

Optimal Stabilization Policy in a Model with Endogenous Sudden Stops:*

Gianluca Benigno

London School of Economics

Huigang Chen

International Monetary Fund

Christopher Otrok

University of Virginia

Alessandro Rebucci

International Monetary Fund

Eric R. Young

University of Virginia

First Draft: October 1, 2007

Preliminary. Comments welcome.
Do not quote without the authors' permission.

*We are grateful to Enrique Mendoza for very helpful discussions, comments and suggestions. Young would like to thank the hospitality of the IMF and the Richmond Fed, where much of this research was conducted. Otrok and Benigno would like to thank the hospitality of the IMF. The views expressed in this paper are exclusively those of the authors and not those of the International Monetary Fund. The usual disclaimer applies.

Abstract

We study optimal stabilization policy in a simple two-good production economy with an occasionally binding credit constraint as in Mendoza (2002). In the model, the policy instrument of the government is a distortionary tax wedge on consumption of non-tradable goods with a balanced budget rule by lump sum transfers. We find that, for a plausible calibration of the model, the optimal policy is highly non linear. If the liquidity constraint is not binding, the optimal tax rate is zero, as in an economy without credit constraint. If the liquidity constraint is binding, the optimal tax rate is negative, meaning that the government subsidizes non tradables consumption. This suggests that the optimal stabilization policy does not have a precautionary component, but it does not imply that the optimal policy is unimportant in tranquil times. When comparing the solution of the model with and without the optimal policy in the presence of the borrowing constraint, we find that agents accumulate 25 percent more debt under the optimal policy, and thus on average save significantly less and consume more. Simple tax rules in which the rate is fixed at different values also shows that the region of the state space in which the constraint may bind can be reduced significantly, given all other structural parameters.

1 Introduction

Much attention has been devoted to understanding the causes of the periodic crises that haunt emerging market countries. Some of these episodes, labeled ‘Sudden Stops’ (see Calvo, 1998), are characterized by a sharp reversal in private capital flows, large drops in output and consumption coupled with large asset price declines and relative prices. Progress has been made in understanding optimal policy responses in models in which the economy *is* in a sudden stop.¹ The focus of this paper is to address the issue of optimal stabilization policy for an economy that *might be* subject to a sudden stop, so as to provide direction on how stabilization policy should be designed both for the tranquil periods in which emerging markets spend most of the time, as well as periods when a crisis is looming on the horizon or the economy is in a sudden stop. That is, we investigate optimal stabilization policy in an environment in which the access to international capital markets is not only incomplete but might also be suddenly curtailed. To the best of our knowledge there are no contributions on the analysis of optimal stabilization policy in this environment, and our work aims at filling this gap in the literature.²

In modelling the possibility of a sudden stop, we follow the contributions of Mendoza (2000, 2002) and assume financial markets are not only incomplete and but access to foreign financing is also imperfect because intermittent and occasionally constrained. In particular, we assume the existence of an international borrowing that cannot be made state-contingent because the asset menu includes only a one period risk-less bond paying off the exogenously given foreign interest rate. In particular the constraint is endogenous because domestic agents’ ability to borrow from foreigners is limited by the endogenous evolution of income and prices. In general in this class of models, agents self insure (e.g., through precautionary saving and associated accumulation of net foreign assets) against the low-probability but high

¹See Christiano, Gust, and Roldos (2002), Cúrdia (2007), and Caballero and Krishnamurthy (2005) on the monetary policy response to these crisis periods.

²Bora and Mendoza (2005) analyze broad alternative policy strategies in such an environment. Adams and Billi (2006) study optimal monetary policy in a very simple new Keynesian model in which the zero bound constraint is occasionally binding. Benigno, Otrok, Rebucci and Young (2007) compare the welfare properties of alternative interest rate rules in a model in which there is also a nominal rigidity.

cost possibility of a sudden stop generated by the occasionally binding credit constraint. Our goal is to explore both the policy response to the sudden stop and how this precautionary savings motive affects the design of the policy rules in tranquil times.

Specifically, ours is a slightly simplified version of the endogenous sudden stop model of Mendoza (2002). This is a two-good (tradables and non-tradables), small open production economy with incomplete markets and an occasionally-binding credit constraint, endogenous discounting, multiple sources of disturbance and tax distortion aimed at achieving quantitative accuracy. We simplify this framework by adopting a more tractable version of endogenous discounting and considering only one (two-state) source of disturbance for the endowment of tradables and distortionary tax in the production and consumption of non-tradable goods, respectively. Despite the introduction of realistic financial frictions, the model is relatively simple—in particular, capital is fixed—and hence cannot fully explain all aspects of fluctuations of a typical emerging market economy. However the model is rich enough to capture important features of aggregate fluctuations in these economies, including in particular the debt deflation dynamics observed during episodes of Sudden Stop.

In the optimal policy analysis, we focus on the tax wedge on non-tradable consumption, with a balanced budget rule by lump sum transfers as in Mendoza (2002). We therefore omit government debt policy considerations. We first compute the optimal policy and then compare it to alternative simple, non-contingent tax rules.

The main result of the analysis is that the optimal stabilization policy is highly non-linear. If the credit constraint is not binding, optimal policy would mimic the one that would arise in an economy without a credit constraint (zero tax rate in our simple model). This suggests that the optimal policy in tranquil times does not entail a precautionary motive in an economy with no capital and a balanced budget rule by lump sum transfers. Without additional frictions, private sector precautionary saving is all it takes to insure the economy against the risk of sudden stop. If the liquidity constraint is binding, the optimal tax rate is negative, meaning that the government subsidizes non-tradables consumption, thereby supporting both the demand and the supply of non-tradable goods in the economy.

These results do not imply that the optimal policy is unimportant in tranquil times.

When comparing the solution of the model with and without the optimal policy in the presence of the borrowing constraint there are significantly different private sector behavior. Under the optimal policy agents accumulate 25 percent more debt than the economy without the optimal policy. This additional debt allows the agent to increase consumption. Therefore, without the optimal policy agents save more (accumulate less debt) and hence must forgo consumption to self insure.

The paper is most closely related two broad strands of literature. The first strand focuses on financial frictions that may help replicate the main features of the business cycle in emerging market economies—e.g., Mendoza (1991, 2002), Neumeyer and Perri (2005) and Oviedo (2006). The second strand focuses on the analysis of optimal fiscal policy in dynamic general equilibrium models(see for example Chari and Kehoe, 1999). While studies of emerging market business cycles can provide a realistic description of the economic environment in which these economies operate, the question of how policy should be set in such environments remain open. On the other hand, most analysis of optimal stabilization policy are based on descriptions of the economic environment that are unrealistic, as they typically ignore meaningful financial frictions. In this paper we study optimal policy in the presence of a general form of financial friction.

Section 2 describes the model. Section 3 discusses its calibration and solution. Section 4 presents the optimal policy results. Section 5 reports an extensive sensitivity analysis. Section 6 concludes. Details of the numerical algorithm we use to solve the model are in appendix.

2 Model

This section simplifies a model originally proposed by Mendoza (2002), namely a two-good, small open, production economy with liability dollarization and an occasionally binding credit constraint. International financial markets in this economy are not only incomplete, but access to them is also imperfect. Specifically, international borrowing cannot be made state-contingent because the asset menu includes only a one period bond denominated in

units of tradable consumption, paying off the exogenously given foreign interest rate. In addition, domestic agents' ability to borrow from foreigners is limited by the endogenous evolution of income and prices because of the requirement that net foreign liabilities be larger than a given share of GDP, a requirement that we call credit or liquidity constraint. The fact that foreign borrowing is denominated in units of tradable consumption while part of the income on which the debt is leveraged comes from the non-tradables sector give rise to a form of liability dollarization.

Compared to Mendoza (2002), we consider only one source of disturbance, to aggregate productivity in the tradable sector of the economy, and a distortionary tax rate on non-tradable consumption. The specification of endogenous discounting is also simplified by assuming that the agents' discount rate depends on aggregate consumption as opposed to the individual one as in Schmitt-Grohé and Uribe (2003).

2.1 Households

There is a continuum of households $j \in [0, 1]$ that maximize the utility function

$$U^j \equiv E_0 \left\{ \sum_{t=0}^{\infty} \exp(-\theta_t) u(C_t^j - z(H_t^j)) \right\}, \quad (1)$$

with C^j denoting the individual consumption basket and H^j the individual supply of labor. We assume that the expected utility includes an endogenous discount factor as in Mendoza (2002):

$$\begin{aligned} \theta_t &= \theta_{t-1} + \beta \ln(1 + C(C_t^T, C_t^N) - z(H_t)) \\ \theta_0 &= 1, \end{aligned}$$

with C denoting aggregate per capita consumption that the individual household takes as given—so our formulation corresponds to what Schmitt-Grohé and Uribe (2003) call “endogenous discount factor without internalization.”³

³Elastic discounting pins down a well defined net foreign asset position in the deterministic steady state of the model. Due to precautionary savings it may not be necessary in the stochastic model.

For the period utility function we adopt the following functional form (where we omit for simplicity the superscript j),

$$u(C(C_t^T, C_t^N) - z(H_t)) \equiv \frac{1}{1-\rho} \left(C_t - \frac{H_t^\delta}{\delta} \right)^{1-\rho}, \quad (2)$$

where δ is the elasticity of labor supply with respect to the real wage and ρ is the coefficient of relative risk aversion. The consumption basket C is a composite of tradable and non-tradables goods:

$$C_t \equiv \left[\omega^{\frac{1}{\kappa}} (C_t^T)^{\frac{\kappa-1}{\kappa}} + (1-\omega)^{\frac{1}{\kappa}} (C_t^N)^{\frac{\kappa-1}{\kappa}} \right]^{\frac{\kappa}{\kappa-1}}. \quad (3)$$

The parameter κ denotes the elasticity of intratemporal substitution between consumption of tradable and nontradable goods, while ω represents a weighting factor. The corresponding aggregate price index is given by

$$P_t = \left[\omega + (1-\omega) (P_t^N)^{1-\kappa} \right]^{\frac{1}{1-\kappa}};$$

the price of tradables is normalized to 1.

Households maximize utility subject to the following period budget constraint expressed in units of tradable consumption (where again for simplicity we omit the superscript j):

$$C_t^T + (1 + \tau_t^N) P_t^N C_t^N = \pi_t + W_t H_t - B_{t+1} - (1+i) B_t - T_t^T - P_t^N T_t^N, \quad (4)$$

where W_t is the real wage, B_{t+1} denotes the amount of bonds issued with gross real return $1+i$, τ_t^N is a distortionary taxes on non-tradables consumption, and T^T and T^N are lump sum taxes in units of tradables and non-tradables, respectively. π_t represents per capita firm profits and $W_t H_t$ represents the household labor income.

International capital markets are incomplete and, as in Mendoza (2002), we assume that access to the international financial market is also constrained. We assume that the amount that each individual can borrow internationally is limited by a fraction of his current total income:

$$B_{t+1} \geq -\frac{1-\phi}{\phi} [\pi_t + W_t H_t]. \quad (5)$$

This constraint (5) depends endogenously on the current realization of profits and wage income. Roughly speaking, the constraint assumes that only a fraction of current income can be effectively claimed in the event of default, so lenders are unwilling to permit borrowing beyond that limit.⁴

Households maximize (1) subject to (4) and (5) by choosing C_t^N, C_t^T, B_{t+1} , and H_t . The first order conditions of this problem are the following⁵:

$$\frac{C_{C_t^N}}{C_{C_t^T}} = (1 + \tau_t^N) P_t^N, \quad (6)$$

$$u_{C_t} C_{C_t^T} = \mu_t, \quad (7)$$

$$\mu_t + \lambda_t = \exp(-\beta \ln(1 + C(C_t^T, C_t^N) - z(H_t))) (1 + i) E_t[\mu_{t+1}], \quad (8)$$

and

$$z_H(H_t) = C_{C_t^T} W_t \left[1 + \frac{\lambda_t}{\mu_t} \frac{1 - \phi}{\phi} \right]. \quad (9)$$

μ_t and λ_t are the multipliers on the budget and liquidity constraint, respectively. As usual, the relevant transversality conditions are assumed to be satisfied.⁶

2.2 Firms

Following Mendoza (2002) our small open economy is endowed with a stochastic stream of tradable goods, $\exp(\varepsilon_t^T) Y^T$, where ε_t^T is a random Markov disturbance, and produces non-tradable goods, Y^N . Firms produce non-tradables goods Y_t^N based on a Cobb-Douglas technology

$$Y_t^N = AK^\alpha H_t^{1-\alpha},$$

⁴See Kiyotaki and Moore (1998) for a formal derivation of a similar constraint based on collateral and Arellano and Mendoza (2002) for a discussion of alternative specifications.

⁵We denote with $C_{C_t^N}$ the partial derivative of the consumption index C with respect to non-tradable consumption. u_C denotes the partial derivative of the period utility function with respect to consumption and z_H denotes the derivative of labor disutility with respect to labor.

⁶Transversality conditions are not innocuous in our model, as they will be violated by some initial conditions on debt.

where K is the constant capital stock and A is a scaling factor. Firms choose labor demand H_t to maximize current-period profits π_t :

$$\pi_t = \exp(\varepsilon_t^T) Y^T + P_t^N AK^\alpha H_t^{1-\alpha} - W_t H_t.$$

In equilibrium, the first order condition for the labor demand gives

$$W_t = (1 - \alpha) P_t^N AK^\alpha H_t^{-\alpha}, \tag{10}$$

so the wage is equal to the value of the marginal product. We assume that ε^T is a two-state symmetric process. We abstract from other sources of macroeconomic uncertainty, such as shocks to the technology for producing non-tradables or the world interest rate, because the optimal policy response does not change when we introduce them.

2.3 Government

We follow Mendoza (2002) and assume that the government runs a balanced budget in each period, so that the consolidated government budget constraint is given by

$$\exp(G_t^T) + P_t^N \exp(G_t^N) = \tau_t^N P_t^N C_t^N + T_t^T + P_t^N T_t^N.$$

Stabilization policy is implemented by means of a distortionary tax rate τ_t^N on private domestic non-tradables consumption.⁷

Movements in the primary fiscal balance are offset via lump-sum rebates or taxes. As in Mendoza (2002), we assume that the government keeps a constant level of non-tradable expenditure financed by a constant lump-sum tax (i.e. $\exp(G^N) = T^N$). Changes in the policy variable τ^N are financed by a combination of changes in the lump-sum transfer on tradables, T_t^T and the endogenous response of the relative prices, for given public expenditures on tradable and non-tradables. This simplifying assumption implies that we abstract from the important practical issue of how to finance changes in the tax rate in the case in

⁷Mendoza and Uribe (2000) emphasize how movements in the tax rate can approximate some effects induced by currency depreciation in monetary models of exchange rate determination. As such, it captures one important aspect of monetary policy in emerging markets, which is distinct from the more conventional role of monetary policy in the presence of nominal rigidities.

which these changes would require a subsidy ($\tau^N < 0$). On the other hand this will allow us to focus on the implications of the occasionally binding constraint for the design of the tax policy abstracting from other optimal tax policy considerations.⁸

2.4 Aggregation and equilibrium

We now consider the aggregate equilibrium conditions. Combining the household budget constraint, government budget constraint, and the firm profits we have that the aggregate constraint for the small open economy can be rewritten as

$$C_t^T + P_t^N C_t^N + B_{t+1} = \exp(\varepsilon_t^T) Y^T + P_t^N Y_t^N + (1+i) B_t - \exp(G_t^T) - P_t^N \exp(G_t^N),$$

and the equilibrium condition in the non-tradeable good sector is

$$C_t^N + \exp(G_t^N) = Y_t^N = AK^\alpha H_t^{1-\alpha}. \quad (11)$$

Combining these two equations we have

$$C_t^T = Y_t^T - \exp(G_t^T) - B_{t+1} + (1+i) B_t. \quad (12)$$

Using the definitions of firm profit and wages, the liquidity constraint becomes

$$B_{t+1} \geq -\frac{1-\phi}{\phi} [\exp(\varepsilon_t^T) Y^T + P_t^N Y^N]. \quad (13)$$

3 Calibration and Solution

In this section we discuss model calibration and solution. The calibration of the model is reported in Table 1 and largely follows Mendoza (2002), who calibrates his model to the Mexican economy. To implement this calibration we select the parameters (β, ω, A) to obtain a steady state net foreign liability to GDP ratio of 45 percent, a steady state ratio of tradable to non-tradables consumption of 60 percent, and a steady state relative price of non-tradables equal to one. We choose government spending to be 20 percent in each

⁸We plan to study alternative financing plans in a revision of this paper.

sector, and follow Mendoza (2002) in choosing $\rho = 1$ and $\delta = 2$. We set $\phi = 0.5$, so that the credit constraint is not binding in the deterministic steady state of the model, but can bind with non-zero probability in the stochastic simulations of the model. One important difference compared to Mendoza (2002) is the value of the interest rate; to better reflect the high interest rates that typically prevail in emerging markets, we set $i = 0.0362$ rather than $i = 0.016$. Thus, our value for β is considerably higher than the value used by Mendoza (2002).

In order to compute the competitive equilibrium of the economy, we solve a quasi-planner problem that satisfies the following Bellman equation:

$$V(B_t, \varepsilon_t^T) = \max_{B_{t+1}} \left\{ u(C_t - z(H_t)) + \exp(-\beta \ln(C_t - z(H_t))) E[V(B_{t+1}, \varepsilon_{t+1}^T)] \right\}. \quad (14)$$

The constraints on the problem are the competitive equilibrium conditions (6)-(9), the aggregate consumption definition (3), and the collateral constraint (5). Our algorithm for solving this functional equation is contained in Appendix B. To summarize, we use a spline parameterization for the value function, solve the maximization using feasible sequential quadratic programming methods, and solve for the fixed point using value iteration with Howard's improvement steps.

Figure 1 plots the policy function $B_{t+1} = g(B_t, \varepsilon_t^T)$ for the case in which $\tau^N = 0$. Panel A considers $\kappa = 0.5$ and shows that the decision rule for the low state intersects the 45° line at the boundary of the constrained region; that is, if the economy perpetually received the low shock, it would converge to a level of debt for which the collateral constraint is just binding. If the economy happened to find itself in the interior of the constrained region, it would diverge to $B = -\infty$, violating the implicit no-Ponzi condition that requires long-run solvency. Therefore the decision rules must be truncated at the boundary; this divergence would also occur if the economy happened to be currently in the high state, since there exists a positive probability that the state would switch. Panel B considers the case of κ larger than one (i.e., $\kappa = 2$). The decision rule for the low state intersects the 45° line at the boundary of the constrained region as in the case in which $\kappa = 0.5$. However, there now exists the optimal decision rule for the economy *inside* the constrained region for both

the high and low state of the productivity process. Therefore, if the economy starts in the interior of the constrained region, it will move out of it in a finite number of periods with probability one, and without ever returning inside the constrained region. This difference is due to the fact that with $\kappa > 1$, higher labor effort covers the total income shortage in order to meet the borrowing constraint.

Figure 2 compares the equilibrium functions with and without the credit constraint. The first point to observe is that both labor effort and consumption are lower in the presence of the credit constraint, reflecting precautionary savings motives driven by the possibility of hitting the constraint. Consumption is lower because households save a higher fraction of their market resources to accumulate foreign assets; the reduction in consumption drives down the relative price of non-tradables, reducing the real wage and lowering labor effort.⁹ These equilibrium functions also demonstrate the sharp decline in aggregate activity generated by a Sudden Stop—as the debt position of the economy approaches the credit constraint, both consumption and labor effort drop dramatically, dragging down the relative price of non-tradables and total non-tradables output.¹⁰ The shape of these functions are important when discussing the cause of the Sudden Stop in this model. Sudden Stops are caused by a succession of bad shocks in the model, not by one bad draw, but the effects are felt before the economy reaches the binding region.

Precautionary saving induced by the constraint is quantitatively significant in the model. To quantify it, note that the average net foreign asset position in the ergodic distribution of the economy with no stabilization policy and no collateral constraint is $B = -3.3$ (or about -150 percent of GDP), while in the economy with no stabilization policy and the constraint has $B = -0.822$ (or about -30 percent of GDP). This difference is very large, considering the small shocks that hit this economy and the low degree of risk aversion. In contrast, Aiyagari (1994) found that measured uninsurable idiosyncratic earnings risk, which is an order of magnitude larger than the shocks here, generates only a 3 percent increase in the aggregate

⁹For the preferences considered here, there is no wealth effect on labor supply, so the substitution effect driven by the low cost of leisure is the only effect operative.

¹⁰Concave consumption functions are a standard prediction of buffer stock models of precautionary savings (See Carroll, 2004).

capital stock. The main reason that precautionary savings is large here is the fixed return to saving (i.e. the foreign interest rate); additional wealth accumulation does not reduce the return, a mechanism that tends to weaken precautionary wealth accumulation in closed economy settings, such as the one studied by Aiyagari (1994).

4 Optimal Policy

To compute the optimal policy we add τ^N as a control to (14) and solve the problem with the same approach. The policy function for τ^N , as well as for total lump sum transfers over GDP (to quantify the financing costs of the policy action), for the two states of the tradable endowment process is plotted in Figure 3.

Optimal policy is nontrivial in this model economy and may have two roles. First, as in other incomplete market models (such as Aiyagari 1995), it may be possible to increase welfare by choosing policies that reduce agents precautionary savings. This role for policy is independent of the presence or absence of the credit constraint and relies only on the general inefficiency of incomplete market models.¹¹ The second role for policy is related to the occasionally binding credit constraint. There are two possible (though not exclusive) goals for policy in the presence of the this credit constraint—to reduce the probability of reaching the constraint or minimize the effects when it binds. We find that optimal policy actually achieves both goals. it lowers the likelihood of entering the binding region and it mitigates the effects of the binding constraint by “moving” it outward, in the sense that policy is chosen so as to make the multiplier exactly zero in all periods, in both binding and nonbinding states.

In the model without a collateral constraint, there is no policy trade off, and setting $\tau^N = 0$ is always optimal, despite the incompleteness of the international asset market. The tax wedge τ^N does not affect the intertemporal decisions in the model and hence has no role to play to mitigate the consequence of market incompleteness. In the model with the

¹¹Our model also features an externality—the elastic discount factor depends on aggregates and therefore agents do not internalize the effect of current consumption and labor supply on discounting. But this effect should be minor since the discount factor is nearly inelastic.

constraint, there is a trade-off between efficiency (i.e., to minimize marginal distortions by setting $\tau^N = 0$), and the need to reduce the probability of hitting the constraint or relax it when it is binding. When the constraint (13) is binding, the optimal policy for τ^N is to subsidize aggressively non-tradable consumption. In the region of the state space in which the constraint (13) is not binding, the optimal policy is again $\tau^N = 0$. This latter result has the important implication that policy in tranquil times can be modelled satisfactorily as in the case in which there is no constraint, provided no other distortions affecting private sector behavior are present.

The effect of decreasing τ^N optimally can be observed in Figure 4, which plots the policy functions for labor supply, the value of non-tradables output, and total consumption, as well as the value function, with $\tau^N = 0$ and τ^N optimally set. As we can see the effect of setting policy optimally is to smooth the non-linearity in the policy functions for any level of the endogenous state. With such a subsidy, demand and to a lesser extent supply for non-tradable goods increases, as a result the relative price of non-tradables goods rises, yielding higher non-tradables output and hence collateral for the credit constraint. And more collateral permits the economy to borrow more than it otherwise could do in the absence of a policy response.¹²

Figure 4 also shows that the optimal policy of τ^N is such that the liquidity constraint becomes “just binding”; that is, the policy function for B_t is tangent to the binding region and the corresponding multiplier λ_t of the liquidity constraint remains 0. The goal of optimal policy is to distort the economy as little as possible, and any deviation of the shadow price of the credit constraint from zero is costly. Therefore the planner relaxes the constraint just enough to make it non-binding. But the constraint is not relaxed beyond this, because that involves additional subsidies that are welfare-reducing if the constraint is not restricting consumption possibilities further.

¹²Interestingly, results for $\kappa > 1$ (not reported), with and without optimal tax policy, show that consumption, labor, and nontradable price are all increasing when B becomes more negative with optimal tax policy, as opposed to decreasing when B becomes more negative without optimal tax policy. The value function with optimal tax policy decreases smoothly when B becomes more negative, while it declines sharply to minus infinity in the low state without optimal tax policy.

The average net foreign asset position in the ergodic distribution of the economy is affected significantly by optimal policy, reflecting the effects of the subsidy on private precautionary savings (See Figure 7): relative to the no stabilization case (with the credit constraint), average debt increases by about 25 percent under the optimal policy to yield a net foreign asset position of about -40 percent of GDP. When measured as a fraction of total precautionary savings generated in the model with the credit constraint, the optimal policy reduces it by 12.5 percent, a nontrivial number. However, the probability of hitting the constraint in the ergodic distribution is 0.15 with optimal tax policy and 0.13 without the optimal tax policy, reflecting in part our choice to set $\phi = 0.5$ in the baseline calibration.¹³

The optimal policy is state-contingent, requiring knowledge of the unobservable shocks for its implementation. We therefore explore also the impact of simple, constant subsidy rules that are not state contingent and can be easily financed (meaning relatively small). Figure 5 reports the binding regions corresponding to alternative fixed levels of τ^N . The corresponding binding region shrinks as the level of the subsidy increases, since the subsidy induces additional non-tradables output.¹⁴

5 Sensitivity Analysis

In this section we explore the robustness of the main results of the analysis to a number of alternative model specifications. We consider alternative values for key structural parameters, as well as alternative parametrizations of the stochastic process for the tradable endowment.

5.1 Alternative parameter values

As the optimal policy hinges on the labor effort behavior and the substitutability between tradable and non-tradable goods in consumption, it is important to consider alternative values for κ , δ , and ϕ . We consider six alternative cases, each of which entails changing only

¹³The Appendix explains how we plan to compute the welfare gains from optimal policy, in terms of consumption equivalents, but these calculations have not been implemented yet.

¹⁴Interestingly, this suggests that a small overvaluation, which effectively subsidizes consumption of non-tradable goods, may be a desirable policy option.

one parameter at a time, and the results are summarized in Figure 6. The figure plots the decision rules only for the low productivity state. We consider the following alternative cases: $\kappa = .3$ and $\kappa = 1.8$ (less or more substitutability between tradable and non tradable goods in consumption than in the baseline); $\delta = 1.2$ or $\delta = 5$ (higher and lower labor elasticity than in baseline); and $\phi = 0.5$ or $\phi = 0.7$ (credit constraint less or more likely to be occasionally binding). As we can see the results are broadly robust, except in the case of a lower labor effort curvature.

When tradables and non-tradables goods become closer substitutes ($\kappa = 1.8$), optimal policy would cut taxes less aggressively compared to the baseline specification. The general principle of optimal policy is to relax the borrowing constraint by increasing the value of collateral when the constraint becomes binding (i.e. by raising $P_t^N Y_t^N$). When the intratemporal elasticity of substitution between tradables and non tradables is higher, it is more efficient to do so by increasing the relative price of non-tradables and decreasing non tradables production. Indeed, for a given relative price of non tradables and a given subsidy, a higher substitutability between tradables and non tradables will push the demand for tradable goods higher. Since tradable output is exogenously given, demand needs to be decreased in order to clear the tradable goods market if the economy cannot borrow from abroad. For a relatively higher κ this could be achieved with a relatively lower subsidy. Non-tradables demand will rise relatively more than with a lower κ so that the relative price of non tradables is higher, real wages are lower, and non-tradables production is lower since agents will decrease their labor supply (there is only the substitution effect here determined by the decrease in real wages). The opposite logic applies in the case in which $\kappa = .3$.

When labor supply becomes more elastic ($\delta = 1.2$), optimal policy would cut taxes more aggressively compared to the baseline specification. In this case it is efficient to relax the borrowing constraint by increasing non-tradables production and decreasing the relative price of non-tradables. Indeed, for a given real wage the more elastic is labor supply the higher is production of non-tradables. Equilibrium in the non-tradables goods market is achieved by decreasing the relative price of non-tradables and increasing demand by subsidizing non-tradables consumption more aggressively than in the baseline parametrization. The opposite

logic applies in the case in which labor supply is less elastic ($\delta = 5$).

When the constraint is more severe ($\phi = 0.7$), the probability that the constraint becomes binding is higher for a given value of the state, B_t and it is optimal to cut taxes more aggressively for a given value of the state. A higher value of the collateral is reached by increasing both the relative price of non-tradables and non-tradables production compared to the baseline specification.

5.2 Alternative parametrization of the stochastic process for the tradeable endowment

The relatively small probabilities of entering the constrained region of the state space may be affecting the results of the analysis, and may be a reflection of the assumptions made on the shock process for the tradeable endowment. A larger state space for the shocks may lead to a larger risk premium on borrowing near the constraint, and hence to additional precautionary saving. An increase in the state space of the shocks leads to a non-constant conditional probability of entering the binding state. Such changes in conditional probability very well may alter the optimal rules [TO BE COMPLETED]

6 A model with capital accumulation and alternative financing

This section investigates the role that capital may have in affecting the optimal rules. The model we use has a one factor production technology. Adding capital to the production function may lead to an optimal tax response even when the credit constraint is not binding, and hence introduce a precautionary component in the optimal policy, due to the complementarity of labor and capital. In our model, when the constraint binds, labor falls with the optimal subsidy, a result which may not be robust to the introduction of endogenous capital accumulation.

The introduction of capital also allows us to investigate alternative specifications of the budget rule and the financing of the optimal policy. In equilibrium, the amount of financing

needed to implement the optimal policy maybe large. If the budget is balanced by a distortionary capital tax rather than a lump sum tax, one may find it optimal to begin to use the consumption subsidy more actively away from the constraint. This is because in our model there is no cost of financing the (large) consumption subsidy and hence a large subsidy can be applied right when the constraint binds. If there is an increasing cost of the consumption subsidy, one may wish to start with a smaller subsidy away from the constraint that increases as the constraint is approached. Financing the subsidy through a distortionary capital tax is one way to capture this increasing cost. [TO BE COMPLETED]

7 Conclusions

In this paper we studied optimal stabilization policy in a small open economy in which there is the risk of an endogenous Sudden Stop due to the presence of an occasionally binding credit constraint. We find that, for a plausible calibration of the model, the optimal policy is non linear. If the liquidity constraint is not binding, the optimal tax rate is zero, in the absence of other distortions, like in an economy without a credit constraint. This suggests that, to a first approximation, stabilization analysis for the normal times can be conducted in more conventional models. If the liquidity constraint is binding, however, the optimal tax rate is negative, meaning that the government should subsidize non-tradables consumption. Simple, fix subsidy rules in which the tax rate is fixed at different negative values show that the region on the state space in which the constraint may bind can be reduced significantly given all other structural parameters. Completing a thorough sensitivity analysis of these results is work in progress.

A Appendix

This appendix reports the model steady state and provides the details of the numerical algorithm we use to solve the model and compute optimal policy.

A.1 Steady State

The deterministic steady state equilibrium conditions are given by the following set of equations. The first four correspond to the first order conditions for the household maximization problem,

$$\begin{aligned} \left(\frac{1-\omega}{\omega}\right)^{\frac{1}{\kappa}} \left(\frac{C^T}{C^N}\right)^{\frac{1}{\kappa}} &= (1+\tau^N)P^N, \\ \left(C - \frac{H^\delta}{\delta}\right) \omega^{\frac{1}{\kappa}} \left(\frac{C^T}{C}\right)^{-\frac{1}{\kappa}} &= \mu, \\ \left(1 + \frac{\lambda}{\mu}\right) &= \exp\left(-\beta \ln\left(1 + C - \frac{H^\delta}{\delta}\right)\right) (1+i), \\ H^{\delta-1} &= W \omega^{\frac{1}{\kappa}} \left(\frac{C^T}{C}\right)^{-\frac{1}{\kappa}} \left[1 + \frac{\lambda}{\mu} \frac{1-\phi}{\phi}\right], \end{aligned}$$

and the fifth is the definition of the consumption index:

$$C \equiv \left[\omega^{\frac{1}{\kappa}} (C^T)^{\frac{\kappa-1}{\kappa}} + (1-\omega)^{\frac{1}{\kappa}} (C^N)^{\frac{\kappa-1}{\kappa}} \right]^{\frac{\kappa}{\kappa-1}}.$$

The other equilibrium conditions are given by the liquidity constraint

$$B \geq -\frac{1-\phi}{\phi} [Y^T + P^N Y^N]$$

and the equilibrium condition in the tradable sector that will determine the level of tradable consumption in the case in which the liquidity constraint is binding (i.e. $\lambda > 0$)

$$C^T + B = Y^T + (1+i)B - G^T.$$

We then have the production function for the non-tradeable sector and the good market equilibrium for non tradeables.

$$\begin{aligned} Y^N &= AK^\alpha H^{1-\alpha} \\ Y^N &= C^N + G^N. \end{aligned}$$

A.2 Solution Algorithm

Our algorithm is a standard value iteration approach augmented with Howard’s improvement algorithm, also known as policy function iteration.¹⁵ We initialize the algorithm by guessing a value function on the right-hand-side of equation (14). This guess consists of a vector of numbers over a fixed set of nodes in the space (B, ϵ^T) . We then extend the value function to the entire space for B by assuming it is parameterized by a linear spline.

To perform the maximization we use feasible sequential quadratic programming; we first proceed by assuming that the constraint is not binding and solving the optimization problem, obtaining the values for all variables other than B using the competitive equilibrium equations (3), (??), (6), (9), (10), (11) (this step involves solving one equation numerically, which we do using bisection). After the maximization step has obtained a candidate solution we check whether it violates the credit constraint. If it does not, we have computed the maximum for that value in the state space. If the constraint is violated, we replace (9) with (13) holding with equality and solve as before. In some cases, particularly when $\kappa > 1$, there may exist multiple solutions to the equilibrium conditions for given values of (B, B') when the constraint is binding; in these cases we use (9) to compute a value for λ and choose the solution where $\lambda \geq 0$. Thus, we have computed

$$\widehat{V}_0(B_t, \epsilon_t^T) = \max_{B_{t+1}} \left\{ u(C_t - z(H_t)) + \exp(-\beta \ln(1 + C_t - z(H_t))) E \left[V^n(B_{t+1}, \epsilon_{t+1}^T) \right] \right\}.$$

We then use Howard’s improvement algorithm, which iterates on the functional equation

$$\widehat{V}_{n+1}(B_t, \epsilon_t^T) = u(C_t - z(H_t)) + \exp(-\beta \ln(1 + C_t - z(H_t))) E \left[\widehat{V}_n(B_{t+1}, \epsilon_{t+1}^T) \right], \quad (15)$$

where the difference between this equation and (14) is the absence of a maximization step. After N iterations on this equation, we compute the updated value function as $V^{n+1}(B_t, \epsilon_t^T) = \widehat{V}_N(B_t, \epsilon_t^T)$.

We continue until the value function converges. In our implementation we set $T = 40$, although a much smaller number of policy maximization steps is usually sufficient to achieve

¹⁵Judd (1999) and Sargent (1987) contain references for Howard’s improvement algorithm, which is also referred to as policy iteration.

convergence. The number of nodes on the grid for B is 25, and we place most of them in the constrained region where the value function displays severe curvature.

Our algorithm is robust to a number of changes—dropping Howard’s improvement, using cubic splines instead of linear ones, and using alternative maximization procedures. The method implemented is the most efficient—it requires the fewest nodes and the least amount of computational time. While the computational burden posed by this model is modest, once we introduce nominal rigidities, as we do in a companion paper Benigno *et al.* (2007a), computational issues are much more of a concern.

To compute welfare gains from optimal policy, we consider the functional equations

$$V_{PO}(B_t, \varepsilon_t^T) = u(C_{PO}(B_t, \varepsilon_t^T) - z(H_{PO}(B_t, \varepsilon_t^T))) + \exp(-\beta \ln(C_{PO}(B_t, \varepsilon_t^T) - z(H_{PO}(B_t, \varepsilon_t^T)))) E[V_{PO}(B_{PO}(B_t, \varepsilon_t^T), \varepsilon_{t+1}^T)]$$

and

$$V_{CE}(B_t, \varepsilon_t^T) = u(C_{CE}(B_t, \varepsilon_t^T) - z(H_{CE}(B_t, \varepsilon_t^T))) + \exp(-\beta \ln(C_{CE}(B_t, \varepsilon_t^T) - z(H_{CE}(B_t, \varepsilon_t^T)))) E[V_{CE}(B_{CE}(B_t, \varepsilon_t^T), \varepsilon_{t+1}^T)] \quad (16)$$

the first corresponds to the value function in the optimal allocation and the second to the value function in the competitive economy without stabilization policy. We then inflate total consumption in (16) by a fraction χ , keeping the decision rules fixed, so that

$$V_{CE}(B_t, \varepsilon_t^T; \chi) = u((1 + \chi) C_{CE}(B_t, \varepsilon_t^T) - z(H_{CE}(B_t, \varepsilon_t^T))) + \exp(-\beta \ln((1 + \chi) C_{CE}(B_t, \varepsilon_t^T) - z(H_{CE}(B_t, \varepsilon_t^T)))) E[V_{CE}(B_{CE}(B_t, \varepsilon_t^T), \varepsilon_{t+1}^T)]. \quad (17)$$

For each state (B_t, ε_t^T) , we set

$$V_{PO}(B_t, \varepsilon_t^T) = V_{CE}(B_t, \varepsilon_t^T; \chi)$$

and solve this nonlinear equation for χ , which yields the welfare gain from switching the optimal policy conditional on the current state. To obtain the average gain, we simulate using the decision rules from (16) and weight the states according to the ergodic distribution.

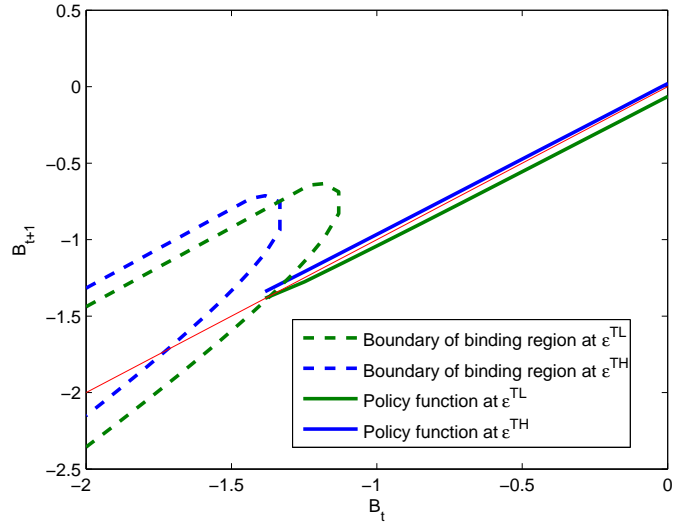
References

- [1] Aiyagari, S. Rao (1994), "Uninsured Idiosyncratic Risk and Aggregate Saving," *Quarterly Journal of Economics* 109(3), pp. 659-84.
- [2] Aiyagari, S. Rao (1995), "Optimal Capital Income Taxation with Incomplete Markets, Borrowing Constraints, and Constant Discounting," *Journal of Political Economy* 103(6), pp. 1158-75.
- [3] Arellano, Cristina and Enrique G. Mendoza (2002), "Credit Frictions and 'Sudden Stops' in Small Open Economies: An Equilibrium Business Cycle Framework for Emerging Markets Crises," in Altug, Sumru, J. Chadha, and C. Nolan, eds., *Dynamic Macroeconomic Analysis: Theory and Policy in General Equilibrium*, Cambridge University Press.
- [4] Carroll, Christopher D. (2004), "Theoretical Foundations of Buffer Stock Saving," NBER Working Paper No. 10867.
- [5] Benigno, Gianluca, Christopher Otrok, Alessandro Rebucci, and Eric R. Young (2007a), "Alternative Monetary Policy Rules in a Model with Endogenous Sudden Stops," in Siklos, Pierre (ed.), *Frontiers in Central Banking*, Frontiers in Economics and Globalization series, Elsevier.
- [6] Benigno, Gianluca, Huigang Chen, Alessandro Rebucci, and Eric R. Young (2007b), "Optimal Monetary Policy in a Model with Endogenous Sudden Stops", work in progress.
- [7] Bora Durdu, Ceyun and Enrique G. Mendoza (2005), "Are Asset Price Guarantees Useful for Preventing Sudden Stops?: A Quantitative Investigation of the Globalization Hazard-Moral Hazard Tradeoff," forthcoming *Journal of International Economics*.
- [8] Caballero, Ricardo J. and Arvind Krishnamurthy (2005), "Inflation Targeting and Sudden Stops," in Bernanke, Ben S. and Michael Woodford, eds., *The Inflation-Targeting Debate*, University of Chicago Press.
- [9] Calvo, Guillermo A. (1998), "Capital Flows and Capital-Markets Crises: The Simple Economics of Sudden Stops," *Journal of Applied Economics* 1(1), pp. 35-54.
- [10] Cúrdia, Vasco (2007), "Optimal Monetary Policy under Sudden Stops," Federal Reserve Bank of New York Staff Report No. 278.
- [11] Christiano, Lawrence J., Christopher Gust, and Jorge Roldos (2004), "Monetary Policy in a Financial Crisis," forthcoming *Journal of Economic Theory*.
- [12] Mendoza, Enrique G. (2002), "Credit, Prices, and Crashes: Business Cycles with a Sudden Stop," in S. Edwards and J. Frankel, eds., *Preventing Currency Crises in Emerging Markets*, University of Chicago Press.
- [13] Mendoza, Enrique G. and Martín Uribe (2000), "Devaluation Risk and the Business-Cycle Implications of Exchange-Rate Management," *Carnegie-Rochester Conference Series on Public Policy* 53, pp. 239-96.

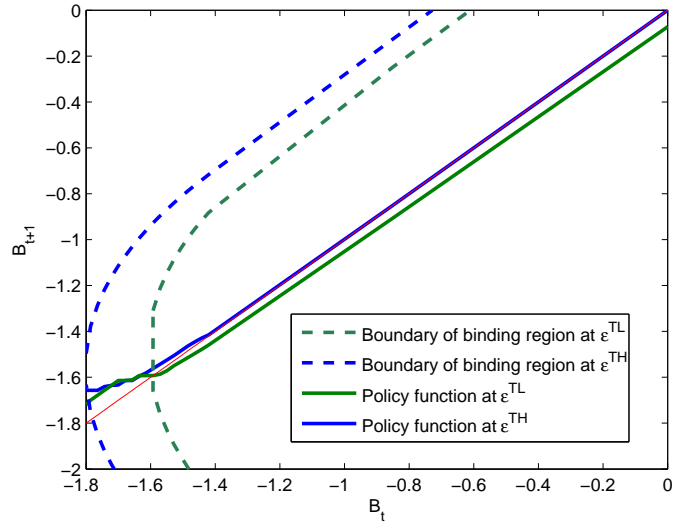
- [14] Neumeyer, Pablo A. and Fabrizio Perri (2005), "Business Cycles in Emerging Economies: The Role of Interest Rates," *Journal of Monetary Economics* 52, pp. 345–80.
- [15] Schmitt-Grohé, Stephanie and Martín Uribe (2003), "Closing Small Open Economy Models," *Journal of International Economics* 61, pp. 163-85.

Table 1. Calibrated parameters and steady state values

Structural parameter values	
Elast. of sub. (tradable and non-tradable goods)	$\kappa = 0.5$
Rel. weight of tradable and non-tradable goods	$\omega = 0.382$
Utility curvature	$\rho = 1$
Labor supply elasticity	$\delta = 2$
Labor share in production	$\alpha = 0.364$
Discount factor	$\beta = 0.0367$
Credit constraint parameter	$\phi = 0.5$
Tradable government consumption	$G_T = -1.609$
Nontradable government consumption	$G_N = -1.179$
Steady state value of endogenous variables	
Home real interest rate	$R = 0.0362$
Per capita home GDP	$Y = 2.54$
Per capita consumption	$C = 2.02$
Per capita tradable consumption	$C_T = 0.79$
Per capita non-tradable consumption	$C_N = 1.23$
Relative price of non-tradable	$P_N = 1$
Per capita NFA	$B = -0.28$
Tax rate on non-tradable consumption	$\tau = 0.0793$

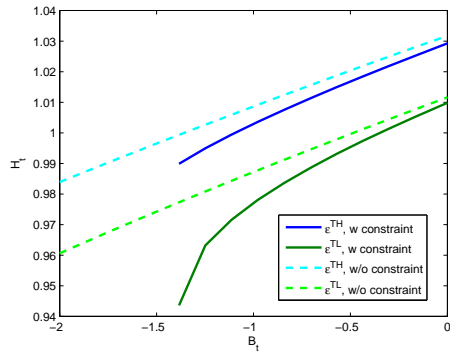


(a) $\kappa = 0.5$

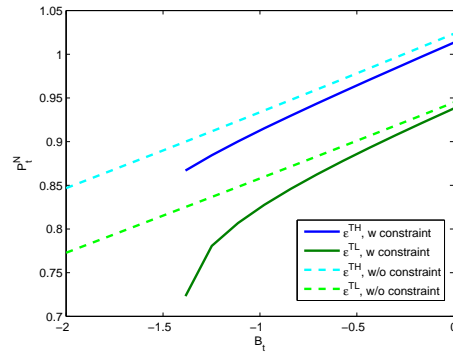


(b) $\kappa = 2$

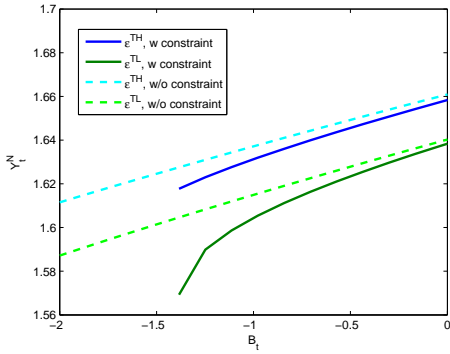
Figure 1: Policy function of net foreign asset with the liquidity constraint and $\tau_t^N \equiv 0$



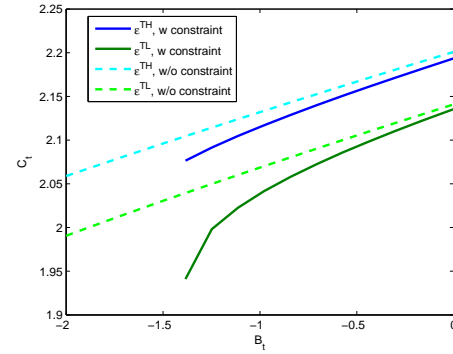
(a) Labor



(b) Nontradable price

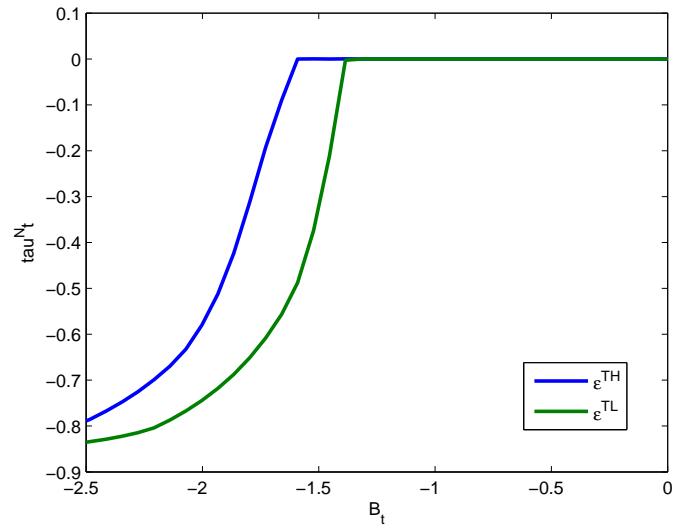


(c) Nontradable production

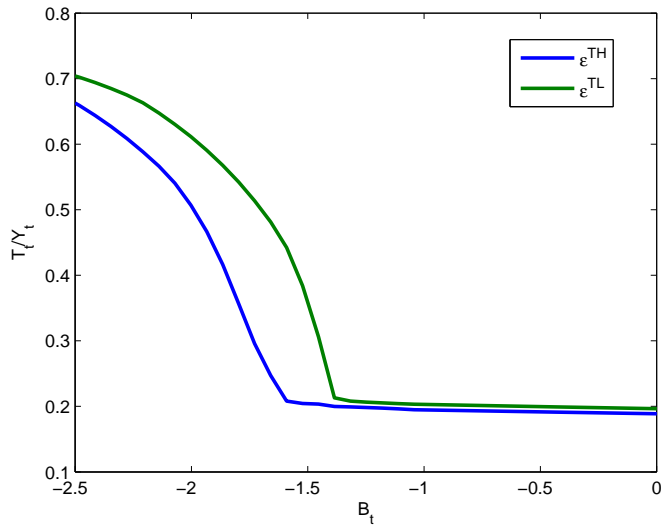


(d) Consumption

Figure 2: Policy functions for key endogenous variables with and without the liquidity constraint and $\tau_t^N \equiv 0$



(a) Policy function for τ^N



(b) Policy function for ratio of total lump-sum tax to GDP (T/Y)

Figure 3: Optimal policy for tax rate and lump-sum tax

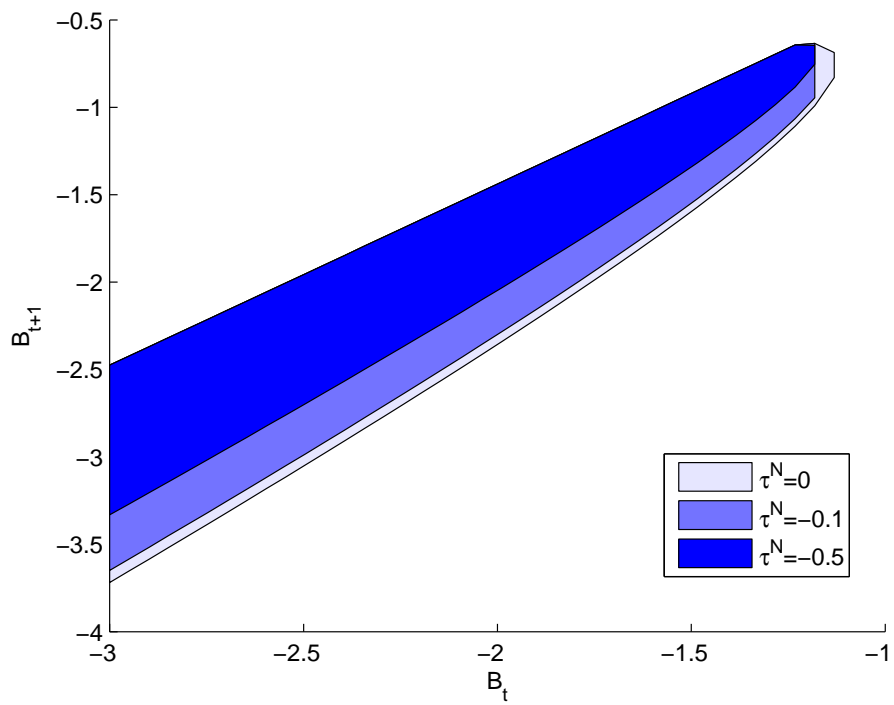
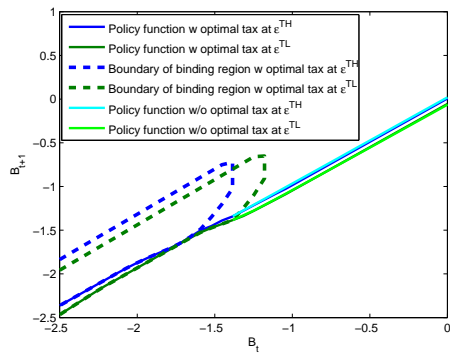
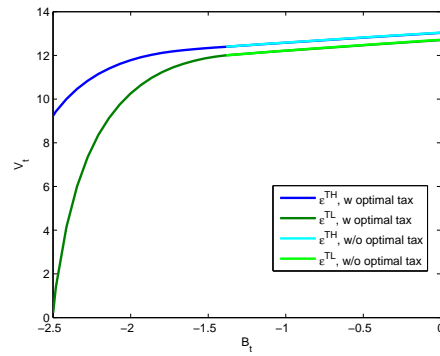


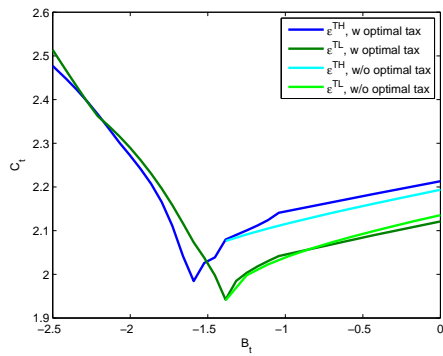
Figure 4: Binding region for alternative simple tax rate



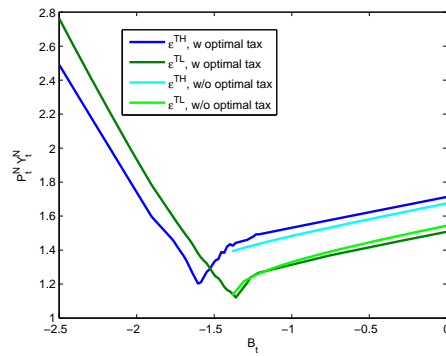
(a) Net worth asset



(b) Value function

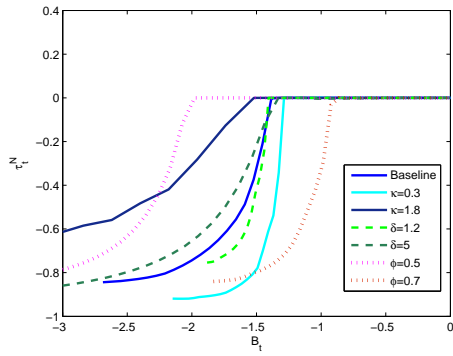


(c) Consumption

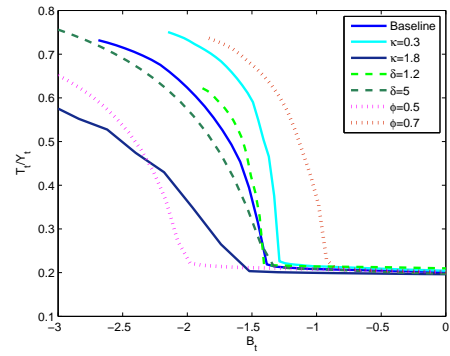


(d) Value of nontradable production

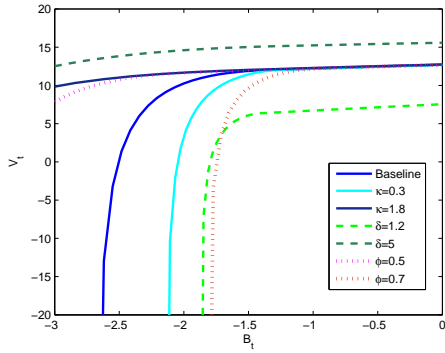
Figure 5: Policy functions for key endogenous variables with and without optimal tax policy



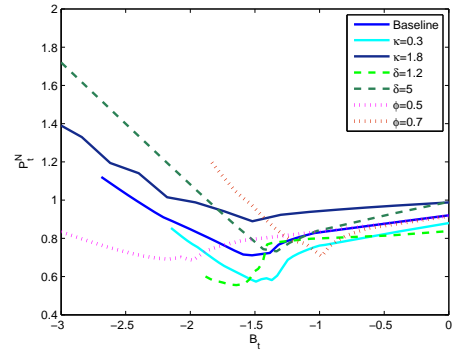
(a) τ^N



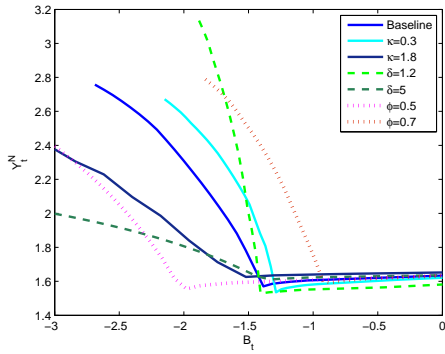
(b) T/Y



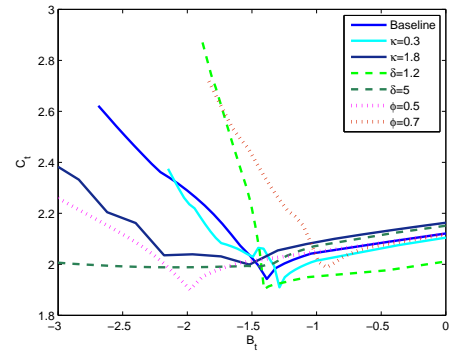
(c) V



(d) P^N



(e) Y^N



(f) C

Figure 6: Sensitivity analysis

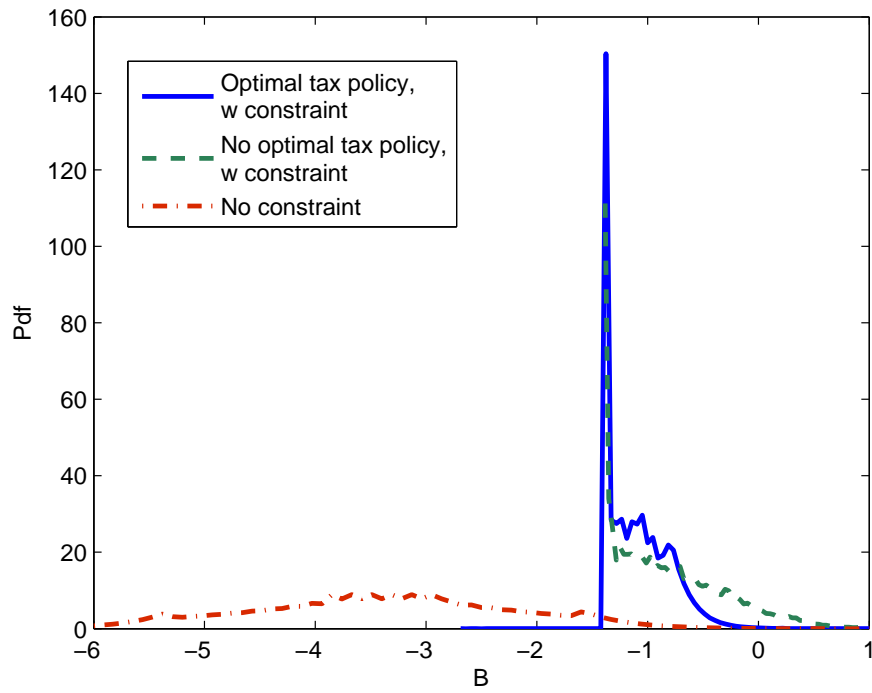


Figure 7: Limiting distributions of net assets