yields the following optimality conditions for each date $t = 0, \ldots, \infty$:

$$z_t F_h(k_t, h_t, v_t) = G'(h_t), \tag{4}$$

$$z_t F_v(k_t, h_t, v_t) = p_v[1 + \theta\mu_t/u'(t)], \tag{5}$$

$$u'(t) = \beta R_t \mathbb{E}_t[u'(t+1)] + \mu_t, \tag{6}$$

$$q_t u'(t) = \beta\mathbb{E}_t\{u'(t+1)[z_{t+1}F_k(k_{t+1}, h_{t+1}, v_{t+1}) + q_{t+1}] + \kappa_{t+1}\mu_{t+1}q_{t+1}\}, \tag{7}$$

where $\mu_t \geq 0$ is the Lagrange multiplier on the collateral constraint and $u'(t)$ denotes $u'(c_t - G(h_t))$.

Condition (4) is the labor market optimality condition equating the marginal disutility of labor supply with the marginal productivity of labor demand, which is also the wage rate. Condition (5) is a similar condition setting the demand for intermediate goods by equating their marginal productivity with their marginal cost. The latter includes the financing cost $\theta\mu_t/u'(t)$, which is incurred only when the collateral constraint binds.

The last two optimality conditions are the Euler equations for bonds and assets, respectively. When the collateral constraint binds, condition (6) implies that the marginal benefit of borrowing to increase c_t exceeds the expected marginal cost by an amount equal to the shadow price of relaxing the credit constraint (i.e., the agent faces an effective real interest rate higher than R_t). Condition (7) equates the marginal cost of an extra unit of assets with its marginal benefit. When the collateral constraint binds, the fact that assets serve as collateral increases the marginal benefit of buying assets by $\beta\mathbb{E}_t\kappa_{t+1}\mu_{t+1}q_{t+1}$.

Using the definition of asset returns ($R^q_{t+1} \equiv [z_{t+1}F_k(t+1) + q_{t+1}]/q_t$) and iterating forward on (7), we can express the pricing condition as the expected present value of dividends (the marginal product of capital) discounted with R^q_{t+1}:

$$q_t = \mathbb{E}_t \sum_{j=0}^{\infty} \left(\prod_{i=0}^{j} \mathbb{E}_{t+i} R^q_{t+1+i} \right)^{-1} z_{t+j+1} F_k(t+j+1). \tag{8}$$

Combining (6) and (7) and the definition of R^q_{t+1}, the expected excess return on assets relative to bonds (i.e., the equity premium, $R^{ep}_t \equiv \mathbb{E}_t(R^q_{t+1} - R_t)$) can be decomposed into a liquidity premium, a collateral effect, and a risk premium as follows:

$$R_t^{ep} = \underbrace{\frac{\mu_t}{u'(t)\mathbb{E}_t m_{t+1}}}_{\text{Liquidity Premium}} - \underbrace{\frac{\mathbb{E}_t(\phi_{t+1} m_{t+1})}{\mathbb{E}_t m_{t+1}}}_{\text{Collateral Effect}} - \underbrace{\frac{\text{cov}_t(m_{t+1}, R_{t+1}^q)}{\mathbb{E}_t[m_{t+1}]}}_{\text{Risk Premium}}, \tag{9}$$

where $m_{t+1} \equiv \beta u'(c_{t+1})/u'(c_t)$ is the one-period-ahead stochastic discount factor, and

$$\phi_{t+1} \equiv \kappa_{t+1} \frac{\mu_{t+1}}{u'(c_t)} \frac{q_{t+1}}{q_t}.$$

The liquidity premium increases R_t^{ep} when the constraint binds, with an effect proportional to μ_t. The collateral effect pushes R_t^{ep} in the opposite direction, because buying more assets at date t improves borrowing capacity at $t + 1$ if the constraint can bind then.[4] The effect of the risk premium depends on how the covariance between the stochastic discount factor and the return on assets changes. The expectation of a binding collateral constraint raises the premium, because it makes the covariance "more negative" as it makes it harder to smooth consumption; but if the constraint is already binding, the covariance rises as the constraint tightens, reducing the risk premium. If the liquidity premium dominates, conditions (8) and (9) imply that a binding collateral constraint exerts pressure to fire-sell assets, raises excess returns, and lowers asset prices.

The above mechanism is at the core of the model's pecuniary externality: higher individual debt leads to more frequent fire sales, driving excess returns up and asset prices down, which in turn reduces the aggregate borrowing capacity of the economy. In addition, because of the efficiency loss induced by the diminished access to working capital financing when the collateral constraint binds, the stream of dividends is also distorted. Moreover, because expected returns rise whenever the collateral constraint is expected to bind at any future date, condition (8) also implies that asset prices at t are affected by collateral constraints, not just when the constraint binds at t, but whenever it is expected to bind at any future date. Hence, expectations about future excess returns (i.e., future liquidity and risk premia and future collateral effects) and dividends feed back into current asset prices. This interaction will play an important role in the normative analysis.

The assumption that assets are not traded internationally is not innocuous. If assets are traded by foreign investors in frictionless markets, asset prices are not affected by a domestic collateral constraint, because they

[4] A similar effect is present when k_{t+1} serves as collateral instead of k_t but its timing changes. In this case, the marginal benefit of holding more assets as collateral shows up as the term $-\mu_t\kappa_t$ in R_t^{ep} (see Mendoza and Smith 2006; Bianchi and Mendoza 2010).

are priced discounting at the world's risk-free rate (see Mendoza and Smith 2006). But if investors face trading costs or other frictions, prices respond and our findings about the optimal policy to tackle the pecuniary externality still hold.[5]

B. *Unregulated Decentralized Competitive Equilibrium*

We define and solve for the DE in recursive form. We denote as s the triplet of date t realizations of shocks $s = \{z_t, \kappa_t, R_t\}$ and separate individual bond holdings under the agent's control, b, from the economy's aggregate bond position, B, on which prices depend. Hence, the state variables for the agent's problem are the individual states (b, k) and the aggregate states (B, s). Aggregate capital is not a state variable because it is in fixed supply. In addition, in order to form expectations of future prices, the agent needs a "perceived" law of motion $B' = \Gamma(B, s)$ governing the evolution of the economy's bond position and a conjectured asset pricing function $q(B, s)$.

The agent's recursive optimization problem is

$$V(b, k, B, s) = \max_{b', k', c, h, v} \{u(c - G(h)) + \beta \mathbb{E}_{s'|s} V(b', k', B', s')\} \tag{10}$$

subject to

$$q(B, s)k' + c + \frac{b'}{R} = q(B, s)k + b + [zF(k, h, v) - p_v v],$$

$$-\frac{b'}{R} + \theta p_v v \leq \kappa q(B, s)k,$$

$$B' = \Gamma(B, s).$$

The solution to this problem is characterized by the decision rules $\hat{b}(b, k, B, s)$, $\hat{k}(b, k, B, s)$, $\hat{c}(b, k, B, s)$, $\hat{v}(b, k, B, s)$, and $\hat{h}(b, k, B, s)$. The decision rule for bond holdings induces an "actual" law of motion for aggregate bonds, which is given by $\hat{b}(B, 1, B, s)$, and the recursive form of (8) induces an "actual" pricing function $\hat{q}(B, s)$.

DEFINITION (Recursive competitive equilibrium). A *recursive competitive equilibrium* is defined by an asset pricing function $q(B, s)$, a perceived law of motion for aggregate bond holdings $\Gamma(B, s)$, and decision rules $\hat{b}(b, k, B, s)$, $\hat{k}(b, k, B, s)$, $\hat{c}(b, k, B, s)$, $\hat{h}(b, k, B, s)$, and $\hat{v}(b, k, B, s)$ with associated value function $V(b, k, B, s)$ such that

[5] The optimal policy would be more complex because the planner would have incentives to alter prices to extract monopolistic rents from foreigners.

1. $\{\hat{b}(b, k, B, s), \hat{k}(b, k, B, s), \hat{c}(b, k, B, s), \hat{h}(b, k, B, s), \hat{v}(b, k, B, s), \hat{\mu}(b, k, B, s)\}$ and $V(b, k, B, s)$ solve the agents' recursive optimization problem, taking as given $q(B, s)$ and $\Gamma(B, s)$;
2. the market for assets clears: $\hat{k}(B, 1, B, s) = 1$;
3. the resource constraint holds:

$$\frac{\hat{b}(B, 1, B, s)}{R} + \hat{c}(B, 1, B, s) = zF(1, \hat{h}(B, 1, B, s), \hat{v}(B, 1, B, s)) + B - p_v \hat{v}(B, 1, B, s);$$

4. the perceived law of motion for aggregate bonds and perceived asset pricing function are consistent with the actual law of motion and actual pricing function, respectively: $\Gamma(B, s) = \hat{b}(B, 1, B, s)$ and $q(B, s) = \hat{q}(B, s)$.

C. *Time-Consistent Planner's Problem*

Comparing competitive equilibria with and without credit constraints, private agents borrow (weakly) less in the former, because the constraints limit the amount they can borrow, and also because they build additional precautionary savings to self-insure against the risk of the sharp consumption adjustments caused by the constraints. In contrast, in the normative analysis that follows we show that the DE with collateral constraints displays overborrowing relative to the SP's borrowing decisions when the collateral constraint does not bind. Hence, the DE with collateral constraints features *underborrowing* relative to the DE without collateral constraints but *overborrowing* relative to the SP equilibrium with the constraints.

We formulate the SP's problem in a manner similar to the "primal approach" to optimal policy analysis, with the planner choosing allocations subject to resource, implementability, and collateral constraints. In particular, the SP chooses b_{t+1} on behalf of the representative firm-household subject to those constraints, but lacking the ability to commit to future policies. Since asset prices remain market determined, the private agent's Euler equation for assets enters in the SP's problem as an implementability constraint. The planner thus does not set asset prices, but it does internalize how its borrowing decisions affect them.

The optimization problem of the private agent changes because b_{t+1} is no longer a choice variable, and this in turn has two implications (see sec. A.1 of the online appendix for the complete formulation of the agent's optimization problem in the constrained-efficient equilibrium). First, the agent now takes as given a transfer T_t, which matches the resources added or subtracted by the SP's bond choices (the SP's budget constraint is $T_t = b_t - (b_{t+1}/R_t)$). Second, the private agent's problem no longer has an Euler equation for bonds, but the agent still faces the working capital constraint, and hence the optimality conditions for v_t and k_{t+1} are still (5) and (7).

Following Klein, Quadrini, and Rios-Rull (2007) and Klein, Krusell, and Rios-Rull (2008), we focus on Markov stationary policy rules that are expressed as functions of the payoff-relevant state variables (b, s). Since the SP cannot commit to future policy rules, it chooses its policy rules at any given period taking as given the policy rules that represent future SPs' decisions. A Markov perfect equilibrium is characterized by a fixed point in these policy rules, at which the policy rules of future planners that the current planner takes as given to solve its optimization problem match those that the current planner finds optimal to choose. Hence, the planner does not have the incentive to deviate from other planners' policy rules, thereby making these rules time consistent.

Let $\mathcal{B}(b, s)$ be the policy rule for bond holdings of future planners that the SP takes as given and $\{\mathcal{C}(b, s), \mathcal{H}(b, s), \mathbf{v}(b, s), \boldsymbol{\mu}(b, s), \mathcal{Q}(b, s)\}$ the associated recursive functions that return the values of the corresponding variables under that policy rule. Given these functions, the optimization problem of the private agents yields a standard Euler equation for assets (see eq. A.3 of the online appendix), which becomes the following SP's asset pricing implementability constraint

$$\begin{aligned} qu'(c - G(h)) = \beta\mathbb{E}_{s'|s}\{&u'(\mathcal{C}(b', s') - G'(\mathcal{H}(b', s')))[\mathcal{Q}(b', s') \\ &+ z'F_k(1, \mathcal{H}(b', s'), \mathbf{v}(b', s'))] \\ &+ \kappa'\boldsymbol{\mu}(b', s')\mathcal{Q}(b', s')\}. \end{aligned} \tag{11}$$

This expression shows that the b' choice of the planner affects asset prices directly, since it affects date t marginal utility (the denominator of the stochastic discount factor). In addition, the choice of b' affects asset prices indirectly by affecting the bond holdings chosen by future planners, along with their associated future allocations and prices.

As noted earlier, the SP maximizes the utility of the representative firm-household subject to the resource, collateral, and implementability constraints. In addition, the planner faces as constraints the optimality conditions for labor and intermediate goods, and the Kuhn-Tucker conditions associated with the collateral constraint in the DE. We show in section A.3 of the online appendix, however, that these additional constraints are not binding and can thus be ignored. Hence, taking again as given $\{\mathcal{B}(b, s), \mathcal{C}(b, s), \mathcal{H}(b, s), \mathbf{v}(b, s), \boldsymbol{\mu}(b, s), \mathcal{Q}(b, s)\}$, the SP's optimization problem can be represented in recursive form as follows:

$$
\begin{aligned}
\mathcal{V}(b, s) &= \max_{c,b',q,h,v} \{u(c - G(h)) + \beta \mathbb{E}_{s'|s} \mathcal{V}(b', s')\}, \\
c + \frac{b'}{R} &= b + zF(1, h, v) - p^v v, \\
\frac{b'}{R} - \theta p^v v &\geq -\kappa q, \\
q u'(c - G(h)) &= \beta \mathbb{E}_{s'|s} [u'(\mathcal{C}(b', s') - G(\mathcal{H}(b', s')))[\mathcal{Q}(b', s') \\
&\quad + z' F_k(1, \mathcal{H}(b', s'), \mathbf{v}(b', s'))] + \kappa' \boldsymbol{\mu}(b', s') \mathcal{Q}(b', s')].
\end{aligned}
\tag{12}
$$

The economy's resource constraint has the multiplier $\lambda \geq 0$. The collateral constraint has the multiplier $\mu^* \geq 0$, which differs from μ because the private and social values from relaxing the collateral constraint differ. The asset pricing implementability constraint has the multiplier $\xi \geq 0$. As mentioned earlier, this constraint requires the planner to choose allocations such that q satisfies the pricing condition from the private asset market.

Given the definition of the recursive planner's problem, it is straightforward to define the constrained-efficient equilibrium.

DEFINITION. The recursive *constrained-efficient equilibrium* is defined by the policy function $b'(b, s)$ with associated decision rules $c(b, s)$, $h(b, s)$, $v(b, s)$, $\mu(b, s)$, pricing function $q(b, s)$, value function $\mathcal{V}(b, s)$, the conjectured function characterizing the decision rule of future planners $\mathcal{B}(b, s)$ and the associated decision rules $\mathcal{C}(b, s)$, $\mathcal{H}(b, s)$, $\mathbf{v}(b, s)$, $\boldsymbol{\mu}(b, s)$, and asset prices $\mathcal{Q}(b, s)$, such that these conditions hold:

1. Planner's optimization: $\mathcal{V}(b, s)$ and the functions $\{b'(b, s), c(b, s), h(b, s), v(b, s), q(b, s)\}$ solve the Bellman equation defined in problem (12) given $\{\mathcal{B}(b, s), \mathcal{C}(b, s), \mathcal{H}(b, s), \mathbf{v}(b, s), \boldsymbol{\mu}(b, s), \mathcal{Q}(b, s)\}$, and $\mu(b, s)$ satisfies condition (5).
2. Time consistency (Markov stationarity): The conjectured policy rules that represent optimal choices of future planners match the corresponding recursive functions that represent optimal plans of the current regulator: $b'(b, s) = \mathcal{B}(b, s)$, $c(b, s) = \mathcal{C}(b, s)$, $h(b, s) = \mathcal{H}(b, s)$, $v(b, s) = \mathbf{v}(b, s)$, $\mu(b, s) = \boldsymbol{\mu}(b, s)$, and $q(b, s) = \mathcal{Q}(b, s)$.

It is worth clarifying that μ does not appear in the SP's problem (12). Section A.1 of the online appendix shows that the constraint (5) does not bind, and this implies that μ can be obtained directly from (5) after solving problem (12).

D. Comparison of Equilibria

The SP and DE solutions differ in two key respects: First, private agents fail to internalize how borrowing choices made at date t affect asset prices at date $t+1$ in states in which the collateral constraint binds. Second, they also do not take into account that when the collateral constraint binds already at t, date t asset prices can be pushed up to enhance borrowing capacity by changing current borrowing choices or by affecting the decisions of future regulators. We characterize these differences by comparing the optimality conditions for consumption, bonds, and asset prices across the two environments.

The SP's optimality conditions rewritten in sequential form are the following:[6]

$$c_t :: \qquad \lambda_t = u'(t) - \xi_t u''(t) q_t, \tag{13}$$

$$\begin{aligned} b_{t+1} :: \quad u'(t) = {} & \beta R_t \mathbb{E}_t\{u'(t+1) - \xi_{t+1} u''(t+1)\mathcal{Q}_{t+1} + \xi_t \Omega_{t+1}\} \\ & + \xi_t u''(t) q_t + \mu_t^*, \end{aligned} \tag{14}$$

$$q_t :: \qquad \xi_t = \frac{\kappa_t \mu_t^*}{u'(t)}, \tag{15}$$

where Ω_{t+1} collects all the terms with derivatives that capture the effects of the planner's choice of b_{t+1} on q_t via effects on the actions of future planners in the right-hand side of the implementability constraint.[7] The term Ω_{t+1} is composed of three terms. The first captures how an extra unit of b_{t+1} affects future consumption and labor disutility and thus affects the discounting of future asset returns (i.e., future marginal utility) that applies when determining q_t. In our quantitative work, this term is always negative, since $c_{t+1} - G(h_{t+1})$ rises with b_{t+1} and $u'' < 0$. The second term includes the effects by which higher b_{t+1} alters q_t by affecting asset prices and dividends at $t+1$. Numerically, asset prices tend to be increasing in bond holdings, and so this second term is usually positive. The third term captures how changes in b_{t+1} affect the tightness of the collateral constraint at $t+1$, thereby affecting the value of collateral and

[6] These expressions are obtained by assuming that the policy and value functions are differentiable and then applying the standard envelope theorem to the first-order conditions of the planner's problem.

[7] In recursive form,

$$\begin{aligned} \Omega' = {} & u''(\mathcal{C}(b',s') - G(\mathcal{H}(b',s')))\{\mathcal{Q}(b',s') + z'F_k(1,\mathcal{H}(b',s'),\mathbf{v}(b',s'))\} \cdots \\ & \{\mathcal{C}_b(b',s') - G'(\mathcal{H}(b',s'))\mathcal{H}_b(b',s')\} + u'(\mathcal{C}(b',s') - G'(\mathcal{H}(b',s'))) \\ & \times\{\mathcal{Q}_b(b',s') + z'[F_{kh}(1,\mathcal{H}(b',s'),\mathbf{v}(b',s'))\mathcal{H}_b(b',s') + F_{kv}(1,\mathcal{H}(b',s'),\mathbf{v}(b',s'))\mathbf{v}_b(b',s')]\} \\ & + \kappa'[\boldsymbol{\mu}_b(b',s')\mathcal{Q}(b',s') + \boldsymbol{\mu}(b',s')\mathcal{Q}_b(b',s')]. \end{aligned}$$

asset prices at t. This third effect is negative. These three effects imply that the sign of Ω_{t+1} is ambiguous, but numerically we find that $\Omega_{t+1} < 0$, implying that the planner has higher incentives to borrow at the margin when the constraint binds.

Next we compare the optimality conditions of the SP and DE. Compare first the condition for c_t. The planner's condition is equation (13), while the corresponding condition in the DE takes the standard form $\lambda_t = u'(t)$. Thus, the shadow value of wealth for the private agent is simply the marginal utility of current consumption, while the social shadow value of wealth adds the amount by which an increase in c_t reduces marginal utility and relaxes the implementability constraint.[8] Moreover, condition (15) shows that the social benefit from relaxing the implementability constraint is positive at date t if and only if the collateral constraint binds for the social planner at t, that is, $\mu^* > 0 \Leftrightarrow \xi_t > 0$. These two conditions together show that, when the collateral constraint binds, the marginal social benefit of wealth of an extra unit of c_t considers how the extra consumption raises equilibrium asset prices, which in turn relaxes the collateral constraint; that is, using (15), the last term on the right-hand side of (13) becomes $-u''(t)q_t[\kappa_t\mu_t^*/u'(t)]$. If the collateral constraint does not bind, $\mu_t^* = \xi_t = 0$ and the shadow values of wealth in the DE and SP coincide.

Compare next the SP's generalized Euler equation for bonds (14) with the corresponding Euler equation in the DE. This comparison highlights the two main properties that distinguish the DE and SP outcomes.

1. *Effects via* q_{t+1}: Condition (14) indicates that the differences identified above in the private and social marginal utilities of wealth, which are differences in marginal benefits of bond holdings "ex post" when the collateral constraint binds, induce differences "ex ante," when the constraint is not binding. In particular, if $\mu_t = 0$, the marginal cost of increasing debt at date t in the DE is the standard term $\beta R_t \mathbb{E}_t u'(t+1)$. In contrast, the second term in the right-hand side of (14) shows that the marginal social cost of borrowing is higher, because the SP internalizes the effect by which the larger debt at t reduces borrowing ability at $t+1$ if the credit constraint binds then. We can use (15) again to make this evident by rewriting the second term in the right-hand side of (14) as $-u''(t+1)q_{t+1}[\kappa_{t+1}\mu_{t+1}^*/u'(t+1)]$, which is positive for $\mu_{t+1}^* > 0$. Intuitively, since the planner values more consumption when the constraint binds ex post, it borrows less ex ante (i.e., there is overborrowing in the DE relative to the SP).

2. *Effects via* q_t: The two Euler equations for bonds also differ in that condition (14) includes effects that reflect the SP's ability to induce

[8] Note that $-\xi_t u''(t)q_t > 0$ because $u''(\cdot) < 0$ and $\xi_t > 0$, as condition (15) implies. Hence, $\lambda_t > u'(t)$.

changes in current asset prices when the constraint binds at t (i.e., $\mu_t > 0$). There are two effects of this kind: First, the term $\xi_t u''(t) q_t$ shows that, when $\mu_t > 0$, the SP internalizes that increasing c_t raises q_t and provides more borrowing capacity. This effect, when present, reduces the social marginal benefit of savings. Second, since the planner cannot commit to future policies, it takes into account how future planners respond to changes in its debt choice (which is a state variable of the next period's planner). As explained above, the derivatives of the future decision rule and pricing function with respect to b_{t+1} are included in Ω_{t+1} and are relevant only when $\mu_t > 0$; otherwise they vanish. Since Ω_{t+1} has an ambiguous sign, this effect can either increase or reduce the social marginal benefit of savings.

Notice a key difference between the q_t and q_{t+1} effects: The latter is relevant only when the constraint has a positive probability of becoming binding at $t + 1$, while the former are relevant only when the constraint is binding at t. Bianchi and Mendoza (2010) and Jeanne and Korinek (2010) study only the effects via q_{t+1}, but the above discussion suggests that the effects operating via q_t should also be part of the analysis.

E. *Decentralization of the Planner's Allocations*

We show now that the SP's equilibrium can be decentralized with a state-contingent tax on debt τ_t.[9] The price of bonds becomes $1/[R_t(1 + \tau_t)]$ in the budget constraint of the private agent in the regulated competitive equilibrium, and there is also a lump-sum transfer T_t rebating tax revenue.[10] The agents' Euler equation for bonds becomes

$$u'(t) = \beta R_t(1 + \tau_t)\mathbb{E}_t u'(t + 1) + \mu_t. \tag{16}$$

Analyzing the SP's optimality conditions together with those of the regulated and unregulated DE leads to the following proposition.

Proposition 1 (Decentralization with debt taxes). The constrained-efficient equilibrium can be decentralized with a state-contingent tax on debt with tax revenue rebated as a lump-sum transfer and the tax rate set to satisfy

$$\begin{aligned} 1 + \tau_t = {} & \frac{1}{\mathbb{E}_t u'(t + 1)} \mathbb{E}_t[u'(t + 1) - \xi_{t+1} u''(t + 1)\mathcal{Q}_{t+1} + \xi_t \Omega_{t+1}] \\ & + \frac{1}{\beta R_t \mathbb{E}_t u'(t + 1)} [\xi_t u''(t) q_t], \end{aligned}$$

[9] Following Bianchi (2011), it is also possible to decentralize the planner's problem using measures targeted directly to financial intermediaries, such as capital requirements, reserve requirements, or loan-to-value ratios.

[10] The tax can also be expressed as a tax on the income generated by borrowing, so that the posttax price would be $(1 - \tau_t^R)(1/R_t)$. The two treatments are equivalent if we set $\tau_t^R = \tau_t/(1 + \tau_t)$.

where the arguments of the functions have been shorthanded as dates to keep the expression simple.

Proof. See section A.2 of the online appendix.

The optimal tax schedule has two components that match the q_t and q_{t+1} effects on the social marginal benefit of savings identified in the SP's Euler equation: The first matches the pecuniary externality via q_{t+1} and is a component denoted the *macroprudential debt tax,* τ^{MP}, which is a tax levied only when the collateral constraint is not binding at t but may bind with positive probability at $t + 1$. Thus, this tax hampers credit growth in good times to lower the risk of future financial instability. Using (15), the macroprudential debt tax reduces to

$$\tau_t^{MP} = \frac{-\mathbb{E}_t[\xi_{t+1} u''(t+1)\mathcal{Q}(t+1)]}{\mathbb{E}_t[u'(t+1)]}. \tag{17}$$

We can also demonstrate that this tax is nonnegative. It is zero whenever the constraint is not expected to bind at $t + 1$, but otherwise it is strictly positive, since $u' > 0$, $u'' < 0$, and $\xi \geq 0$.

The second component of the optimal debt tax is formed by the two terms that match the effects operating through q_t and hence are present only if the collateral constraint binds at t. Since the term $\xi_t u''(t) q_t$ is negative, it pushes for a debt subsidy; but since the term with Ω_{t+1} has an ambiguous sign, the combined effect also has an ambiguous sign, and thus the second component of the tax can be positive or negative.

The above optimal policy analysis modeled the SP as choosing allocations and bonds directly subject to an implementability constraint and showing that those allocations can be decentralized using debt taxes. In section A.3 of the online appendix, we demonstrate that the same outcome can be obtained if we model instead the planner as choosing directly optimal debt taxes under discretion facing allocations and prices that are competitive equilibria. In particular, we show that this approach yields the same allocations and the same taxes. In addition, we also study in section A.4 of the online appendix a case in which debt taxes are restricted to be positive. This is interesting because the optimal τ_t we derived could be negative, which would require introducing other forms of taxation to finance subsidies, particularly lump-sum taxes. Our results show that the optimal macroprudential debt tax τ_t^{MP} has the same form as the one we derived here.

While it was possible to characterize theoretically the differences in the optimality conditions of the DE and SP, the optimal debt tax, and the sign of the macroprudential debt tax, comparing the levels of debt and asset prices in the two equilibria is possible only via numerical simulation. Still, we can develop some intuition using elements of this analysis.

Borrowing decisions and asset prices are related, both when the collateral constraint binds and when it does not. When it binds, it is obvious that higher asset prices support higher debt. When it does not bind, expectations of higher asset prices reduce the need to build precautionary savings and lead to higher borrowing, since collateral constraints are expected to be more relaxed. Hence, understanding differences in asset prices is key for understanding differences in debt choices across the DE and SP. In turn, given the asset pricing condition, differences in expected asset returns are key for understanding how prices differ, and these differences can be characterized analytically.

Expected returns in the DE are characterized by the condition we derived for the equity premium (eq. [9]). The planner's excess returns are given by the following expression, which follows from applying the same treatment to the SP's optimality conditions as we did in the DE:

$$R_t^{ep} = \underbrace{\frac{\mu_t + \xi_t u''(t) q_t + \beta R_t \mathbb{E}_t \xi_t \Omega_{t+1}}{u'(t)\mathbb{E}_t m_{t+1}}}_{\text{Liquidity Premium}} - \underbrace{\frac{\mathbb{E}_t(\phi_{t+1} m_{t+1})}{\mathbb{E}_t m_{t+1}}}_{\text{Collateral Premium}} - \underbrace{\frac{\mathrm{cov}_t(m_{t+1}, R_{t+1}^q)}{\mathbb{E}_t m_{t+1}}}_{\text{Risk Premium}} - \underbrace{\frac{\beta R_t \mathbb{E}_t(\xi_{t+1} u''(t+1) \mathcal{Q}_{t+1})}{u'(t)\mathbb{E}_t m_{t+1}}}_{\text{Externality Premium}}. \tag{18}$$

Excess returns for the SP differ from those for the DE in two respects. First, they carry an externality premium, because the SP internalizes the q_{t+1} effects of borrowing decisions. In fact, simplifying further this premium reduces it to $R_t \tau_t^{MP}$, which is intuitive because the macroprudential tax rate is equal to the magnitude of the wedge the q_{t+1} effect drives into the SP's Euler equation for bonds relative to the DE. Second, the SP's liquidity premium includes two terms absent from the liquidity premium in the DE, which are related to the SP's effects on q_t when the constraint binds at t. As noted before, the first of these terms is negative, which lowers the return on assets, and the second term has an ambiguous sign. In addition to these first-order effects via the externality and liquidity premia, there are also second-order effects operating via endogenous changes in all four premia in the SP's excess returns, since the SP has a stronger precautionary-savings motive and supports allocations and prices that produce less risk.

The net effect of the four premia in the SP's returns can increase or decrease asset prices in the economy with regulation versus the DE. First, the externality premium pushes asset returns higher and asset prices lower, which tilts the portfolio toward bonds and away from risky assets. Second, the additional terms in the liquidity premium can push returns higher or lower, since their combined value has an ambiguous sign. Third, the second-order effects via changes in precautionary savings and risk can have ambiguous effects too, since higher demand for bonds weakens demand for assets, lowering their price; but lower risk premia reduce expected returns, increasing asset prices.

Quantitatively, under our baseline calibration, expected returns are generally higher, asset prices lower, and debt smaller for the SP than for the DE, and particularly so in the good-times regions of the state space in which the macroprudential tax is used. In contrast, during financial crises (which become very infrequent under the optimal policy) returns are significantly lower, prices higher, and debt higher for the SP than for the DE (see sec. J of the online appendix for a detailed comparison of the quantitative asset pricing features of both economies). The lack of commitment is important for these results too. Under commitment, as we describe below, the planner considers how borrowing at any date t affects asset prices in previous periods, which creates a force to sustain higher asset prices even when the constraint does not bind.

F. Time Inconsistency under Commitment

We focused on studying optimal policy without commitment because we found that the problem under commitment yields time-inconsistent optimal plans.[11] A comprehensive analysis of this issue is beyond the scope of this paper, but we provide here the argument that shows why optimal policy under commitment is time inconsistent. Section E of the online appendix provides a detailed description of the planner's optimization problem under commitment and a numerical example.

The planner chooses at date 0 policy rules in a once-and-for-all fashion. In contrast with the problem without commitment, we found that under commitment we do need to carry as constraints the optimality conditions of factor allocations and the Kuhn-Tucker conditions associated with the collateral constraint in the DE, because it cannot be guaranteed that they are always nonbinding. The first-order conditions for consumption, bond holdings, and asset prices in sequential form are the following:[12]

$$c_t :: \qquad \lambda_t = u'(t) - \xi_t u''(t) q_t + \xi_{t-1} u''(t)[q_t + z_t F_k(t) + \kappa_t \mu_t q_t], \qquad (19)$$

$$b_{t+1} :: \qquad \lambda_t = \beta R_t \mathbb{E}_t \lambda_{t+1} + \mu_t^* + \mu_t \nu_t, \qquad (20)$$

[11] This time inconsistency problem does not arise in Lorenzoni's (2008) classic model of fire sales because in his model the asset price is determined by a static condition linking relative productivity of households and entrepreneurs rather than expectations about future marginal utility. Similarly, in Bianchi (2011), borrowing capacity is determined by a static price of nontradable goods.

[12] The problem has seven Lagrange multipliers, but in these first-order conditions only four appear: λ_t; μ_t^*; ξ_t, which are assigned to the same constraints as in the problem without commitment; and ν_t, which is the multiplier assigned to the constraint that requires the complementary slackness condition of the DE to hold.

$$q_t :: \qquad \xi_t = \xi_{t-1}(1 + \kappa_t \mu_t) + \frac{\kappa_t(\mu_t \nu_t + \mu_t^*)}{u'(t)}. \tag{21}$$

The time inconsistency problem is evident from the presence of the lagged multipliers in the first and third conditions.[13] According to (19), the planner internalizes how an increase in consumption at time t helps relax the borrowing constraint at time t and makes it tighter at $t-1$. As (21) shows, this implies that the Lagrange multiplier on the implementability constraint ξ_t follows a positive, nondecreasing sequence, which increases every time the constraint binds. Intuitively, when the constraint binds at t, the planner promises lower future consumption so as to prop up asset prices and borrowing capacity at t, but ex post when $t+1$ arrives it is suboptimal to keep this promise. In line with this intuition, we found in the numerical example of the online appendix that the planner with commitment supports higher asset prices and higher debt than in the DE (which is the opposite of what we found vis-à-vis the SP without commitment).

Section E of the online appendix also shows that state-contingent debt taxes can still be used to decentralize the solutions of the problem under commitment as a competitive equilibrium, except that again this is a noncredible policy because of the time inconsistency of the planner's optimal plans. The macroprudential component of this tax has the same form as in the problem without commitment only if the collateral constraint has never been binding up to date t and is expected to bind with some probability at $t+1$. Otherwise, even if it does not bind at t, the optimal macroprudential taxes differ with and without commitment.

III. Quantitative Analysis

This section studies the model's quantitative implications by conducting numerical simulations for a baseline calibration. The first part describes the calibration and the rest discusses the results.

A. *Calibration*

We calibrate the model to annual frequency using data for all OECD countries between 1984 and 2012.[14] For some variables (e.g., housing

[13] It should be understood that time $t-1$ variables include the history up to time $t-1$ and time t variables represent the history up to time $t-1$ in addition to time t exogenous disturbances.

[14] We include all 34 OECD countries for simplicity. The cross-country averages of national accounts ratios and time-series moments used to calibrate the model change only slightly excluding the nine OECD emerging economies. The data were gathered from OECD National Accounts Statistics and the United Nations UNdata.

wealth and working capital), we used only US data because of data availability limitations.

The functional forms for preferences and technology are the following:

$$u(c - G(h)) = \frac{\left(c - \chi \frac{h^{1+\omega}}{1+\omega}\right)^{1-\sigma} - 1}{1-\sigma}, \qquad \omega, \chi > 0, \sigma > 1,$$

$$F(k, h, v) = e^{z} k^{\alpha_k} v^{\alpha_v} h^{\alpha_h}, \quad \alpha_k, \alpha_v, \alpha_h \geq 0, \quad \alpha_k + \alpha_v + \alpha_h \leq 1.$$

Total factor productivity (TFP) and R follow independent AR(1) processes.[15] TFP shocks follow an AR(1) process: $z_t = \bar{z} + \rho_z z_{t-1} + \varepsilon_t$ with $\varepsilon_t \sim N(0, \sigma_\varepsilon)$ and $\bar{z}$ normalized so that output equals one when $z = \bar{z}$ assuming that the collateral constraint is not binding. The AR(1) process for the logged gross real interest rate is $\ln(R_t) = (1 - \rho_R)\bar{R} + \rho_R \ln(R_{t-1}) + \varsigma_t$ with $\varsigma_t \sim N(0, \sigma_\varsigma)$. These shocks are discretized using Tauchen's quadrature method with three realizations for each shock. The collateral coefficient κ follows a standard two-state, regime-switching Markov process with $\{\kappa^L < \kappa^H\}$, where κ^H represents a normal credit regime and κ^L is a regime with unusually tight credit conditions, in the sense that switches from κ^H to κ^L are infrequent and the mean duration of the κ^L regime is low. For simplicity, this process is assumed to be independent from the Markov processes of z and R. The continuation transition probabilities are denoted $P_{L,L}$ and $P_{H,H}$ for κ^L and κ^H, respectively, and the long-run probabilities are given by $P^L = P_{H,L}/(P_{L,H} + P_{H,L})$ and $P^H = P_{L,H}/(P_{L,H} + P_{H,L})$. The mean durations are $1/P_{L,H}$ and $1/P_{H,L}$ for κ^L and κ^H, respectively.

The calibration proceeds in two steps. First, a subset of parameter values are set using direct empirical evidence or standard values from the literature. Second, given these parameter values, the remaining six parameters are simultaneously determined by solving the model to target jointly six moments from the data.

In the first step, we set the parameters of the R process, the values of the two κ regimes, and the values of $\{\sigma, \omega, \alpha_h, \theta, \alpha_v, \chi\}$. To calibrate the interest rate process, we follow the standard approach in the international macro literature of measuring the world real interest rate using the annualized ex post real return on 90-day US T-bills. This yields $\bar{R} = 1.01$, $\rho_R = 0.68$, and $\sigma_\varsigma = 1.38$ percent.

The values of the credit regimes are set to $\kappa^L = 0.75$ and $\kappa^H = 0.9$. These values are consistent with evidence on loan-to-value (LTV) ratios for both households and firms in the United States and abroad during the financial crisis and prior to the crisis. Demyanyk and Hemert (2011) and

[15] This assumption is in line with the observation that the Basu-Fernald US Solow residual estimates are uncorrelated with the US real interest rate on 90-day T-bills.

Duca and Murphy (2011) show that US mortgage LTV ratios peaked at about 0.9 in the run-up to the crisis; hence we set $\kappa^H = 0.9$. Favilukis, Ludvigson, and Van Nieuwerburgh (2010) note that there was a significant drop in LTV ratios during the crisis, down to maximum values in the 0.75–0.8 range. These LTV ratios are also in the range of cross-country estimates reported by Nguyen and Qian (2012). They report LTVs for both firms and households ranging between 0.72 and 0.9 based on firm-level survey data from the World Bank Enterprise Survey.

The constant relative risk aversion (CRRA) coefficient is set to $\sigma = 1$, which is commonly used in open-economy dynamic stochastic general equilibrium models. The Frisch elasticity of labor supply ($1/\omega$) is set equal to two, in the range of estimates typically used in macro models (see Keane and Rogerson 2012). The parameter χ is set so that mean hours are equal to one, which requires $\chi = \alpha_h$ (with α_h calibrated as described below).

Using national accounts data for all OECD members, we obtained a GDP-weighted average of the ratio of total intermediate goods to gross output of about 0.45 in the 1980–2012 period. Hence we set $\alpha_v = 0.45$. The share of labor in gross output is then set so that it yields the standard OECD labor share in GDP of 0.64 (see Stockman and Tesar 1995). This implies $\alpha_h = 0.64(1 - \alpha_v) = 0.352$.

The value of θ is set to be consistent with an empirical estimate of working capital financing based on cross-sectional US data for 2013 from the Federal Reserve. In particular, we measure working capital as the sum of trade credit liabilities of nonfinancial businesses from the Flow of Funds data set, plus the total of commercial and industrial loans extended by commercial banks with maturity of less than 1 year, from the Survey of Terms of Business Lending. This yields an estimate of 13.3 percent of GDP for total working capital financing. Hence, since total working capital as a share of GDP in the model is given by $\theta p_v v/[F(k, h, v) - p_v v]$ and the ratio of total intermediate goods to GDP in US data for 2013 was 0.8, it follows that $\theta = 0.133/.8 = 0.16$.

The second stage of the calibration sets the values of $\{\rho_z, \sigma_\varepsilon, \alpha_k, \beta, P_{L,L}, P_{H,L}\}$. The values of these six parameters are set jointly so that the DE solution matches the corresponding six target moments from the data listed in table 1.

The values of ρ_z and σ_ε are targeted to match the average autocorrelation and standard deviation of the linearly detrended cyclical component of output across all OECD countries in the 1984–2010 period. The average standard deviation is 0.05 and the average autocorrelation is 0.76. Matching these moments requires setting the autocorrelation of TFP $\rho_z = 0.78$ and the volatility of TFP to $\sigma_\varepsilon = 1.0$ percent.

The target for setting the value of β is an estimate of the net foreign asset position (NFA) as a share of GDP that excludes the government sector

TABLE 1
CALIBRATION

Parameters Set Independently	Value	Source/Target
Risk aversion	$\sigma = 1$	Standard value
Share of inputs in gross output	$\alpha_v = 0.45$	Cross-country average OECD
Share of labor in gross output	$\alpha_h = 0.352$	OECD GDP labor share = 0.64
Labor disutility coefficient	$\chi = 0.352$	Normalization to yield average $h = 1$
Frisch elasticity	$1/\omega = 2$	Keane and Rogerson (2012)
Working capital coefficient	$\theta = 0.16$	US working capital/GDP ratio = 0.133
Tight credit regime	$\kappa^L = 0.75$	US postcrisis LTV ratios
Normal credit regime	$\kappa^H = 0.90$	US precrisis LTV ratios
Interest rate process	$\bar{R} = 1.1\%$, $\rho_R = 0.68$ $\sigma_R = 1.86\%$	US 90-day T-bills
Parameters Set by Simulation	**Value**	**Target**
TFP process	$\rho_z = 0.78$, $\sigma_\varepsilon = 0.01$	OECD average for standard deviation and autocorrelation of GDP
Share of assets in gross output	$\alpha_k = 0.008$	Value of collateral matches total credit
Discount factor	$\beta = 0.95$	NFA = −25%
Transition probability κ^H to κ^L	$P_{H,L} = 0.1$	4 crises every 100 years (see online app. F2)
Transition probability κ^L to κ^L	$P_{L,L} = 0$	1-year duration of crises (see online app. F2)

(since government is not included in the model).[16] This estimate was constructed using US data from the Flow of Funds data set for 2013. We did not target the time-series average because the US NFA-GDP ratio has displayed a marked downward trend since the early 1980s as a result of the Global Imbalances phenomenon. Since the Flow of Funds data provide a breakdown of domestic versus foreign financing only in terms of the overall funding for the total domestic nonfinancial sectors, which includes the government, we compute first the fraction of the net credit liabilities of the domestic nonfinancial sectors financed by the rest of the world (0.2) and then apply this fraction to the total net credit liabilities of the private domestic nonfinancial sectors (−1.21), which yields a private NFA position of $0.2 \times (-1.21) = -0.249$ as a share of GDP. The model's

[16] We also control for the absence of government purchases by deducting a time- and state-invariant amount of autonomous expenditures in the resource and budget constraints, calibrated to match the 16 percent average share of government expenditures in GDP in US data over the 1984–2012 period.

decentralized equilibrium yields an unconditional mean of b as a share of GDP that matches this ratio with $\beta = 0.95$.

In setting the share of capital in value added, we cannot follow the standard approach of setting it to the observed share of about one-third, because this estimate includes capital income accrued to the entire capital stock, while the model considers only capital that is in fixed supply. Instead, we set the capital share so that the value of assets usable as collateral can support levels of leverage comparable with those observed in the data (i.e., the values in the interval defined by κ^L and κ^H). In particular, we set α_k so that the collateral constraint in the κ^L regime holds with equality when evaluated at the unconditional averages of asset prices, debt, and working capital. That is, we adjust α_k until this condition holds: $E[q_t] = -E[b_{t+1} + \theta p_v v_t]/\kappa^L$. Given the NFA target of -24.9 percent of GDP, the working capital estimate of 13.3 percent of GDP, and the value of κ^L, the condition holds when $\alpha_k = 0.008$.[17]

Finally, we calibrate the transition probabilities of the credit regime-switching process so as to match the frequency and duration of financial crises in the data. To construct estimates of these two statistics, we applied the methodology proposed by Forbes and Warnock (2012) to identify the timing and duration of sharp changes in financial conditions. A financial crisis is defined as an event in which the linearly detrended current account is above two standard deviations from its mean. Since the current account is the overall measure of financing of the economy vis-à-vis the rest of the world, the unusually large current accounts represent unusually large drops in foreign financing. The starting (ending) dates of the events are set in the year within the previous (following) 2 years in which the current account first rose (fell) above (below) one standard deviation. Using the data for all OECD countries over the 1984–2012 period, we obtained financial crises with a frequency of 4 percent and a mean duration of 1 year. The model calibrated with $P_{L,L} = 0$ and $P_{H,H} = 0.9$, and applying the same criteria to define financial crises and their duration, yields financial crises with a frequency of 3.8 percent and a mean duration of 1 year.

The model is solved using a global, nonlinear solution algorithm taking into account the occasionally binding, stochastic credit constraint. The DE solution is obtained using a time iteration algorithm. In the SP's problem, we use a nested fixed-point algorithm: In the inner loop, we solve for policy functions and value functions using value function iteration,

[17] This value is similar to what would be obtained if we impose the same average price of the baseline calibration in a deterministic steady state in which the constraint is not binding. In this case, the steady-state pricing condition implies $q = \alpha_k(1 - \beta)$, and using the same average price and the same value of β as in the baseline calibration would imply $\alpha_k = 0.012$. Risk and binding borrowing constraints alter the implied value of α_k.

given future policies. In the outer loop, we update future policies given the solution to the Bellman equation, which ensures Markov stationarity. Further details are provided in section B of the online appendix.

B. Financial Crises Dynamics

In order to analyze the model's ability to generate financial crises and the effectiveness of the optimal policy at reducing the frequency and severity of crises, we conduct an event analysis of model-simulated data for the DE and SP economies. We examine averages across financial crises events in a long time-series simulation, defining crises in the same way as in the data.[18]

The first important result of this event analysis is that the time-consistent macroprudential policy reduces significantly the frequency of crises. The model was calibrated so that the DE matches the 4 percent crises frequency observed in the data. Under the same calibration, the frequency of crises in the SP is only 0.02 percent. Thus, financial crises become extremely rare under the optimal policy.[19]

The ability of the DE to generate financial crises and the effect of the optimal policy on their severity are illustrated by constructing event windows with the simulated data comparing the DE and SP. The results are presented in figure 1, which shows 9-year event windows for total credit (bonds plus working capital) as a share of GDP, asset prices, output, and consumption, as well as windows that show the evolution of the exogenous shocks.

We construct comparable event windows for the two economies following this procedure: First, we simulate the DE for 100,000 periods and identify financial crises using the event study methodology we borrowed from the empirical literature described earlier. Second, we construct 9-year event windows centered at the crisis year, denoted date t, by computing averages for each variable across the cross section of crisis events at each date. This produces the DE dynamics plotted as the red, continuous lines in figure 1. Third, we take the initial bond position at $t-5$ of the DE and the sequences of shocks the DE went through in the 9-year window, and we pass them through the policy functions of the SP. Finally, we average in

[18] In sec. G of the online appendix we follow a different approach and examine instead the DE's predicted time-series dynamics for the global financial crisis using a window spanning the 2000–2009 period and compare these dynamics with US and European data and with what the event would have looked like under the optimal policy.

[19] We identify financial crises for the SP using the credit thresholds of the DE in levels. Recomputing the thresholds using the standard deviation of credit in the SP, which is smaller, the frequency of crises rises slightly but remains much lower than in the DE. Our results are also largely robust to alternative crisis definitions.

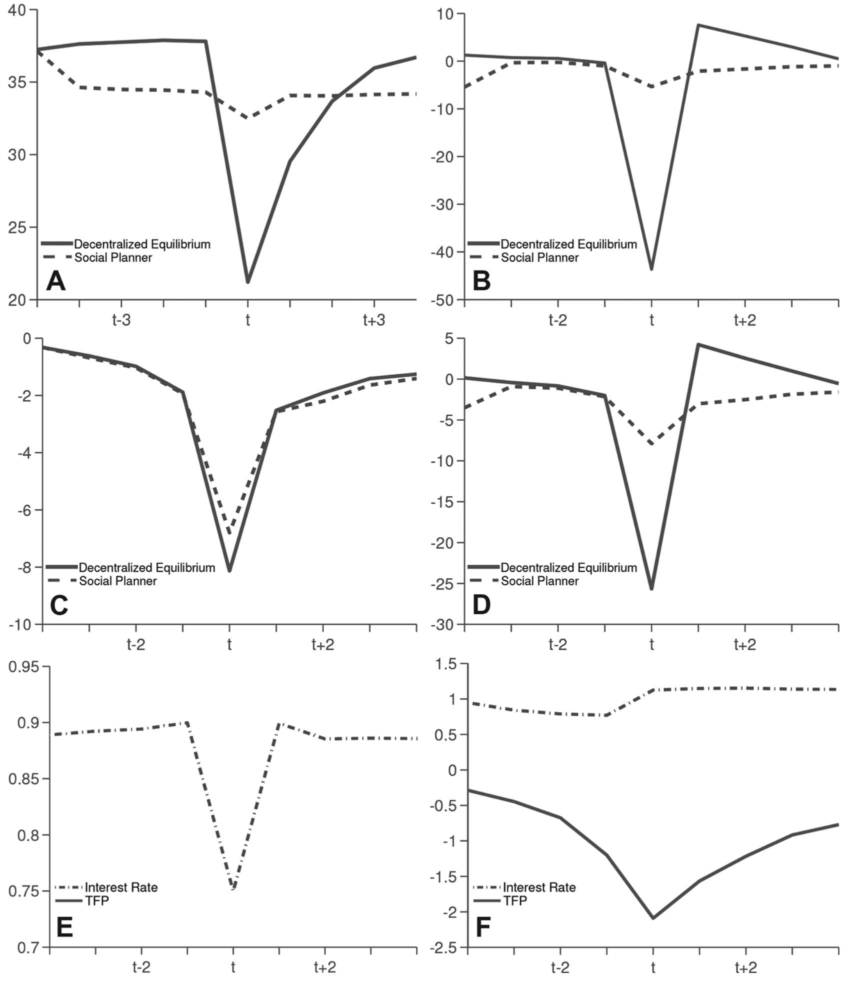

FIG. 1.—Comparison of crises dynamics. Panel A shows the credit-GDP ratio in percent. Panels B (asset price), C (output), D (consumption), and F (TFP and interest rate shocks) are plotted as percentage differences relative to unconditional averages. Panel E shows mean financial shock. Color version available as an online enhancement.

each date the cross-sectional sample of the SP to generate the averages shown as the blue, dashed line in figure 1.

Panel A of figure 1 shows that the pecuniary externality results in significant overborrowing in the DE in the periods before the crisis. At $t-5$ both DE and SP start from the same credit-GDP ratio by construction. But starting at $t-4$, and for the rest of the precrisis years, credit under the SP is roughly 3 percentage points of GDP below the DE average. In contrast, credit in the DE rises in the years before the crises, peaking at about 38 percent of GDP. As a result of this overborrowing, the DE builds up more leverage and experiences a larger collapse in credit when a financial crisis hits. Credit falls almost 18 percentage points of GDP in the DE between $t-1$ and t versus 1.5 percentage points in the SP; and although it rises at a fast pace after the crisis, 4 years later it remains below its long-run average. Note, however, that by then the DE is again generating more credit than the SP.[20]

Asset prices (panel B), output (panel C), and consumption (panel D) also fall more sharply in the DE than in the SP. The declines in consumption and asset prices are particularly larger (-26 vs. -8 percent for consumption and -43.7 vs. -5.4 percent for asset prices). The asset price collapse plays an important role in explaining the more pronounced decline in credit in the DE, because it reflects the full impact of the Fisherian deflation. Output falls almost 2 percentage points more in the DE than in the SP because of the higher shadow price of inputs produced by the tighter binding constraint on access to working capital.

Panel E shows that financial crises are preceded largely by regimes with κ^H and coincide with regime switches to κ^L. Panel F shows that TFP is declining, on average, before financial crises and reaches a trough of about 2 percent below the mean when a crisis hits; after that it recovers. The real interest rate falls slightly on average before financial crises and then rises about 50 basis points when crises occur and remains stable in the years after. Thus, financial crises in the DE are associated, on average, with adverse TFP, interest rate, and financial shocks. Note, however, that the model also generates crises with positive TFP shocks when leverage is sufficiently high and an adverse financial shock hits.

Summing up, this event analysis delivers two main results: First, financial amplification driven by the Fisherian mechanism is strong in the model, producing financial crises with deep recessions.[21] Second, the pecuniary externality is quantitatively large, resulting in an optimal policy that is very effective at reducing the magnitude and frequency of crises.

Table 2 shows additional statistics that summarize the effectiveness of the optimal policy. In addition to the reductions in the probability of crises and the asset price collapse during a crisis documented above, this table shows that the excess return on assets averages 4.8 percent during financial crises in the DE versus 0.8 percent in the SP. About half of the large excess return in the DE is due to the collateral effect identified in equation (9), and the rest is due to the liquidity and risk premia. The average debt tax over the entire state space is 3.6 percent.

[20] The model produces large credit drops partly because all intertemporal credit is in the form of one-period bonds, whereas loans in the data have, on average, a longer maturity.

[21] Mendoza (2010) shows that this holds also in models with capital accumulation.

TABLE 2
Summary Statistics

	Decentralized Equilibrium	Social Planner
Crisis statistics:		
Probability of crisis	4.0	.02
Asset price drop	−43.7	−5.4
Equity premium	4.8	.7
Mean tax and welfare gains:		
Macroprudential debt tax		3.6
Welfare gains		.30

Note.—The price drop and equity premium are averages conditional on financial crises events. The debt tax and welfare gains are unconditional averages over the model's limiting distribution of bonds and shocks.

The welfare gain of the optimal policy is 30 basis points on average. To compute these welfare gains, we calculate standard compensating consumption variations for each initial state (B, s) that equalize expected utility across the DE and SP. Formally, for a given initial state (B, s) at date 0, the welfare effect of the optimal policy is computed as the value of $\gamma(B, s)$ that satisfies this condition:

$$\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t u(c_t^{DE}(1+\gamma) - G(h_t^{DE})) = \mathbb{E}_0\sum_{t=0}^{\infty}\beta^t u(c_t^{SP} - G(h_t^{SP})). \qquad (22)$$

The mean welfare gain of 30 basis points reported in table 2 is the average $\gamma(B, s)$ computed with the DE's ergodic distribution. In Section III.D, we analyze the variation of the welfare gains across (B, s) pairs.

The welfare gains of the optimal policy arise from two sources: first, the reduced variability of consumption in the SP versus the DE, because the credit constraint binds more often in the DE, and when it binds it induces a larger adjustment in asset prices and consumption; second, the efficiency loss in production that occurs in the DE because of the effect of the credit friction on working capital and factor allocations. Again, since the collateral constraint binds more often in the DE than in the SP, there is a larger efficiency loss in the former.

C. *Borrowing Decisions and Amplification*

The manner in which the optimal policy reduces amplification and tackles the pecuniary externality can be illustrated by comparing borrowing decisions across the DE and SP. Figure 2 shows the decision rules for bonds $\mathcal{B}^{DE}(B, s)$ and $\mathcal{B}^{SP}(B, s)$ as the red continuous and blue dashed curves, respectively. Bond choices for $t+1$ (B') are shown in the vertical axis as functions of bond holdings at t in the horizontal axis (B), for val-

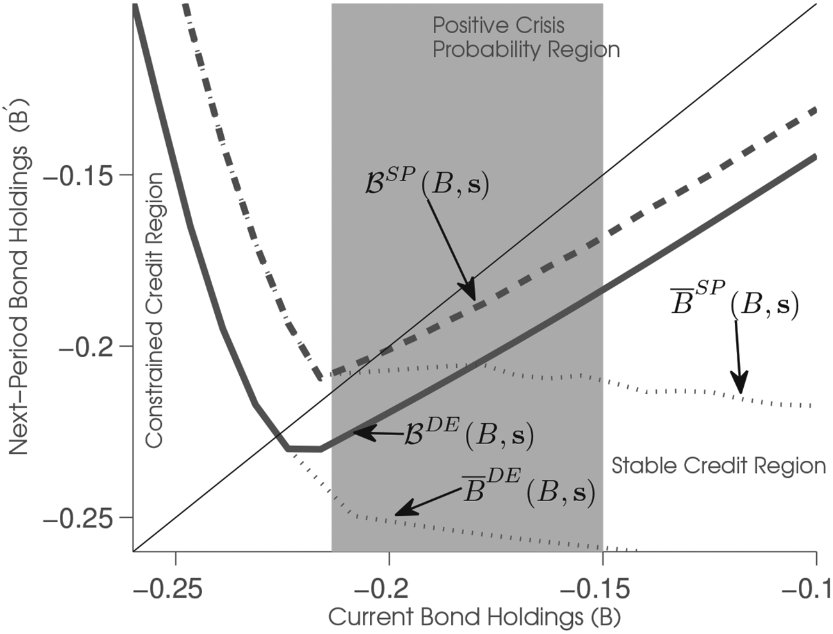

FIG. 2.—Bond decision rules and borrowing limits. Color version available as an online enhancement.

ues of the shocks set to κ^L, high R, and average TFP. The figure also shows the debt limits of each economy ($\bar{\mathcal{B}}^{DE}(B, s)$ and $\bar{\mathcal{B}}^{SP}(B, s)$).[22]

The bond decision rules are divided into three regions: The leftmost region is the *constrained credit region*, which is defined by the values of B that represent sufficiently high initial debt (low B) such that the collateral constraint already binds for the SP. The center region is the *positive crisis probability region*. This region is characterized by financial instability, in the sense that the constraint is not binding at t, but values of B' chosen by private agents in the DE are low enough so that for some values of the shocks at $t + 1$ the collateral constraint binds. As shown in Section II, this is the region in which the regulator uses the macroprudential debt tax. At equilibrium, the long-run probability of observing states in this region is almost 94 percent in the SP solution. Hence, while crises are near-zero probability events under the optimal policy, macroprudential debt taxes are used nearly all the time. Finally, the rightmost region is the *stable credit region*, where B is high enough so that both the constraint is not binding at t and the probability of hitting it next period is zero for both DE and SP.

The V-shaped bond decision rules are a feature of financial frictions models that incorporate a strong Fisherian deflation mechanism. This

[22] These limits are defined as $-\kappa q^{DE}(B, s) + p_v \hat{v}^{DE}(B, 1, B, s)$ and $-\kappa q^{SP}(B, s) + p_v \hat{v}^{SP}(B, s)$.

is in contrast with standard Bewley-style incomplete-markets models of heterogeneous agents and real business cycle models of the small open economy, both of which produce monotonically increasing decision rules. The point at which the decision rules switch slope corresponds to the value of B at which the collateral constraint is marginally binding in each economy (i.e., it holds with equality, but the choice of debt is exactly the same debt allowed by the credit constraint). To the right of this point, the collateral constraint does not bind and the decision rules are upward sloping. To the left of this point, the decision rules are sharply decreasing in B, because a reduction in B results in a sharp fall in asset prices caused by the Fisherian deflation mechanism, which tightens the borrowing constraint, thus increasing B'. In line with these results, the decision rules lie above their corresponding borrowing limits to the right of the values of B at which the constraint becomes binding, and to the left the decision rules must be equal to their corresponding borrowing limits.

A second, and more important, feature of the bond decision rules from the perspective of the normative analysis is that the SP's decision rule is uniformly higher than in the DE for all values of B (i.e., there is "overborrowing" in the DE relative to the SP in all three regions). Recall, however, that as we explained in Section II, prices and bond choices can be higher or lower in the SP than in the DE. Indeed we found that with other parameterizations the two decision rules can be closer, and there can even be instances in which the DE chooses higher B'.

The differences in bond choices across DE and SP may seem small, but they lead to large differences in prices and allocations when a crisis occurs. The nonlinear financial amplification dynamics that make this possible, and the SP's ability to weaken them, are illustrated in figure 3. This figure shows the decision rules for bonds over the interval $-0.25 \leq B \leq -0.17$ for two different triples of s. The ones labeled positive shock are for κ^H, and the ones labeled negative shock are for κ^L, using for both average TFP and a high value of R. The ray from the origin is the stationary choice (45-degree) line, where $B' = B$.

Figure 3 can be used to visualize the dynamics of financial amplification in the DE and compare them with the SP via the following experiment: Assume that both DE and SP start in a hypothetical first period with bonds at point O, which is the intersection of DE's bond decision rule under positive shocks with the 45-degree line. Starting at this point, agents in the DE choose bond holdings D such that $D = O$, since $B' = B$. Hence, DE ends the period with the same amount of bonds it started with. Assume then that the second period arrives and the realization of κ is κ^L. The DE starts at point D, but now the collateral constraint becomes binding, and the Fisherian deflation of asset prices forces a sharp, nonlinear upward adjustment of the bond position such that B' increases to point D', reducing debt from about -0.245 to about -0.185. Compare this with

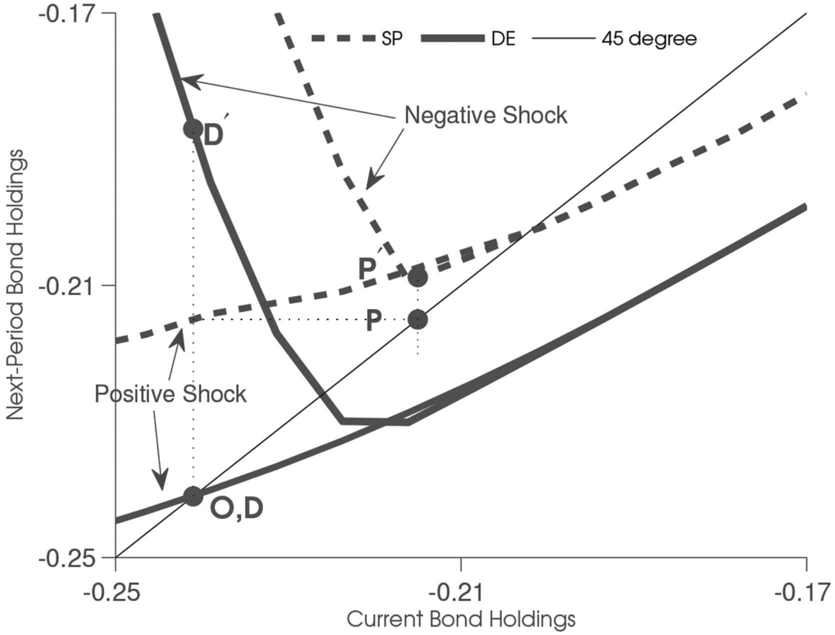

FIG. 3.—Amplification dynamics in response to adverse shocks. Color version available as an online enhancement.

what happens in the SP case. Starting at O, the planner's decision rule increases bond holdings (lowers debt) to about -0.22, to end the first period at point P. Hence, SP ends with debt slightly below what agents in the DE chose (i.e., -0.22 vs. -0.245, respectively). The second period arrives, but now the correction in debt triggered by the binding collateral constraint is small, as the choice of B' rises from P to P'. Hence, the slightly smaller initial debt of the SP versus the DE in the second period results in a sharply smaller upward adjustment in B' for the planner (about 50 basis points in percentage of GDP vs. roughly 700). This is the mechanism that produces the SP's significantly smaller financial crises shown in the event analysis.

The differences in borrowing decisions and asset prices of the DE and SP are also reflected in two important differences in the cumulative long-run distributions of realized asset returns (see fig. 4). First, the SP shows more mass at higher returns, which partly reflects that the externality premium identified in equation (18) is large; or since this premium can be expressed as $R_t \tau_t^{MP}$, it can also be viewed as an implication of the macroprudential debt tax. Second, the distribution for the DE displays a fat left tail, which corresponds to states in which negative shocks hit when

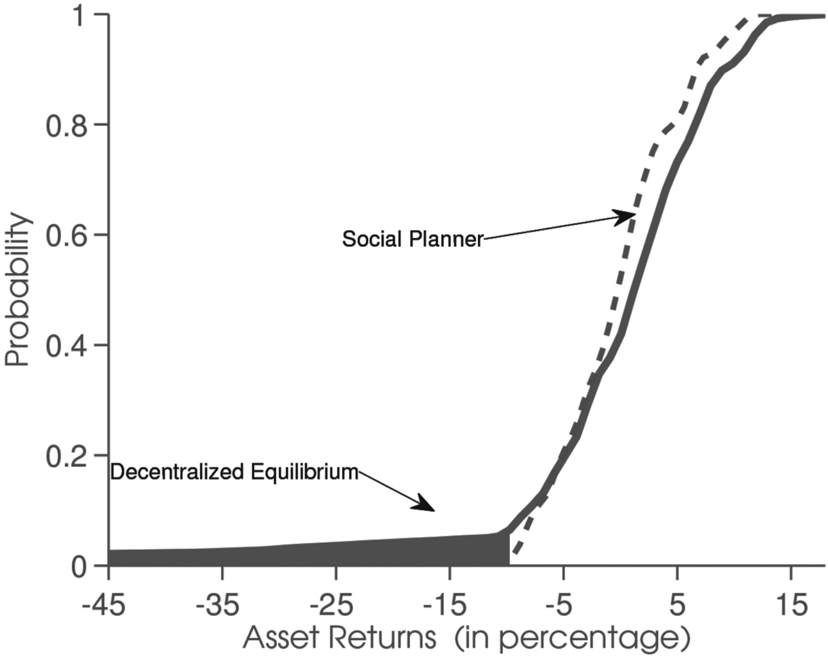

Fig. 4.—Ergodic distribution of asset returns. Color version available as an online enhancement.

agents have a relatively high level of debt. Intuitively, the standard effect of negative shocks reducing expected dividends and putting downward pressure on asset returns is amplified by the effect of asset fire sales that occur if the collateral constraint binds.

The fat tail of the distribution of asset returns in the DE, and its substantial effects on the risk premium due to the associated time-varying risk of financial crises, are important results because they are an endogenous equilibrium outcome resulting from the nonlinear asset pricing dynamics when the debt-deflation mechanism is at work. Fat tails in asset returns are also highlighted in the recent literature on asset pricing and "rare disasters," but this literature generally treats financial disasters as resulting from exogenous stochastic processes. More details on the asset pricing implications and the implications of macroprudential policy are reported in section J of the online appendix.

D. *Macroprudential Debt Tax and Welfare Effects*

We now study the quantitative features of the macroprudential debt tax (τ^{MP}) and its welfare implications. Panel A of figure 5 shows the tax

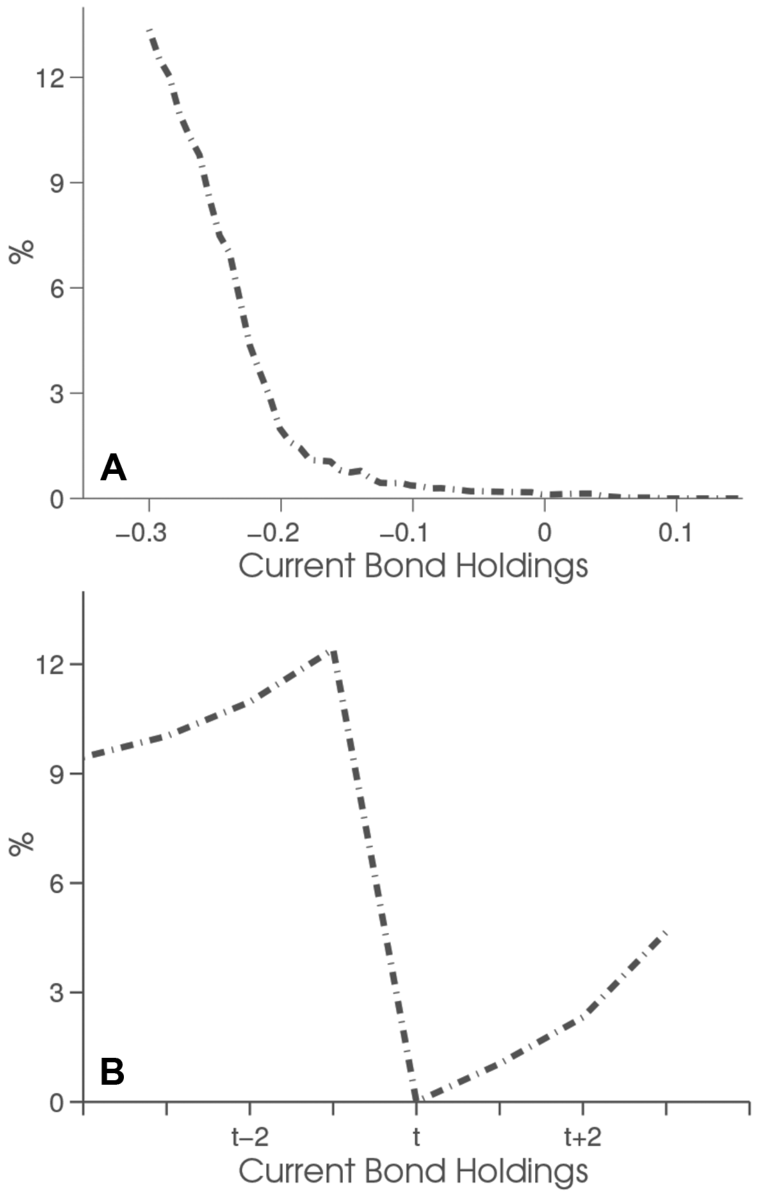

FIG. 5.—Optimal macroprudential tax. Panel A shows the tax schedule in good states, and panel B shows tax dynamics around crises. Color version available as an online enhancement.

schedule as a function of B for average TFP, high R, and κ^H. Panel B shows the event analysis evolution of the tax around financial crises.

Panel A shows that the tax is zero when the value of B at date t is such that the economy is in the stable credit region, because the probability of hitting the collateral constraint at $t+1$ is also zero. When B is low enough to be in the positive-crisis-probability region, the constraint is still not binding at t; but it can bind at $t+1$, and so the tax is positive. In this region, the tax is higher at lower B (i.e., it is increasing in current debt), because this makes it more likely that the constraint will become binding at $t+1$ and that if it does it will be more binding than at higher values of B. The tax can be as high as 13 percent when debt is about 30 percent.

Panel B shows that the tax is positive and rising in the 4 years prior to the financial crisis. Recall from figure 1 that these are also the years in which credit and leverage rise in the unregulated DE. Hence, the policy is taxing debt to reduce the overborrowing that occurs in the good times, so as to mitigate the magnitude of a financial crisis when it occurs. The tax peaks at about 12 percent in the year just before the crisis. When the crisis hits the tax is zero, because at this point $\mu_t > 0$ and the probability of $\mu_{t+1} > 0$ is zero; and hence the prudential aspect of the policy vanishes. The tax increases slightly the year after the crisis and then rises rapidly to reach about 7 percent at $t+4$.

As noted earlier, the long-run average of the macroprudential debt tax is 3.6 percent. In addition, it has a standard deviation that is roughly half the standard deviation of GDP and a correlation of .7 with the leverage ratio. This is consistent with the prudential rationale behind the tax: The tax is high when leverage is building up and low when the economy is deleveraging. Note, however, that since leverage itself is negatively correlated with GDP, the tax also has a negative GDP correlation. Finally, the tax also has a positive correlation with "credit conditions" as reflected in κ_t, again in line with arguments often used to favor macroprudential policy.

Jeanne and Korinek (2010) also computed macroprudential debt taxes to correct a similar pecuniary externality but found that they have much weaker effects on financial crises than in our setup: The asset price drop is reduced from 12.3 to 10.3 percent, compared with 43.6 to 5.4 percent in our analysis. In their model, the credit constraint is determined by the aggregate level of assets $\bar{K}$ and a constant term ψ (i.e., their constraint is $b_{t+1}/R \geq -\kappa q_t \bar{K} - \psi$), with parameters calibrated to $\kappa = 0.046$, $\psi = 3.07$, and $q_t \bar{K} = 4.8$. This implies that the effects of the credit constraint are driven mainly by ψ, and only 7 percent of the borrowing ability depends on the value of assets ($0.07 = 0.046 \times 4.8/(0.046 \times 4.8 + 3.07)$). As a result, the Fisherian deflation effect and the pecuniary externality are both weak, and thus macroprudential policy cannot be very effective. Moreover, since they model output as an exogenous, regime-switching Markov process, such that the probability of a crisis equals the exogenous probability of the low-output regime, macroprudential policy cannot affect the probability of crises either.

The welfare gains of the optimal policy are illustrated in figure 6. Panel A shows the state-contingent schedule of welfare gains as a function of B for the same "good" state with average TFP, high R, and κ^H as in figure 5. Panel B shows the event analysis dynamics of the welfare gains around financial crises events. In looking at these results, keep in mind that the values of γ are generally small because the model is in the class of stationary-consumption, representative-agent models with CRRA preferences that produce small welfare effects due to consumption variability (see Lucas 1987). Moreover, although the efficiency loss in production at work when the collateral constraint binds can be relatively large and add to the welfare effects, this is a low-probability event because of the low probability of hitting the constraint.

The schedule of welfare gains as a function of B in panel A is bell shaped in the region with a positive probability of crisis at $t + 1$. It rises sharply as B rises from -0.25, peaking at about a 0.35 welfare gain when $B = -0.18$, and then falls gradually. The welfare gains continue to fall gradually, and almost linearly, as B moves into the stable credit region and reaches 0.26 percent when $B = 0.15$. This pattern is due to the differences in the optimal plans of the regulator vis-à-vis private agents in the DE. In the region where a crisis is possible at $t + 1$, the SP's allocations projected as of date t for the future differ sharply from those of the DE, because of the latter's higher magnitude and frequency of crises, and this generally enlarges the welfare gains of the optimal policy. Notice that, since the regulator's allocations involve more savings and less current consumption, there are welfare losses in terms of current utility for the regulator, but these are outweighed on average by less vulnerability to sharp decreases in future consumption during financial crises. In the constrained credit region, since asset prices are relatively more depressed for SP and this leads to a tighter credit constraint, the losses from cutting consumption can outweigh the future gains from lower exposure to crises. As the level of debt falls and the economy enters the stable credit region, financial crises are unlikely at $t + 1$ or are likely much further into the future, and thus the welfare gains of the policy (or the costs of the externality) decrease.

Panel B shows that the welfare gains of the optimal policy rise in the years before the crisis to a peak around 0.36 percent at $t - 1$. When the crisis hits, the welfare gain drops to near 0.32 percent, because by then the crisis has arrived and the prudential aspect of the optimal policy is less valuable; but right after the crisis, the welfare gain increases sharply. As noted before, the unconditional average welfare gain computed using the DE's ergodic distribution is about 0.3 percent. These welfare gains may seem small, but they are much higher than the welfare gains of eliminating business cycles obtained with the same CRRA coefficient of $\sigma = 1$

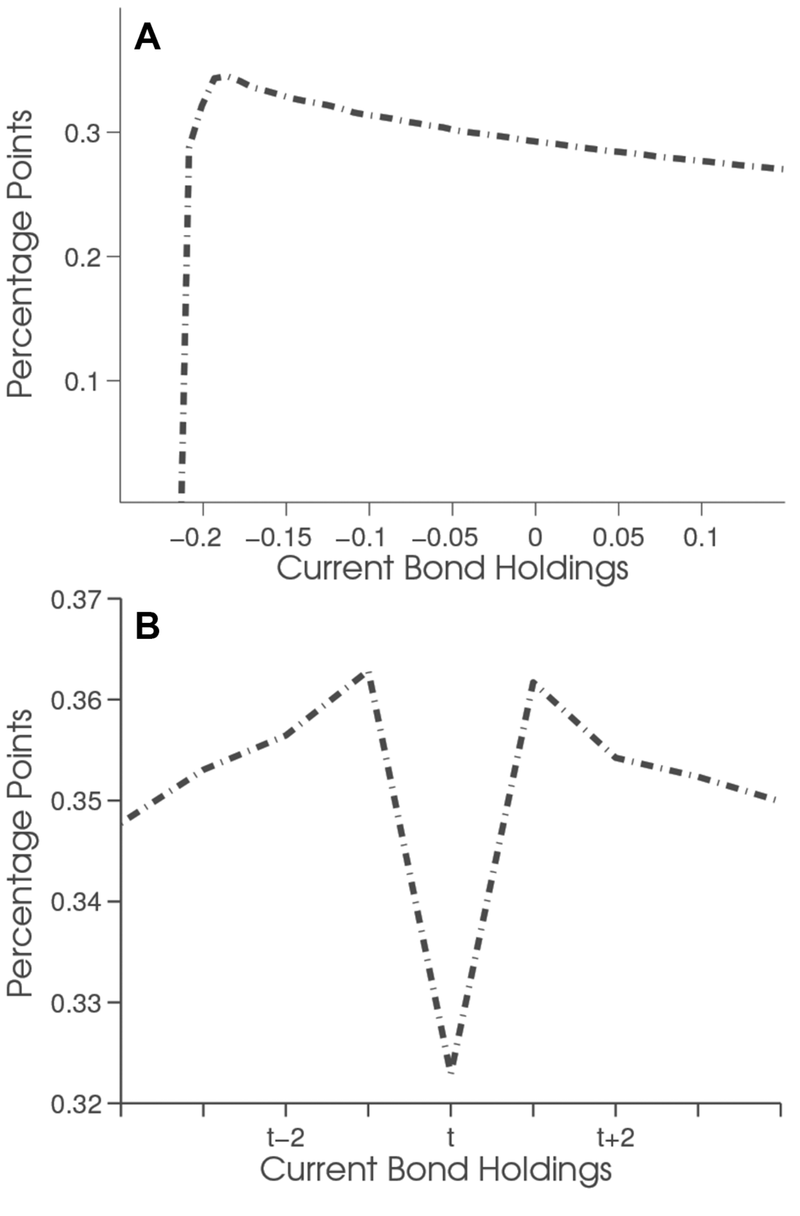

FIG. 6.—Welfare gains of the optimal policy. Panel A shows the welfare schedule in good states, and panel B shows welfare dynamics around crises. Color version available as an online enhancement.

in calibrations to US data (e.g., Lucas [1987] estimated a gain of only 0.0005).

E. *Simple Macroprudential Rules*

The state-contingent nature of the optimal policy has the usual drawback that complex state-contingent rules are difficult to implement in practice and therefore rarely used. In particular, there is concern for the ability of regulators to track accurately financial conditions and adjust macroprudential tools optimally and in a timely fashion (e.g., Cochrane 2013). On the other hand, if macroprudential policy is limited to the relatively simple rules that regulators typically use, the question that is often raised is whether these simpler rules are effective. In light of these concerns, we examine the effectiveness of two simple rules: first, a time- and state-invariant debt tax (a "fixed tax") and, second, in the spirit of Taylor's rule for monetary policy, a "macroprudential Taylor rule" that makes the tax a function of credit. The key insight of this analysis is that simple rules can still be welfare improving if they are designed carefully; otherwise they can yield outcomes that are worse than the unregulated decentralized equilibrium.

Consider first the fixed tax. Figure 7 shows the effects of fixed taxes ranging from 0 to 2 percent on the long-run probability of financial crises (panel A) and on welfare (panel B). Fixed taxes reduce the likelihood of crises monotonically from 4 to 2.6 percent as the tax rises from 0 to 2 percent. This occurs because as debt is taxed more, agents build less leverage and are less vulnerable to crises; but this does not mean that they are necessarily better off. Recall in particular that the optimal τ^{MP} fluctuates roughly half as much as GDP and is positively correlated with leverage, while this rule keeps the tax constant. As a result, fixed taxes yield welfare gains when computed conditional on initial states in which the constraint is not binding but can produce welfare losses otherwise. This is due to the negative short-run effects of debt taxes on asset prices and the tightness of the collateral constraint, which occur in turn because the increased cost of borrowing shifts demand from assets to bonds. There is also a positive, second-order effect of debt taxes on asset prices, because of a reduction in the riskiness of assets, but this effect is dominated by the first-order effect of taxes on the relative demand for bonds.

Panel B shows the average, maximum, and minimum welfare gain for constant taxes in the 0–2 percent range (recall that the average welfare gain under the optimal policy is 0.3 percent). This plot illustrates two results. First, fixed taxes are always inferior to the optimal policy: The maximum (average) welfare gain of fixed taxes peaks at about 0.07 (0.03) percent with a tax of 0.6 percent, significantly smaller than the SP's average welfare gain (see table 3). Second, some fixed taxes are welfare reducing.

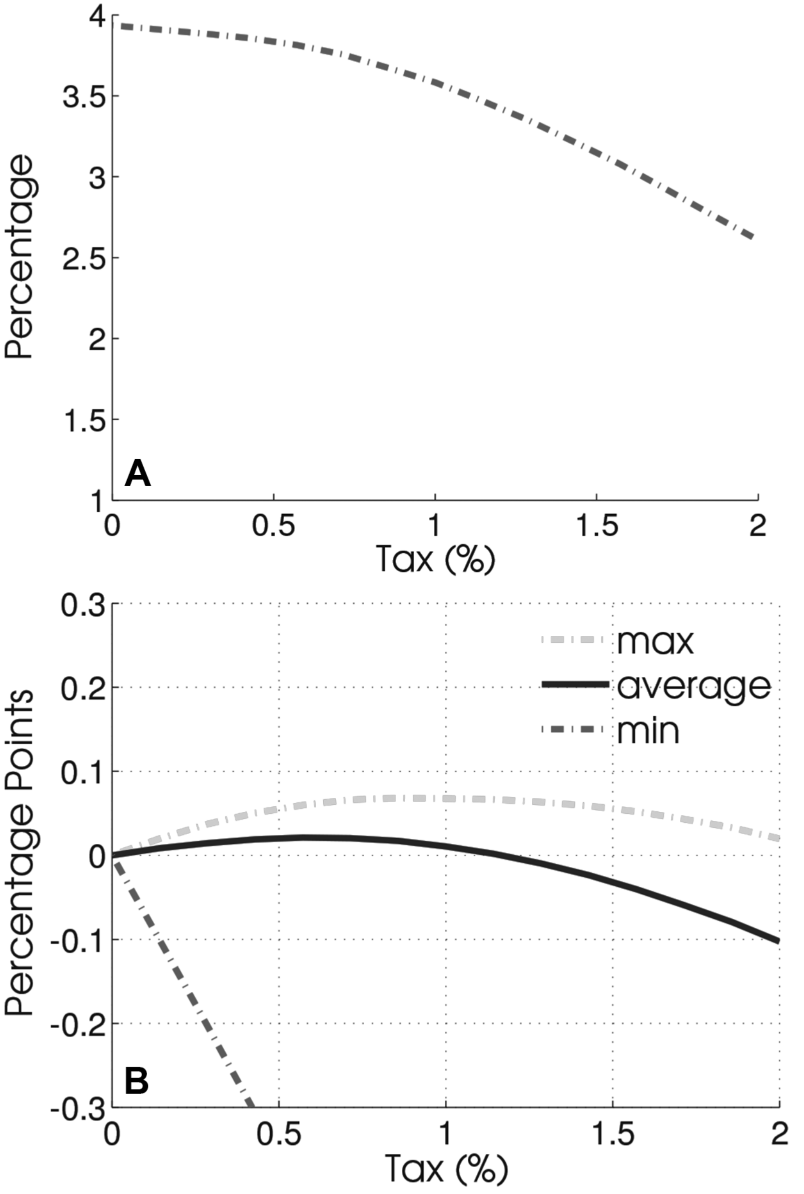

Fig. 7.—Effects of fixed debt taxes on probability of crises (panel A) and welfare gains (panel B). Color version available as an online enhancement.

TABLE 3
PERFORMANCE OF OPTIMAL AND SIMPLE POLICY RULES

	Decentralized Equilibrium	Optimal Policy	Best Taylor	Best Fixed
Welfare gains (%)	. . .	.30	.09	.03
Crisis probability (%)	4.0	.02	2.2	3.6
Drop in asset prices (%)	−43.7	−5.4	−36.3	−41.3
Equity premium (%)	4.8	.77	3.9	4.3
Tax statistics:				
Mean	. . .	3.6	1.0	.6
Standard deviation relative to GDP	. . .	.5	.2	. . .
Correlation with leverage	. . .	.7	.3	. . .

NOTE.—Moments for optimal policy are for the macroprudential debt tax. "Mean" under Best Fixed corresponds to the welfare-maximizing fixed tax.

Fixed taxes reduce welfare in a subset of the state space, which is reflected in the fact that the minimum welfare gain is always negative for all values of fixed taxes in panel B, and this subset grows as the fixed tax rate rises (the largest welfare cost reaches −1.5 percent as the tax approaches 2 percent). When the subset of the state space in which fixed taxes cause welfare losses is large enough, the average welfare gain also turns negative. This occurs for fixed debt taxes above 1.2 percent.

Fixed taxes can reduce welfare because they reduce asset prices when the collateral constraint binds, making financial crises worse. This suggests that a regulator considering only fixed taxes should trade off the prudential benefit of the taxes in restraining credit growth in good times against their adverse effects in making financial crises worse. This trade-off is reflected in the welfare-maximizing fixed tax of about 0.6 percent (see panel B). This tax is significantly smaller than the 3.6 percent average optimal macroprudential tax, and it achieves an average welfare gain about one-tenth of that obtained with the optimal tax (see table 3).

Fixed taxes are also much less effective at reducing the magnitude of financial crises. As figure 8 shows, under the welfare-maximizing fixed tax of 0.6 percent, crisis dynamics are about the same as in the unregulated DE. Adding to this result the above findings showing a small reduction in the probability of crises (from 4 to 3.6 percent) and a negligible average welfare gain (0.03 percent), we conclude that fixed debt taxes are an ineffective macroprudential policy tool. Moreover, since fixed taxes higher than 1.2 percent reduce welfare, in fact they are at best ineffective.

The macroprudential Taylor rule allows the tax to vary with the borrowing choice, according to the following piecewise, isoelastic function:[23]

[23] We also evaluated rules including other variables such as asset prices, the interest rate, TFP, output or the leverage ratio, or conditioning on whether the collateral constraint binds, but their performance did not yield noticeable gains compared with this simpler rule.

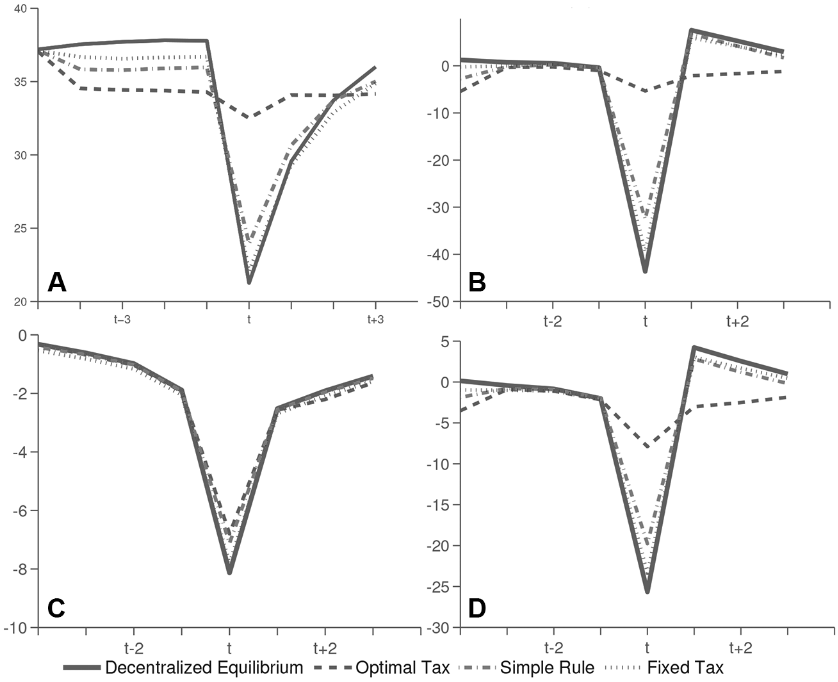

FIG. 8.—Event analysis: decentralized equilibrium, optimal policy, and simple policies. Panel A shows the credit/GDP ratio, panel B the asset price, panel C output, and panel D consumption. Color version available as an online enhancement.

$\tau_t = \max[0, (1 + \tau_0)(b_{t+1}/\bar{b})^{\eta} - 1]$, where τ_0 is a constant term, and η is the elasticity of the tax with respect to the excess of the borrowing choice b_{t+1} relative to a target $\bar{b}$. Note that, since under the baseline calibration b_{t+1} is always negative, the ratio $b_{t+1}/\bar{b}$ is positive, and hence $\eta > 0$ implies that the tax rises as debt rises above its target. The cutoff at zero rules out subsidies on debt, in line with the result that the macroprudential tax is nonnegative, and allows us to avoid having to model other taxes to pay for these subsidies.

We set τ_0 to the value of the welfare-maximizing fixed tax (0.6 percent) and search numerically for an "optimal" pair $(\eta, \bar{b})$ that maximizes the average welfare gain, computing the average as before, using the ergodic distribution of the DE without regulation.[24] This procedure yields $\eta = 2$ and $\bar{b} = -0.23$, which is 200 basis points lower than the DE average, in line with the notion that the macroprudential tax aims to reign on overborrowing.

[24] Optimizing the various formulations of the rule that we studied is computationally intensive, because for each one the model has to be solved for all combinations of values of the relevant elasticity coefficients specified in predetermined grids.

The macroprudential Taylor rule yields an average debt tax of 1 percent, higher than the best fixed tax of 0.6 percent but lower than the mean optimal tax of 3.6 percent (see table 3). This rule also yields taxes that fluctuate less and are less correlated with leverage than the optimal taxes. In terms of the effectiveness of this policy at affecting crises' probability, magnitude of crises, and welfare gains, the rule is much better than the fixed taxes but still clearly inferior to the optimal policy. The rule yields a welfare gain of about 0.1 percent, a third of the gain under the optimal policy, and lowers the probability of crisis to about half of the 4 percent in the DE. Figure 8 shows that crises dynamics are less severe than in the DE and under fixed taxes but still more severe than under the optimal policy. Recall also that these are results that hold for optimized values of the parameters of the tax rule. As with the fixed tax, one can produce outcomes that are significantly inferior for other parameter values.

An issue often discussed together with the effectiveness of simple macroprudential policy rules is whether it is feasible to construct a parsimonious statistical framework that can yield accurate "early warnings" of financial crises. We examined this issue by conducting an experiment similar to the one Boissay et al. (2016) proposed, treating the model as a true data-generating process and testing whether parsimonious logit regressions could yield warnings as accurate as the model's in terms of the fractions of type 1 and type 2 errors in crises prediction.[25] In the results reported in section H of the online appendix, we show that a regression using the ratio of total credit to GDP produces fractions of both errors similar to those produced by the model, which is consistent with the findings of Boissay et al.

In summary, the results for the two simple rules we examined highlight both the benefits and dangers of simple macroprudential policies: If institutional limitations prevent regulators from using optimal, state-contingent macroprudential policy instruments, it is possible to end up with environments in which the policy is welfare reducing. This contrasts sharply with the results in Bianchi (2011), because in his setup fixed taxes do not have negative effects on borrowing capacity across states, whereas here they do because of the forward-looking nature of asset prices.

IV. Conclusions

This paper performed a theoretical and quantitative analysis of macroprudential policy in a dynamic equilibrium model of financial crises, in which a collateral constraint limits access to intertemporal debt and work-

[25] Type 1 errors occur when a warning is not issued at t but a crisis occurs at $t + 1$, and type 2 errors occur when a warning is issued at t but a crisis does not occur at $t + 1$.

ing capital to a fraction of the market value of asset. A binding constraint creates financial amplification via the classic Fisherian debt-deflation mechanism and introduces a fire sale externality, because agents do not internalize the systemic effects of higher debt positions.

We compared theoretically and quantitatively the competitive equilibrium with that of an economy in which a macroprudential regulator makes borrowing decisions and internalizes the externality. We showed that the forward-looking nature of asset prices causes the optimal policy under commitment to be time inconsistent: The regulator promises lower future consumption to prop up current asset prices when the constraint binds, but ex post, keeping this promise is suboptimal. In a version of the model calibrated to OECD data, the optimal time-consistent macroprudential policy achieves significant reductions in financial fragility. The optimal policy yields a welfare gain of roughly a third of a percent, with a debt tax that is about 3.6 percent on average, 60 percent more volatile than output and with a correlation with leverage of .7.

Our results also suggest that the state-contingent complexity of the optimal policy is a nontrivial hurdle. Rules that are much simpler can be effective too, but they can be counterproductive if they are not designed carefully. Fixed debt taxes are at best ineffective, because when targeted to maximize their welfare gain, they yield negligible reductions in the magnitude and frequency of crises and a negligible rise in welfare; if set higher than that target (including at the average of the optimal tax rate), they produce outcomes worse than the unregulated equilibrium. A macroprudential Taylor rule that makes the tax a function of the ratio of debt to a target, with an elasticity optimized to maximize the welfare gain, is more effective, albeit still less than the optimal policy.

This paper focused on a specific form of credit market failure, namely, pecuniary externalities via asset prices that arise when individual borrowing capacity is limited by collateral constraints. As noted in the introduction, the modeling of financial frictions with similar collateral constraints is fairly common in the macro-finance literature. Moreover, its appeal as a reasonable framework for studying macroprudential policy follows from favorable quantitative results showing that these constraints embody a powerful, nonlinear amplification mechanism capable of producing financial crises with features similar to those observed in the data (e.g., Mendoza 2010). Still, this class of models does not capture all relevant features of recent financial crises and policy debates. In particular, the following items should be in the agenda for future research.

1. *Explicit modeling of financial intermediaries.*—The 2008 crisis in the United States did feature highly levered households, but highly levered financial intermediaries exposed to systemic risk and funding pressures were at the center of the crisis too. In addition, several new regulatory policies proposed in the Dodd-Frank Act, such as the Volcker rule or the new

regulations on derivatives trading, are targeted directly at financial intermediaries and not much related with the macroprudential policy we studied. On the other hand, several financial policies that have been put in place are akin to our macroprudential tax on debt, such as the Basel III countercyclical capital buffer, the liquidity coverage ratios, and the loan-to-value regulatory ratios that central banks of several countries have imposed on residential mortgages (e.g., Finland, Hong Kong, Indonesia, New Zealand, Poland, and South Korea). Indeed, the stated goal of these policies is to make credit costlier in periods in which it is expanding rapidly at the aggregate level.[26] An analysis of the trade-offs involved in the use of these instruments in macro models with a richer financial intermediation setup is clearly warranted.[27]

2. *Heterogeneity across countries and across agents.*—In our model, exposure to systemic risk is summarized by the leverage of a representative entity. In reality, leverage ratios, income volatility, and the types of assets or income flows used as collateral differ within and across households, financial, and nonfinancial corporations. Our results illustrate the potential benefits and complexities that macroprudential policy faces in a representative agent setting, but clearly considering agent heterogeneity and its implications for macroprudential policy is important. Moreover, there are also significant differences in contractual and regulatory practices across countries that affect financial amplification, pecuniary externalities, and hence the optimal policy.[28] In addition, since financial markets are globally integrated, this cross-country heterogeneity makes it important to study the potential for strategic interaction and the need for coordination of macroprudential policies.

3. *Interaction between different financial and nonfinancial frictions.*—Within models with collateral constraints, we studied one in which debt cannot exceed a fraction of the market value of assets (i.e., a stock constraint affected by asset prices), but constraints that limit debt to fractions of incomes valued in units of the denomination of debt (i.e., a flow constraint affected by relative goods prices) are also pervasive, as in the case of scoring limits on household credit or covenants requiring firms to maintain cash flows relative to contracted debt service. Pecuniary externalities and macroprudential debt taxes have been examined in models with these flow constraints (e.g., Bianchi 2011; Benigno et al. 2013), but time inconsistency does not arise because only contemporaneous goods prices

[26] Bianchi (2011) provides a model in which LTV ratios and capital requirements can be made equivalent to the macroprudential debt tax. In the United States, this tax or equivalent measures have been advocated by Stein (2013) and Cochrane (2014), among others.

[27] In this regard, the recent studies by Gertler and Kiyotaki (2010), Bianchi and Bigio (2014), Boissay et al. (2016), and Gertler, Kiyotaki, and Prestipino (2016) provide useful insights.

[28] For instance, recourse mortgages in Spain vs. nonrecourse mortgages in several US states resulted in much higher foreclosure rates in the latter than in the former.

appear in the collateral constraint. If future relative prices were determinants of borrowing capacity, time inconsistency would reappear. The implications for macroprudential policy of the interaction between collateral constraints of either type and other relevant frictions affecting financial markets or other markets are also important to study. For example, adverse selection in credit contracts may produce sharper drops in asset prices and feed back into financial constraints and fire sales. Exchange rate regimes and nominal rigidities can also affect the magnitude of the real effects resulting from collateral constraints and pecuniary externalities (recent work by Ottonello [2014] and Farhi and Werning [2016] sheds light on this issue).

4. *Informational frictions.*—There is a large theoretical and empirical literature studying the effects of incomplete and imperfect information on financial transmission. Research incorporating these issues into models of the class we studied here is at an early stage, but the results from Bianchi, Liu, and Mendoza (2016), modeling noisy news, and Bianchi, Boz, and Mendoza (2012), modeling learning about regime changes in loan-to-value ratios, suggest that the effectiveness of macroprudential policy can be significantly affected by informational frictions. These studies also raise important questions about the implications of heterogeneous information sets or beliefs across private agents and financial regulators for macroprudential policy.

References

Amiti, M., and D. Weinstein. 2011. "Exports and Financial Shocks." *Q.J.E.* 126 (4): 1841–77.

Arellano, C., Y. Bai, and P. Kehoe. 2012. "Financial Markets and Fluctuations in Volatility." Staff Report no. 466, Res. Dept., Fed. Reserve Bank Minneapolis.

Benigno, G., H. Chen, C. Otrok, A. Rebucci, and E. R. Young. 2013. "Financial Crises and Macro-Prudential Policies." *J. Internat. Econ.* 89 (2): 453–70.

Bernanke, B. 2010. "Financial Reform to Address Systemic Risk." Speech at the Council on Foreign Relations, Washington, DC, March.

Bernanke, B., and M. Gertler. 1989. "Agency Costs, Net Worth, and Business Fluctuations." *A.E.R.* 79 (1): 14–31.

Bianchi, J. 2011. "Overborrowing and Systemic Externalities in the Business Cycle." *A.E.R.* 101 (7): 3400–3426.

Bianchi, J., and S. Bigio. 2014. "Banks, Liquidity Management and Monetary Policy." Working Paper no. 20490, NBER, Cambridge, MA.

Bianchi, J., E. Boz, and E. G. Mendoza. 2012. "Macroprudential Policy in a Fisherian Model of Financial Innovation." *IMF Econ. Rev.* 60 (2): 223–69.

Bianchi, J., C. Liu, and E. G. Mendoza. 2016. "Fundamentals News, Global Liquidity and Macro-Prudential Policy." *J. Internat. Econ.* 99:S2–S15.

Bianchi, J., and E. G. Mendoza. 2010. "Overborrowing, Financial Crises and 'Macroprudential' Policy." Working Paper no. 16091, NBER, Cambridge, MA.

Boissay, F., F. Collard, and F. Smets. 2016. "Booms and Banking Crises." *J.P.E.* 124 (2): 489–538.

Borio, C. 2003. "Towards a Macroprudential Framework for Financial Supervision and Regulation?" *CESifo Econ. Studies* 49 (2): 181–215.

Boz, E., and E. G. Mendoza. 2014. "Financial Innovation, the Discovery of Risk, and the U.S. Credit Crisis." *J. Monetary Econ.* 62 (March): 1–22.

Chaney, T., D. Sraer, and D. Thesmar. 2012. "The Collateral Channel: How Real Estate Shocks Affect Corporate Investment." *A.E.R.* 102 (6): 2381–2409.

Cochrane, J. H. 2013. "The Danger of an All-Powerful Federal Reserve." *Wall Street J.*, August 26. http://online.wsj.com/news/articles/SB10001424127887323906804579036571835323800.

———. 2014. "Toward a Run-Free Financial System." Paper no. 2425883, Soc. Sci. Res. Network.

Demyanyk, Y., and O. V. Hemert. 2011. "Understanding the Subprime Mortgage Crisis." *Rev. Financial Studies* 24 (6): 1848–80.

Duca, J. V., J. Muellbauer, and A. Murphy. 2011. "House Prices and Credit Constraints: Making Sense of the US Experience." *Econ. J.* 121 (552): 533–51.

Farhi, E., and I. Werning. 2016. "A Theory of Macroprudential Policies in the Presence of Nominal Rigidities." *Econometrica* 84 (5): 1645–1704.

Favilukis, J., S. C. Ludvigson, and S. Van Nieuwerburgh. 2010. "The Macroeconomic Effects of Housing Wealth, Housing Finance, and Limited Risk-Sharing in General Equilibrium." Working Paper no. 15988, NBER, Cambridge, MA.

Forbes, K. J., and F. E. Warnock. 2012. "Capital Flow Waves: Surges, Stops, Flight, and Retrenchment." *J. Internat. Econ.* 88 (2): 235–51.

Gan, J. 2007. "Collateral, Debt Capacity, and Corporate Investment: Evidence from a Natural Experiment." *J. Financial Econ.* 85 (3): 709–34.

Gertler, M., and N. Kiyotaki. 2010. "Financial Intermediation and Credit Policy in Business Cycle Analysis." In *Handbook of Monetary Economics*, vol. 3, edited by B. M. Friedman and M. Woodford. Amsterdam: Elsevier.

Gertler, M., N. Kiyotaki, and A. Prestipino. 2016. "Wholesale Banking and Bank Runs in Macroeconomic Modeling of Financial Crises." In *Handbook of Macroeconomics*, vol. 2, edited by J. B. Taylor and H. Uhlig. Amsterdam: Elsevier.

Greenwood, J., Z. Hercowitz, and G. W. Huffman. 1988. "Investment, Capacity Utilization, and the Real Business Cycle." *A.E.R.* 78:402–17.

Jeanne, O., and A. Korinek. 2010. "Managing Credit Booms and Busts: A Pigouvian Taxation Approach." Working Paper no. 16377, NBER, Cambridge, MA.

Jermann, U., and V. Quadrini. 2012. "Macroeconomic Effects of Financial Shocks." *A.E.R.* 102 (1): 238–71.

Keane, M., and R. Rogerson. 2012. "Micro and Macro Labor Supply Elasticities: A Reassessment of Conventional Wisdom." *J. Econ. Literature* 50:464–76.

Kiyotaki, N., and J. Moore. 1997. "Credit Cycles." *J.P.E.* 105:211–48.

Klein, P., P. Krusell, and V. Rios-Rull. 2008. "Time-Consistent Public Policy." *Rev. Econ. Studies* 75 (3): 789–808.

Klein, P., V. Quadrini, and V. Rios-Rull. 2007. "Optimal Time-Consistent Taxation with International Mobility of Capital." *B.E. J. Macroeconomics* 5 (1).

Korinek, A. 2009. "Systemic Risk-Taking: Accelerator Effects, Externalities, and Regulatory Responses." Manuscript, Univ. Maryland.

Korinek, A., and E. G. Mendoza. 2014. "From Sudden Stops to Fisherian Deflation: Quantitative Theory and Policy." *Ann. Rev. Econ.* 6:299–332.

Lorenzoni, G. 2008. "Inefficient Credit Booms." *Rev. Econ. Studies* 75:809–33.

Lucas, R. 1987. *Models of Business Cycles.* New York: Blackwell.

Mendoza, E. G. 2010. "Sudden Stops, Financial Crises, and Leverage." *A.E.R.* 100 (5): 1941–66.

Mendoza, E. G., and V. Quadrini. 2010. "Financial Globalization, Financial Crises and Contagion." *J. Monetary Econ.* 57 (1): 24–39.

Mendoza, E. G., and K. A. Smith. 2006. "Quantitative Implications of a Debt-Deflation Theory of Sudden Stops and Asset Prices." *J. Internat. Econ.* 70 (1): 82–114.

Mendoza, E. G., and M. E. Terrones. 2008. "An Anatomy of Credit Booms: Evidence from Macro Aggregates and Micro Data." Working Paper no. 14049, NBER, Cambridge, MA.

Nguyen, H., and R. Qian. 2012. "The Cross-Country Magnitude and Determinants of Collateral Borrowing." Policy Research Working Paper no. 6001, World Bank, Washington, DC.

Ottonello, P. 2014. "Optimal Exchange Rate Policy under Collateral Constraints and Wage Rigidity." Manuscript, Columbia Univ.

Perri, F., and V. Quadrini. 2011. "International Recessions." Working Paper no. 17201, NBER, Cambridge, MA.

Reinhart, C., and K. Rogoff. 2009. *This Time Is Different: Eight Centuries of Financial Folly.* Princeton, NJ: Princeton Univ. Press.

Schmitt-Grohé, S., and M. Uribe. 2014. "Downward Nominal Wage Rigidity, Currency Pegs, and Involuntary Unemployment." Manuscript, Columbia Univ.

Stein, J. C. 2012. "Monetary Policy as Financial Stability Regulation." *Q.J.E.* 127 (1): 57–95.

———. 2013. "The Fire-Sales Problem and Securities Financing Transactions." Remarks at the Workshop on Fire Sales as a Driver of Systemic Risk in Triparty Repo and Other Secured Funding Markets, Fed. Reserve Bank New York.

Stockman, A., and L. Tesar. 1995. "Tastes and Technology in a Two-Country Model of the Business Cycle." *A.E.R.* 85 (1): 168–85.

Uribe, M. 2006. "On Overborrowing." *A.E.R. Papers and Proc.* 96 (2): 417–21.

Uribe, M., and V. Z. Yue. 2006. "Country Spreads and Emerging Countries: Who Drives Whom?" *J. Internat. Econ.* 69 (1): 6–36.