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The Information Content of Capital Controls

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Abstract

Capital controls, policy measures used by governments to regulate cross-country financial flows, have become standard policy options in many emerging market economies. This paper will focus on what capital controls reveal about the state of the economy and the implications of such revelation for policy efficacy. Using a small open economy model with a collateral constraint and overborrowing relative to the social optimum, this paper incorporates a representative agent's Bayesian updating of information in response to change in policy and show that the efficacy of capital controls to contain financial crises and improve welfare could be undermined if the agent rationally learns from policy. Empirically, this paper finds that capital controls convey important information market participants use to improve their understanding of fundamentals. This paper highlights the need for policymakers to consider the unintended consequences of information revelation in the design of capital flow management policies.

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The Information Content of Capital Controls*

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1 Introduction

Capital controls, residency-based or currency-based measures used to regulate cross-country financial flows, are increasingly considered part of the standard financial stability policy tool-kit for many emerging market economies(EMEs). During the first quarter of 2020, the COVID-19 crisis caused unprecedented capital outflows from EMEs, further highlighting the need to better understand capital flow management. A widely-held view in the recent academic literature and in policy institutions is that national authorities can mitigate the effects of inefficient and destabilizing capital inflows by the active use of capital controls. However, as have been found for other types of macroeconomic policies, an announcement of policy changes conveys not only the action itself, but also information about the authorities' views on the state of the economy. Rational market participants can be expected to learn from policy announcements and adjust their behavior accordingly. Capital controls can convey invaluable information about economic fundamentals.[1] The current literature has paid limited attention to the information conveyed by capital controls and what this means for policy effectiveness.

This paper shows that capital controls convey useful information about economic fundamentals and this can dampen the effectiveness of capital controls in mitigating the effects of excessive capital inflows. I analyze a small open economy model in which agent borrows more than socially optimal and capital controls are deployed to address overborrowing. Contrary to previous research, the agent in this model learns from capital controls and updates their information set of economic fundamentals accordingly. I find that when people learn from policy, capital controls can lead to unintended consequences such as larger consumption drops and currency devaluations

[1]Paul Tucker, in the International Monetary Fund(IMF)'s third rethinking macroeconomic policy conference, neatly summarized the importance of understanding information revelation as follows: *Any macroprudential measures will reveal not only the action itself but also information about the authorities' views on the state of the financial system. In contrast to monetary policy, where the data on the economy are in the public domain, a prudential policymaker has lots of private information about vulnerabilities in individual financial institutions and the linkages among those institutions. If the market is surprised that the policymaker is concerned enough to act, credit conditions might tighten sharply if market participants conclude, on the basis of the information newly available to them, that the actions taken are insufficient. If, by contrast, the market has been ahead of the authorities in sporting a lurking threat to stability and so is relieved that the policymaker is finally waking up, credit conditions might even ease. There are many scenarios in-between.*

during a financial crisis. Moreover, welfare gains from policy may become negative. Empirically, I present evidence from Brazilian data that expectations of economic fundamentals respond to capital control announcements: first, the paper uses a high-frequency strategy to show that such announcements tend to affect daily forecasts of GDP collected by the Central Bank of Brazil; second, the paper constructs an econometric model to nowcast Brazilian GDP with real-time macroeconomic data, and shows that such announcements reduce the forecast errors of the model.

In the theoretical section, I incorporate learning from policy into a standard model researchers use to study capital controls in emerging market economies. In this two-sector small open economy model, borrowing by domestic agent is limited by tradable and nontradable income through a collateral constraint. This environment features a pecuniary externality because individual agents do not internalize the effect of their borrowing decisions on the value of collaterals and hence on borrowing capacity. Capital controls are usually deployed by the government to mitigate the effect of over-borrowing by agents arising from the pecuniary externality. I incorporate three novel features in this setting to model learning from policy: first, the government knows more about future economic fundamentals than the representative agent. Second, the agent knows that the government is levying capital control taxes according to a simple policy rule which reveals useful information previously unknown to her. Last but not least, the agent learns from policy by completing a Bayesian updating of her information set when she observes policy changes.

A version of my model is calibrated to the Brazilian economy and the quantitative model features unintended consequences of capital controls when people learn from policy. I choose the Brazilian economy between 2006 and 2013 because the country experienced large and volatile capital inflows during the period and actively used capital controls to manage such inflows with some success. I solve the calibrated model for the decentralized equilibrium[2], the equilibrium with policy interventions but no learning from policy and most importantly, the equilibrium with both. When people learn from policy, the domestic economy borrows more from foreign countries and experiences more severe financial crisis in the sense of larger consumption drops,

[2]Equilibrium with no policy intervention

real exchange rate depreciations and capital outflows relative to the cases of no policy and no learning. This is because agents are less uncertain about the future and save less for precautionary reasons. When this mechanism is strong enough, imposing capital controls could result in welfare losses relative to the decentralized equilibrium.

The key assumption in my model is that people learn about economic fundamentals from capital controls. In the empirical section, I provide some evidence of this assumption from an event study of capital control announcements in Brazil and from an exercise nowcasting Brazilian real GDP. Event studies using high-frequency data show that expectation of economic fundamentals in Brazil respond meaningfully to major capital control announcements. Specifically, I use daily survey data of market participants' median expectation of quarterly real GDP growth collected by the Central Bank of Brazil and I consider six major capital control announcements in the country between 2008 and 2013. On average, a tightening(loosening) announcement is associated with a downward(upward) revision of real GDP growth forecast of 0.23%.

Since the survey data averages many forecasters' expectations constructed with different methodologies, and hence can be hard to interpret in greater details, I provide a second set of empirical evidence by taking a stand on how to form expectations of fundamentals. Specifically, I put myself in the position of a forecaster who employees a commonly-used econometric model and uses all types of available macroeconomic data to produce nowcasts[3] of Brazilian quarterly GDP growth rates in real-time. Including capital control announcements in the forecaster's information set helps improve the precision of her nowcast. The magnitude of such improvement measured in the nowcasting model provides a basis for the calibration of key model parameters related to Bayesian updating and learning in my quantitative model earlier.

2 Literature Review

This paper contributes to several strands of the international macroeconomics literature. First, it adds to the recent theoretical literature of macro-prudential policies and

[3] A nowcast is a forecast of the present or the very-near future when data have yet to be released.

capital controls(Erten, Korinek and Ocampo(2020) provides a nice summary of this literature) by incorporating signaling through and learning from such credit regulations. Academic and policy consensus prior to the global financial crisis(GFC) viewed restrictions to free financial flows across countries as almost undesirable as restrictions on free trade. The policy consensus has shifted in the wake of the GFC (see Ostry et al. (2010) and IMF Strategy, Policy and Review department (2011)), and the recent academic literature is now focused on better understanding the proper role of capital controls. A number of papers, including Mendoza (2010), Korinek and Jeanne (2010), Bianchi (2011), Korinek (2011), Jeanne (2012), Brunnermeier and Sannikov (2014), Heathcoate and Perri (2016), among others, explore the role of macro-prudential interventions or restrictions on capital flows by introducing an externality of people not considering the effect of their actions on borrowing capacity. My paper builds on Bianchi (2011) and Bianchi, Mendoza and Liu (2016). In the former, uncertainties regarding economic fundamentals are present, but the representative agent does not attempt to reduce it. In the latter, the agent receives a noisy but useful signal about fundamentals to learn from. However, the signal is an exogenous state variable and hence the agent's information set does not change with respect to policy actions. My paper differs from both of these papers: the agent learns from policy actions and hence her information set changes with respect to policy.

Second, this paper also contributes to the empirical literature on capital controls. Instead of focusing on the efficacy (Edison and Rehinhart (2001), Forbes (2007), Edwards and Rigobon (2009), Magud, Reinhart and Rogoff (2011), Klein(2012), Forbes et al. (2015), Ben Zeev (2017), to name only a few) or unintended consequences ((Miniane and Rogers (2004), Forbes et al. (2016) among others)) of capital controls, I attempt to identify the empirical relationship between capital control announcements and expectations of fundamentals by looking at high-frequency survey data and by employing a nowcasting model, an empirical methodology new to this literature. Moreover, my model provides possible explanations for some empirical findings in this literature, such as these in Klein (2012) and Forbes et al. (2015).

Last but not least, this paper joins several earlier papers to explore signaling of and learning about fundamentals through macroeconomic policies in general. Most notably, Nakamura and Steinsson(2016) argue that people's belief about underlying economic fundamentals (the natural rate of interest) change with Federal Reserve announcements, and this information mechanism has important implications for the overall effectiveness of U.S. monetary policy, as it works against the traditional mechanism in a New Keynesian motenary model. Garcia-Schmidt (2015) considers information asymmetry between the government and a foreign lender in an equilibrium sovereign default model. When the foreign lender knows less about future output than the government, volatility of sovereign spreads increases substantially. My paper pursues a similar research agenda for a different kind of policy.

3 A model where agent learns from capital controls

In this section, I construct a two-sector small open economy model with three novel features to study the implications of agent learning from capital controls. The model features an occasionally binding collateral constraint which limits international borrowing, as in Bianchi (2011). There are three main points of departure from previous studies: 1) Asymmetric information between government and the representative agent: government knows more about economic fundamentals, and the agent knows that government knows more. 2) Government levies capital control taxes according to a simple policy rule which reveals its superior information of fundamentals. 3) The agent learns about fundamentals from capital controls by completing a Bayesian updating of her information set upon observing a policy action.

3.1 Representative agent's problem

Consider a representative agent DSGE model with a tradable goods sector and a nontradable goods sector. Tradable goods can be sold to foreigners and nontradable goods can only be consumed in the domestic economy. The economy is populated by a continuum of identical, infinitely-lived agents with preferences given by:

$$E_0 \Sigma_{t=0}^{\infty} \beta^t u(c_t) \tag{1}$$

$$c_t = [\omega (c_t^T)^{-\eta} + (1-\omega)(c_t^N)^{-\eta}]^{-\frac{1}{\eta}} \tag{2}$$

where β is the discount factor, the period utility function $u(.)$ has the constant-relative-risk-aversion(CRRA) form and c_t is a CES aggregator of tradable and non-tradable goods with elasticity of substitution $\frac{1}{1+\eta}$. In each period, the agent receives an endowment of tradable goods y_t^T, which follows a first-order Markov process, and an endowment of nontradable goods y_t^N, which is normalized to 1 for convenience.

The only foreign financial asset available is a one-period, non state-contingent bond denominated in units of tradables. The bond pays an interest rate R_t, which follows an exogenous process driven by global liquidity conditions. This assumption is meant to capture the observation that emerging economies usually borrow in short-term debt denominated in foreign currency. In each period, the government levies a capital control tax τ_t on bond issued in the current period maturing in the next period. Tax revenue collected from the capital control tax is rebated to the agent as a lump-sum transfer, T_t.

In each period, the agent chooses tradable consumption, nontradable consumption and bond holdings to maximize the expected discounted sum of her utility, subject to equation 3, her budget constraint and equation 4, her collateral constraint:

$$(1+\tau_t) b_{t+1} + c_t^T + p_t^N c_t^N = b_t(1+R_t) + y_t^T + p_t^N y_t^N + T_t \tag{3}$$

$$b_{t+1} \geq -(\kappa^N p_t^N y_t^N + \kappa^T y_t^T) \tag{4}$$

where the price of tradables is normalized to 1. As in Bianchi(2011), the central externality of this model is introduced through the collateral constraint, which restricts the amount of debt to a fraction of the market value of the agent's tradable and nontradable endowment income[4]. This collateral constraint is usually perceived as

[4]As in the literature, the margin requirement is the same for tradable and nontradable endowments. There are reasons to believe that the margin requirement should be different, as nontradables are harder to seize in the event of default. Appendix A.D provides a more detailed discussion on

arising from institutional or informational frictions which are not modeled explicitly. The first-order conditions with respect to c_t^T,c_t^N and b_{t+1} are given below:

$$\lambda_t = u_T(t) \tag{5}$$

$$p_t^N = (\frac{1-\omega}{\omega})(\frac{c_t^T}{c_t^N})^{\eta+1} \tag{6}$$

$$\lambda_t = \beta(1+R_t)(1+\tau_t)E_t\lambda_{t+1} + \mu_t \tag{7}$$

where λ_t and μ_t are Lagrangian multipliers of the budget constraint and the collateral constraint and they may be interpreted as the shadow value of wealth and the shadow benefit of relaxing the collateral constraint, respectively. $u_T(t)$ is the marginal utility of tradable consumption. Equation 5 equates the marginal utility of tradable consumption to the shadow value of wealth. Equation 6 equates the marginal rate of substitution between tradable and nontradable goods to their relative price. Equation 7 is the Euler equation for bonds: when the collateral constraint is binding, a wedge between the current and the future shadow value of wealth is given by μ_t, the shadow benefit of relaxing the collateral constraint.

The collateral constraint amplifies the negative income shock to the economy: when such a negative shock hits the domestic economy, agent wants to cut c_t^T to be able to borrow more. However, from equation 6, this causes a drop in p_t^N, the relative price of nontradables, which further tightens the right hand side of equation 4 and causes the borrowing capacity to decrease even more, exacerbating the effects of the negative income shock.

To complete the description of the representative agent's problem, the following complementary slackness conditions are also needed:

$$\mu_t \geq 0 \tag{8}$$

$$(b_{t+1} + (\kappa^N p_t^N y_t^N + \kappa^T y_t^T))\mu_t = 0 \tag{9}$$

this topic.

Finally, markets for both tradable goods and nontradable goods clear:

$$c_t^N = y_t^N \tag{10}$$

$$b_{t+1} + c_t^T = b_t(1 + R_t) + y_t^T \tag{11}$$

Bianchi(2011) has shown that the Ramsey optimal capital control taxes a social planner uses to fully internalize the pecuniary externalities is given by:

$$\tau_t^* = \frac{E_t \mu_{t+1}^{sp} \Psi_{t+1}}{E_t u_T(t+1)} - \frac{\mu_t^{sp} \Psi_t}{\beta(1+r) E_t u_T(t+1)} \tag{12}$$

where $\Psi_t \equiv \frac{\kappa^N p_t^N c_t^N}{c_t^T (1+\eta)}$ indicates how much the collateral value changes at equilibrium when there is a change in tradable consumption.

3.2 Government and capital controls

The government has superior information about future economic fundamentals: it knows y_{t+1}^T at time t. I focus on tradable income because its realization drives the relative price of nontradables, the tightness of the collateral constraint and hence financial stability in this model. The assumption that the government knows more than the private agent is motivated by several considerations. First, the academic literature of the information content of U.S. monetary policy(Romer and Romer (2010) and Nakamura and Steinsson (2018)) assumes that the Federal Reserve possesses some knowledge of the economy that the private sector does not have. Second, the empirical section in this paper shows evidence that private forecasts of fundamentals responds to capital control announcements by the government. Lastly, the assumption is motivated by the observation that a capable regulator or policymaker, in general, possesses superior knowledge on information relevant to its regulatory responsibilities because it has the unique mandate of supervision and because the private sector sometimes does not think about the externalities of its actions[5]. Hence, I choose

[5] A real world example is as follows: a financial regulator is charged with the mandate of maintaining financial stability. Hence, she accumulates knowledge and gains expertise through research in this subject area, information collection authorized by the law, on-site examination of financial institutions, stress tests and other activities. The regulator does not know more than a private sector firm about how to run its business, but she does knows more about the overall state of what it regulates, a point neatly summarized by Raghuram Rajan in one of his interviews: *FINANCE*

Brazil's experience with capital controls for my case study in the empirical section later on, hoping to get as close to the concept of a capable policymaker of capital controls as possible.

To mitigate the pecuniary externality arising from the collateral constraint, the government implements capital controls by taxing next period bond holdings of the agent. As in equation 7, the tax distorts the agent's intertemporal Euler's equation by making future borrowings more costly. I employ a policy rule of the capital control tax rate as a linear function of future states instead of using τ_t^*, the Ramsey optimal tax rates. The policy rule is preferred than Ramsey-optimal tax for my purposes for three reasons: first, as noted in other works, the optimal tax schedule varies across different states in a complicated way, so regulators may find it difficult to implement it in time to respond to an ongoing financial crisis. Second, this tax rule is quantitatively similar to an optimal tax in reducing the frequency and severity of a financial crisis and delivering welfare gains. Last but not least, this simple rule facilitates learning by the agent about economic fundamentals: an optimal state-contingent tax may prove hard or even impossible for the agent to extract information from. The policy rule is as follows:

$$\tau_t = \phi_0 + \phi_1 y_{t+1} + v_t \tag{13}$$

$$v_t = \alpha + \rho v_{t-1} + \epsilon_t \tag{14}$$

It consists of two components: the first component is related to next-period tradable income. Intuitively, if the government sees a lower future tradable income, this implies a lower tradable consumption allocation and hence a lower relative price of nontradables, so the collateral constraint is more likely to bind. In this case, the government sets a higher tax rate on borrowings to try to prevent the economy from hitting the collateral constraint. $\phi_1 < 0$ captures the procyclical nature of optimal capital control tax as shown in Schmitt-Grohe and Uribe(2017), and it is also consistent with

& DEVELOPMENT, March 2015, Vol. 52, No. 1: These are smart guys. They're from Goldman Sachs. They're from JPMorgan. They're paid a ton of money. They're the smartest kids in the room. Why would they blow up their business? And who are we, you know, low-paid regulators, thinking that we know more about their business than they do? And the answer is no, we don't know more about their business than they do, but we have different incentives. They're locked into this competitive frenzy. And we're the guys who can stop them.

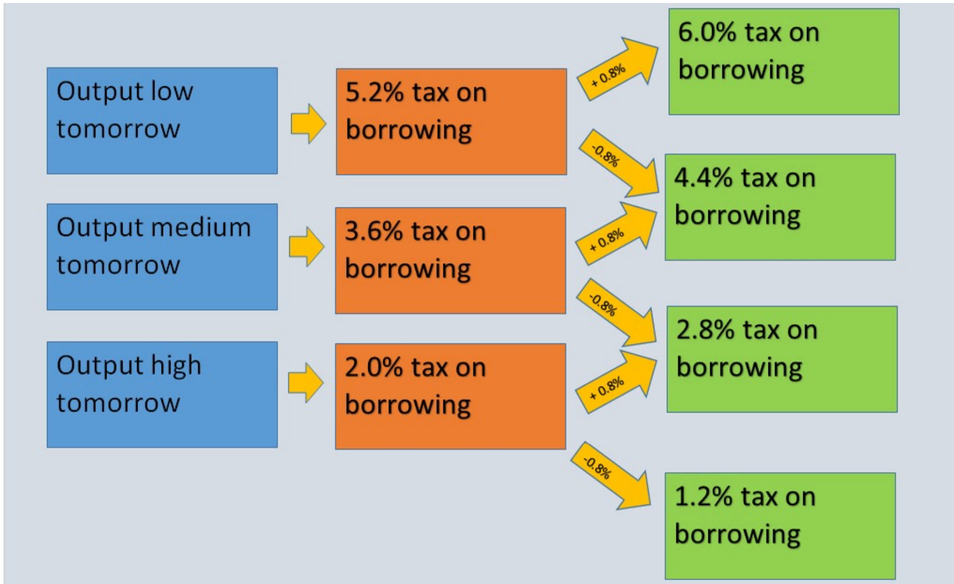
evidence presented later in the empirical section that GDP growth forecasts respond negatively to a tightening of capital controls. The second component of the policy rule is v_t, a random shock term which follows an AR(1) process. Its interpretation is analogous to that of an exogenous shock to a Taylor rule (Taylor (1993) and Christiano, Eichenbaum and Evans (1998)): the term can represent exogenous shocks to policymakers' preferences, measurement errors in policymakers' data or other shocks not related to the systematic responses to variations in the state of the economy. The shock term is uncorrelated with other state variables. The government knows both components and hence the tax rate τ_t, while the agent only observes τ_t, but cannot tell its components apart.

Figure 1 illustrates the policy rule for my benchmark calibration with three states (high, medium and low) for tradable incomes: when next-period tradable income is medium, the government imposes a baseline tax rate of 3.6% on bond holdings. When a high (low) future income is observed, it lowers (increases) the tax rate by 1.6% to 2.0% (5.2%). However, the government cannot set the exact tax rate it would like, because a random shock pushes the rate up or down by 0.8%. Hence, the agent observes four different tax rates in this setting. The magnitude of the random shock is a half of 1.6%, the absolute value of the difference between the baseline rate and the higher(lower) rate. This calibration ensures the agent does not have perfect information about future states after learning: for instance, the actual tax rate after a medium output realization and a positive shock equals the tax rate after a high output realization and a negative shock. What matters is that the agent learns something useful after observing the tax rates.

Finally, all tax revenue collected are rebated to the representative agent as a lump-sum transfer and the government budget balances in each period:

$$T_t = \tau_t b_{t+1} \tag{15}$$

Figure 1: Illustration of the policy rule of capital control tax rate



3.3 Information structure

In this section, I describe the agent's information structure and how it changes with learning. Unlike the government, the agent does not observe tradable income one period ahead. This means the agent has incentives to learn from useful signals to improve her understanding of future tradable income. The agent learns from an exogenous signal, as in prior literature, and from capital control policy actions, a novel feature of this paper.

First, I describe the information structure prior to learning from policy: this is a benchmark of how much the agent knows without observing policy actions. The structure is proposed by Durdu et al.(2013) and used in Bianchi, Liu and Mendoza(2016), which I base my analysis on. The agent receives a noisy but useful signal about future tradable income. Each period, the signal s_t is realized after y_t^T. The agent makes use of the signal and tradable income this period to form expectation about next period tradable income according to the Bayes rule. The information updating process prior to observing capital controls is given by equation 16 to 20. The probability of a signal conditional on an income level is:

$$p(s_t = i | y^T_{t+1} = l) = \theta, i = l \tag{16}$$

$$p(s_t = i | y^T_{t+1} = l) = \frac{1-\theta}{N-1}, i \neq l \tag{17}$$

The agent forecasts next period tradable income conditional on current period information:

$$p(y^T_{t+1} = l | s_t = i, y^T_t = j) = \frac{p(s_t = i | y^T_{t+1} = l) p(y^T_{t+1} = l | y^T_t = j)}{\Sigma_n p(s_t = i | y^T_{t+1} = n) p(y^T_{t+1} = n | y^T_t = j)} \tag{18}$$

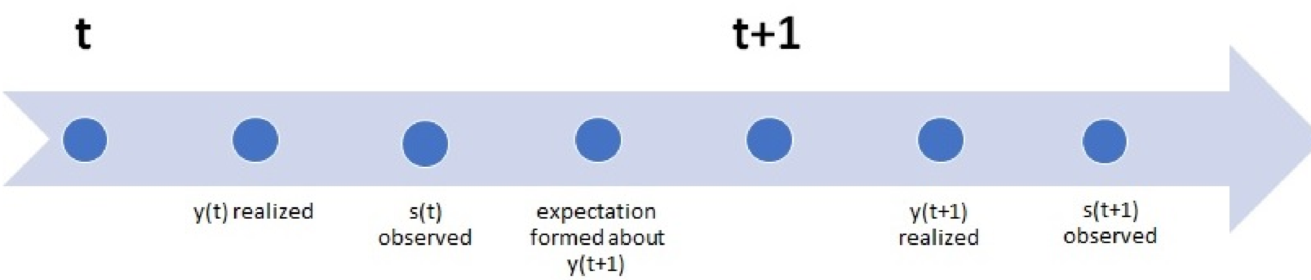
The Markov process of the joint evolution of tradable income and signal is given by:

$$\Pi(y^T_{t+1}, s_{t+1}, y^T_t, s_t) = p(|s_{t+1} = k, y^T_{t+1} = l | s_t = i, y^T_t = j) \tag{19}$$

$$= p(y^T_{t+1} = l | s_t = i, y^T_t = j) \Sigma_m p(s_{t+1} = k | y^T_{t+2} = m) p(y^T_{t+2} = m | y^T_{t+1} = l) \tag{20}$$

The timeline of the model prior to learning from policy is shown below:

Figure 2: Model timeline without learning from policy



In this paper, the agent learns from policy itself in addition to learning from the exogenous signal. When the government levies capital control tax, the agent utilizes this information to help herself better understand economic fundamentals. She completes a Bayesian updating of the probability distribution of future tradable endowment when she observes a capital control tax, because she understands the government knows more and is revealing its knowledge through the policy rule. Although the agent cannot tell the deterministic and the random components of the tax rule apart, she knows the form of the policy rule and the value of parameters in the rule. Hence, her estimates of the likelihood of observing a certain tax rate conditioning on next period tradable income is:

$$p(\tau_t = k | y^T_{t+1} = l) = p(\phi y^T_{t+1} + v_t = k | y^T_{t+1} = l) = p(v_t = k - \phi l) \tag{21}$$

In this equation, the agent knows the underlying process for v_t, but she does not observe v_t directly. To extract useful information from capital controls, she must form an estimate of $p(\tau_t = k | y^T_{t+1} = l)$. The agent knows the random component of the tax rule last period, since $v_{t-1} = \tau_{t-1} - \phi_0 - \phi_1 y_t$ and both τ_{t-1} and y_t are observed this period. So her estimates involves keeping track of v_{t-1} and using it to form expectations:

$$p(v_t = k - \phi l) = p(\alpha + \rho v_{t-1} + \epsilon_t = k - \phi l) = p(\epsilon_t = k - \phi l - \alpha - \rho v_{t-1}) \tag{22}$$

Figure 1 helps illustrate equation 22: if the agent observes a tax rate of 6.0%, she knows this can only be the result of a low future income realization coupled with a positive random shock this period. However, if she observes a tax rate of 4.4%, one of the following two situations could be true: either future income is low and the random shock is low, or future income is medium and the random shock is high. The probabilities she assigns to these events are based on whether she thinks the random shock is high or low today, which are in turn based on whether it was high or low yesterday due to persistence of v_t.

Using the Bayes rule and the law of total probability, the agent's forecast of future tradable income conditional on a specific observed capital control tax rate is:

$$p(y^T_{t+1} = l | \tau_t = k) = \frac{p(\tau_t = k | y^T_{t+1} = l) p(y^T_{t+1} = l)}{\Sigma_n p(\tau_t = k | y^T_{t+1} = n) p(y^T_{t+1} = n)} \tag{23}$$

As discussed before, the agent knows y^T_t and s_t before observing capital controls. Her forecast of tradable income conditional on all information at time t is:

$$p(y^T_{t+1} = l | s_t = i, y^T_t = j, \tau_t = k) = \frac{p(\tau_t = k | y^T_{t+1} = l) p(y^T_{t+1} = l | s_t = i, y^T_t = j)}{\Sigma_n p(\tau_t = k | y^T_{t+1} = n) p(y^T_{t+1} = n | s_t = i, y^T_t = j)} \tag{24}$$

and hence the joint evolution of income and signal is given by:

$$p(y_{t+1}^T = l, s_{t+1} = m | s_t = i, y_t^T = j, \tau_t = k) = \tag{25}$$

$$\frac{p(\tau_t = k | y_{t+1}^T = l, s_{t+1} = m) p(y_{t+1}^T = l, s_{t+1} = m | s_t = i, y_t^T = j)}{\Sigma_{n,m} p(\tau_t = k | y_{t+1}^T = n, s_{t+1} = m) p(y_{t+1}^T = n, s_{t+1} = m | s_t = i, y_t^T = j)} \tag{26}$$

If the agent observes a capital control tax, the precision of her forecast regarding future tradable income increases. Finally, the joint evolution of income, signal and tax rate is given by:

$$p(y_{t+1}^T = l, s_{t+1} = m, \tau_{t+1} = n | s_t = i, y_t^T = j, \tau_t = k) = \tag{27}$$

$$p(\tau_{t+1} = n | y_{t+1}^T = l, s_{t+1} = m) p(y_{t+1}^T = l, s_{t+1} = m | s_t = i, y_t^T = j, \tau_t = k) \tag{28}$$

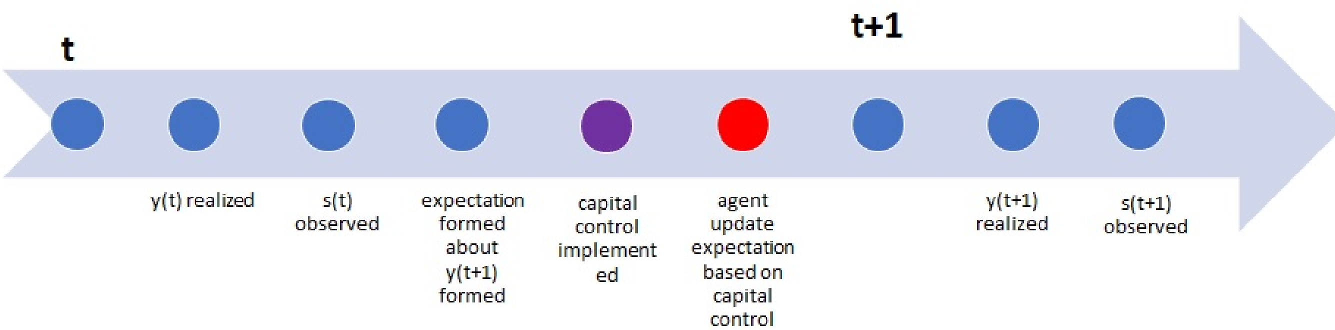
where

$$p(\tau_{t+1} = n | y_{t+1}^T = l, s_{t+1} = m) = \Sigma_k p(\tau_{t+1} = n | \tau_t = k) p(\tau_t = k | y_{t+1}^T = l, s_{t+1} = m) \tag{29}$$

This joint process is then combined with the evolution of other exogenous state variables to form the entire transition probability matrix the agent uses to form expectations in her dynamic programming problem.

The timeline of the model with learning from policy is given by figure 3:

Figure 3: Model timeline with learning from policy



3.4 Equilibrium definition

I define three equilibria here: the decentralized equilibrium (denoted **DE**), where there is no policy intervention at all; the equilibrium with policy intervention through the capital control policy rule but no learning from policy(denoted **P**); the equilibrium with both policy intervention and learning from policy (denoted **PL**).

Definition 1 defines a decentralized equilibrium in the domestic economy.

Definition 1. Given the state contingent processes y_t^T, s_t, R_t and given that $\tau_t = 0 \forall t$, **DE** is a sequence of price p_t^N and allocations b_{t+1}, c_t^T, c_t^N such that:
1. Agent maximizes her utility subject to the budget constraint and the collateral constraint, taking p_t^N as given.
2. Markets for tradable goods and nontradable goods clear.
3. Agent learns from the exogenous signal s_t to forecast future tradable income as in equations 16-20.

Definition 2 defines an equilibrium with policy intervention but no learning from policy.

Definition 2. Given the state contingent processes y_t^T, s_t, R_t, v_t and government policy τ_t, **P** is a sequence of price p_t^N and allocations b_{t+1}, c_t^T, c_t^N such that:
1. Agent maximizes her utility subject to the budget constraint and the collateral constraint, taking p_t^N and τ_t as given.
2. Government levies capital control tax τ_t according to equation 13.
3. Markets for tradable goods and nontradable goods clear.
4. Agent learns from the exogenous signal s_t to forecast future tradable income as in equations 16-20.

Definition 3 defines an equilibrium with both policy intervention and learning from policy.

Definition 3. Given the state contingent processes y_t^T, s_t, R_t, v_t and government policy τ_t, **PL** is a sequence of price p_t^N and allocations b_{t+1}, c_t^T, c_t^N such that:
1. Agent maximizes her utility subject to the budget constraint and the collateral constraint, taking p_t^N and τ_t as given.
2. Government levies capital control tax τ_t according to equation 13.
3. Markets for tradable goods and nontradable goods clear.
4. Agent learns from both the exogenous signal s_t and the capital control tax τ_t to forecast future tradable income as in equations 23-26.

The last equilibrium concept is the novelty of this paper. To see how this concept differs from equilibrium definitions in previous works, I write down the dynamic programming problem of the agent in recursive form, where state variables are collected in the vector $z_t = (y_t^T, s_t, R_t, \tau_t, v_{t-1})'$:

$$V_t(b_t, z_t) = \underset{c_t^T, c_t^N, b_{t+1}}{max} [u([\omega(c_t^T)^{-\eta} + (1-\omega)(c_t^N)^{-\eta}]^{-\frac{1}{\eta}}) + \beta E_{z_{t+1}|z_t} V_{t+1}(b_{t+1}, z_{t+1})] \tag{30}$$

subject to

$$(1+\tau_t)b_{t+1} + c_t^T + p_t^N c_t^N = b_t(1+Rt) + y_t^T + p_t^N y_t^N + T_t \tag{31}$$

$$b_{t+1} \geq -(\kappa^N p_t^N y_t^N + \kappa^T y_t^T) \tag{32}$$

This problem is different from previous works since τ_t and v_{t-1} are additional state variables for the agent to keep track of, in order to extract useful information about fundamentals from capital controls.

3.5 Model Mechanisms

In addition to increasing the cost of borrowing, capital controls affect the representative agent's decision making through two additional mechanisms related to learning from policy. The first mechanism is about precautionary savings. When the agent observes capital controls, she learns more about next period tradable income and is less uncertain about overall income tomorrow. This leads to less saving for precautionary reasons and hence more overall borrowings, which undermines financial stability as borrowings are associated with the pecuniary externality.

To see how this mechanism works in more details, note that the agent accumulates precautionary savings for two reasons:

1. *Prudence.* The third derivative of a CRRA utility function is positive:

$$u(c) = \frac{c^{1-\gamma}}{1-\gamma} \tag{33}$$

$$u'''(c) = \gamma(\gamma+1)c^{-\gamma-2} > 0 \tag{34}$$

which leads to an increase in savings in response to an increase in future income uncertainty even in the absence of a collateral constraint.

2) *The presence of a collateral constraint.* To illustrate, consider the special case of a quadratic utility function so there is perfect smoothing of tradable consumption in the absence of the collateral constraint. Since nontradable consumption is equal to nontradable endowment each period due to market clearing, we have:

$$c_t^T = E_t c_{t+1}^T \quad \text{if} \quad b_{t+1} > -(\kappa^N p_t^N y_t^N + \kappa^T y_t^T) \tag{35}$$

$$c_t^T = b_t(1+R_t) + y_t^T + (\kappa^N p_t^N y_t^N + \kappa^T y_t^T) \quad \text{if} \quad b_{t+1} = -(\kappa^N p_t^N y_t^N + \kappa^T y_t^T) \tag{36}$$

The pairwise conditions above can be rewritten in a more concise form:

$$c_t^T = \min[E_t c_{t+1}^T, b_t(1+R_t) + y_t^T + (\kappa^N p_t^N y_t^N + \kappa^T y_t^T)] \tag{37}$$

where

$$E_t c_{t+1}^T = E_t \min[E_{t+1} c_{t+2}^T, b_{t+1}(1+r) + y_{t+1}^T + (\kappa^N p_{t+1}^N y_{t+1}^N + \kappa^T y_{t+1}^T)] \tag{38}$$

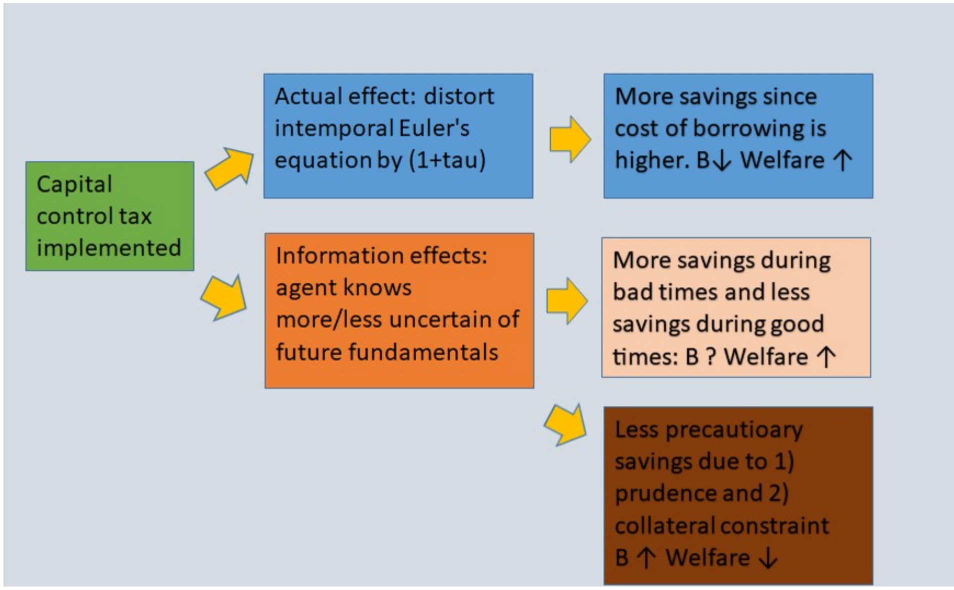
If future income uncertainty increases, low realization of y_{t+1}^T becomes more likely and the collateral constraint is more likely to bind, reducing the value of the right hand side of equation 38 and hence the value of c_t^T. This is a reason to accumulate precautionary savings even in the absence of prudence.

Because of the two reasons above, capital controls can be less efficient in reducing borrowings when the agent learns from it than when she does not. This is because the agent updates her information set and reduces precautionary savings precisely when she sees policy actions. In contrast, the agent in Bianchi, Liu and Mendoza(2016) learns through an exogenous signal and hence the Bayesian updating of the agent's information set is unrelated to policy actions. My model has a distinct feature of a policymaker "fighting against herself": a tax on bond holdings reduces borrowings and hence mitigates the pecuniary externality associated with it; on the other hand, information revealed through policy action increases borrowing and aggravates the externality.

A second mechanism through which learning affects decision making is one of better timing of borrowing/saving decisions. In the absence of externalities, more information helps the agent make better decisions regarding consumption and hence improves welfare, as the optimal choices in the absence of new information are always available. In this specific setting, news have asymmetric effects due to the collateral constraint (see Guerrieri and Iacoviello(2017) for a discussion of the asymmetry of a collateral constraint when the collateral is housing wealth): goods news have less impact on the agent's decision making since the collateral constraint is more likely to be slack when the collateral is worth more; on the other hand, bad news have more impact because the collateral constraint is more likely to bind when the collateral is worth less. By having more information about the value of future collaterals, the agent borrows less during bad times and more during good times. The effect of this mechanism on overall borrowing is ambiguous, but it increases overall welfare.

In sum, capital controls influence the agent's decisions through three mechanisms: a conventional mechanism of changing the cost of borrowing and two informational mechanisms involving precautionary savings and better timing of borrowing decisions, respectively. Figure 4 summarizes these mechanisms. The implications of learning from policy for policy efficacy depends on the relative strength of each mechanism, which is a quantitative question to be answered in the next section.

Figure 4: Model mechanisms



4 Quantitative Studies

In this section, I calibrate the model to the Brazilian economy and evaluate the quantitative implications of learning about economic fundamentals from capital controls. Using global nonlinear methods as in Bianchi(2011), I solve for the decentralized equilibrium, the equilibrium with policy but no learning and the equilibrium with both policy and learning.

4.1 Calibration

Table 1.1 summarizes values assigned to parameters in the model. A period in the model represents a year[6]. The first section follows Bianchi(2011) and Bianchi, Liu and Mendoza(2016) in choosing the relevant moments to target, except that I use Brazilian data instead of Argentinian data to be consistent with the empirical section. The log of tradable income is modeled as a first-order autoregressive process and estimated with the HP-filtered cyclical components of Brazilian tradable GDP from the World Development Indicator(WDI) from 1960 to 2016; the parameter ω is the

[6]I choose not to calibrate the model to quarterly data because Schmitt-Grohe and Uribe(2018) have shown that a quarterly calibration for this model leads to equilibrium underborrowing instead of overborrowing.

tradable share in the CES aggregator and is calibrated to match a 33 percent share of tradable production for Brazil; the discount factor β is set so that the average net foreign asset-to-GDP ratio in the model equals its historical average in Brazil, which is equal to -32 percent in Lane and Milesi-Ferretti(2011).

Table 1: Calibration of the quantitative model

parameter	value
y^N, nontradable endowment	1
N, number of states for tradable endowments	3
$E[y^T]$, expectation of tradable endowments	1
ρ_{y^T}, persistence of tradable process	0.63
σ_{y^T}, standard deviation of tradable process	0.060
β, discount factor	0.90
γ, coefficient of relative risk aversion	2
$\frac{1}{1+\eta}$, elasticity of substitution	0.83
κ, share of pledgeable collateral	0.34
θ, signal precision	1/3
ω, share of tradable consumption in the aggregator	0.33
R^h, interest rate in low liquidity regime	1.0145
R^l, interest rate in high liquidity regime	0.9672
F_{hh}, persistence of low liquidity regime	0.9333
F_{ll}, persistence of high liquidity regime	0.6
ϕ_0, intercept in the tax rule	14.27
ϕ_1, slope in the tax rule	-10.67
T_m, determinstic component of tax when future income is medium	3.6
ρ_T, persistence of random component of tax	0.9
σ_T, standard deviation of random component of tax	0.8

The second section of the table contains parameter values specific to my model with learning from policy. T_m is calibrated to the optimal flat tax rate in Bianchi(2011). In the model, the forecast of next period output and the mean squared forecast error(MSFE) before the agent observes capital controls can be expressed as:

$$E_t y^T_{t+1}(\theta) = \Sigma_l l p(y^T_{t+1} = l | s_t = i, y^T_t = j) \tag{39}$$

$$MSFE(\theta) = E_t(E_t y^T_{t+1}(\theta) - y^T_{t+1})^2 \tag{40}$$

After capital controls are observed, the forecast and MSFE of the forecast are updated to reflect the arrival of new information:

$$E_t y^T_{t+1}(\theta, \tau_t) = \Sigma_l l p(y^T_{t+1} = l | s_t = i, y^T_t = j, \tau_t = k) \tag{41}$$

$$MSFE(\theta, \tau_t) = E_t(E_t y^T_{t+1}(\theta, \tau_t) - y^T_{t+1})^2 \tag{42}$$

ρ_T, σ_T and θ are chosen such that $MSFE(\theta, \tau_t) - MSFE(\theta)$, the MSFE reduction resulting from the arrival of new information in capital controls, matches the magnitude measured later in the empirical section, where I complete a nowcast of Brazilian real GDP and use capital control announcements to help improve the nowcast. Given σ_T, ϕ_0 and ϕ_1 are then set such that the agent does not have perfect information regarding next period tradable output after learning from policy.

4.2 Quantitative Results

In this section, I compare and contrast the long-run and financial crisis moments of the three different equilibria: the decentralized equilibrium (denoted **D**); the equilibrium with only policy intervention (denoted **P**); the equilibrium with both policy intervention and learning from policy(denoted **PL**). When people learns from capital controls, these policy actions may entail unintended consequences such as higher debt levels and more severe financial crisis in the sense of larger consumption drops and currency depreciation. When the reduction of precautionary savings is strong enough, capital controls may even lead to welfare losses.

The first and second columns in Table 2 show that the effects of the tax rule are quantitatively similar to these of the Ramsey-optimal tax: financial crisis happens much less frequently, the economy accumulates less debt and the current account is less volatile. Capital controls also reduce the severity of a financial crisis: the magnitudes of consumption drops, real exchange rate depreciations and capital outflows are mitigated by capital controls. The tax rule is associated with a welfare gain of about 0.14% relative to the decentralized equilibrium. These results are consistent with findings in Bianchi (2011) about the effects of an optimal tax. In sum, the assumption of a simple tax rule does not make a material difference in the study of capital controls, allowing me to use the simple rule to facilitate learning from policy.

Table 2: The effects of capital controls and learning from capital controls

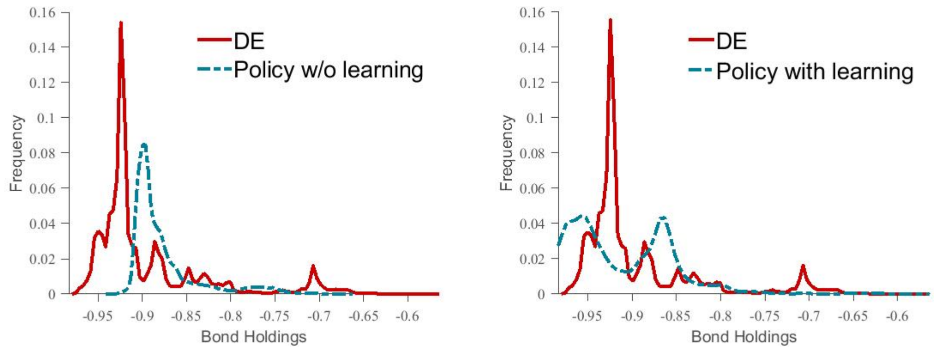
	DE	P	PL
Long-run moments			
Long-run probability of financial crisis	7.53%	1.47%	0.97%
Mean debt/GDP level	30.6	30	31.8
Standard deviation of current account	3.4%	2.0%	2.3%
Welfare gain relative to DE	n.a.	0.14%	0.33%
Financial crisis moments			
Consumption drop in crisis	12.67%	10.05%	13.47%
RER depreciation in crisis	34.66%	26.62%	38.48%
Current account drop in crisis	10.69%	7.93%	12.48%

Financial crisis is defined as a period in simulation when capital outflow exceeds two standard deviation of the mean of the ergodic distribution of current account and the collateral constraint binds.

I proceed to discuss what happens when agent learns from capital controls. The second and third columns in Table 2 compares long-run and crisis moments of policy equilibria with and without learning(**PL** and **P**). When the agent learns from policy and saves less for precautionary reasons, the economy accumulates more debt and the current account is more volatile in **PL** than in **P**. A financial crisis is also more severe in **PL**, in the sense of larger consumption drops, real exchange rate depreciations and capital outflows in a crisis. These effects are contrary to the intention of policymakers implementing capital controls. The effect of learning on the frequency of financial crisis is ambiguous: good news, induce more borrowing and a higher likelihood of hitting the collateral constraint, but borrowing capacity also increases since the collateral is worth more. In this calibration, financial crises are slightly less frequent with learning.

However, a more interesting comparison is between the decentralized equilibrium(**D**) and the equilibrium with tax rule and learning(**PL**), namely, between the first and third column of Table 2. Most conclusions in the last paragraph are still true: the economy accumulates more debt in **PL** than in **D**; a financial crisis is also more severe. In other words, if agent learns from policy, policymaker could do worse in reducing

Figure 5: Ergodic bond holding distributions in **D** and **PL**



over-borrowing and mitigating the severity of a financial crisis than if it does nothing to intervene. Figure 5 shows the ergodic distribution of bond holdings in **D** and in **PL**. As in Bianchi(2011), in the absence of learning, capital controls reduce the economy's exposures to high debt levels in the left tail of the distribution, as shown in the left panel. With learning, however, this is no longer true: the economy has significant exposures to high debt levels that increases the economy's vulnerability to a financial crisis. The efficacy of capital controls in ensuring financial stability is undermined by the fact that the agent learns about fundamentals of the economy from observed policy measures themselves.

In the baseline results, there is a 0.33% welfare gain of **PL** relative to **D**. In this sense, isn't the policymaker actually doing better when agent learns? It turns out the welfare result in this model with learning from policy is fragile and depend on the relative strength of the three different mechanisms at work. I discuss this in greater details in the next subsection.

4.3 Welfare

Are capital controls welfare-improving if agents learn from policy? The answer depends on the relative strength of the different mechanisms at work in the model. Capital controls increases the cost of borrowing, which improves welfare by helping to make financial crises less frequent and less severe. In addition, learning from capital controls has two opposite effects on welfare: more information improves welfare by helping the agent make more informed decisions; more information also reduces precautionary savings and hence reduces welfare when pecuniary externality is present. The net effect of capital controls on welfare depends on whether the perils of less precautionary savings is quantitatively more important than the other two mechanisms combined. The 0.33% welfare gain in table 2 is exaggerated because the setting overstates the benefit of more information. I proceed to alter the relative strength of the different mechanisms and show that a smaller welfare gain or even welfare losses are plausible in this model.

I increase the strength of the precautionary savings mechanism and decrease the benefits from more information to show that capital controls can lead to negative welfare gains when people learns from them. First, I consider the case where a capital control tax is present only some of the time(only when the optimal taxes imposed by a social planner is positive), instead of all the time, as is the case in the benchmark setting. This specification prevents the benefits of having more information from being exaggerated, since the agent is not receiving new information in all states. Let τ_t be the tax rule defined in equations 13-14 and τ_t^* be the optimal tax defined in equation 12, the capital control tax rates are on-and-off now:

$$\tau_t^{New} = 1(\tau_t^* > 0)\tau_t \tag{43}$$

Definition 4 defines an equilibrium(denoted **PL2**) with both policy intervention and learning from policy; capital control taxes are on-and-off in this equilibrium.

Definition 4. Given the state contingent processes y_t^T, s_t, R_t, v_t and government policy τ_t^{New}, **PL2** is a sequence of price p_t^N and allocations b_{t+1}, c_t^T, c_t^N such that:
1. Agent maximizes her utility subject to the budget constraint and the collateral constraint, taking p_t^N and τ_t^{New} as given.
2. Government levies capital control tax τ_t^{New} according to equation 43.
3. Markets for tradable goods and nontradable goods clear.
4. Agent learns from both the exogenous signal s_t and the capital control tax τ_t^{New} to forecast future tradable income as in equations 23-26.

Second, I change the relative risk aversion parameter such that the precautionary savings motive is stronger. κ, the share of endowment pledged as collateral, is not suitable for this purpose: if κ is lowered, the agent might have more incentive to insure against hitting the constraint, but financial crisis moments also change at the same time, since a binding constraint is part of the definition of a crisis. Therefore, I increase the strength of the precautionary savings mechanism by experimenting with different values of γ, the coefficient of relative risk aversion.

Table 3: Welfare gains under **PL2**

γ	2	2.5	3	4
Welfare gains relative to **D**	-0.13%	-0.16%	-0.2%	-0.34%

Table 3 presents welfare gains of capital controls of **PL2** relative to **D** for different values of risk aversion. For empirically plausible values of γ, there is actually welfare losses associated with one-and-off taxes, as the precautionary savings mechanism is stronger than the other two mechanisms combined. This is further confirmed by the fact that the welfare losses are larger as the relative risk aversion parameter takes on higher values.

In sum, if the agent is reasonably risk-averse and capital controls are put on only when necessary, welfare losses due to learning about future fundamentals can be quantitatively more important than welfare gains from policy. Hence, policymakers should consider how others in the economy adjusts their understanding of fundamentals in response to policy actions.

4.4 Implications of the model with learning

The implications of this model can help rationalize several findings in the empirical literature of capital controls. First, optimal capital control policy usually constitutes inflow controls in the case of over-borrowing and outflow controls in the case of under-borrowing. Therefore, the presence of learning and information revelation renders inflow controls less efficient than outflow controls in ensuring financial stability, since it reduces precautionary savings in both cases. This is in line with empirical findings in Forbes, Fratzscher and Straub(2015), where the authors documented that the effects of outflow controls on exchange rate and capital flows are both statistically and economically more significant than these of inflow controls. Second, market participants in countries with on-and-off control measures (Gate countries) may find it easier to learn about fundamentals from repeated experiences than market participants in countries where there is no change to control measures for a long time (Wall countries). Hence, inflow controls should work better in Wall countries than in Gate countries, since learning reduces precautionary savings less in the former. The main empirical findings in Klein (2012) is supportive of this view: among inflow measures, persistent controls are more efficient than episodic measures in reducing financial fragility and moderating exchange rate movements.

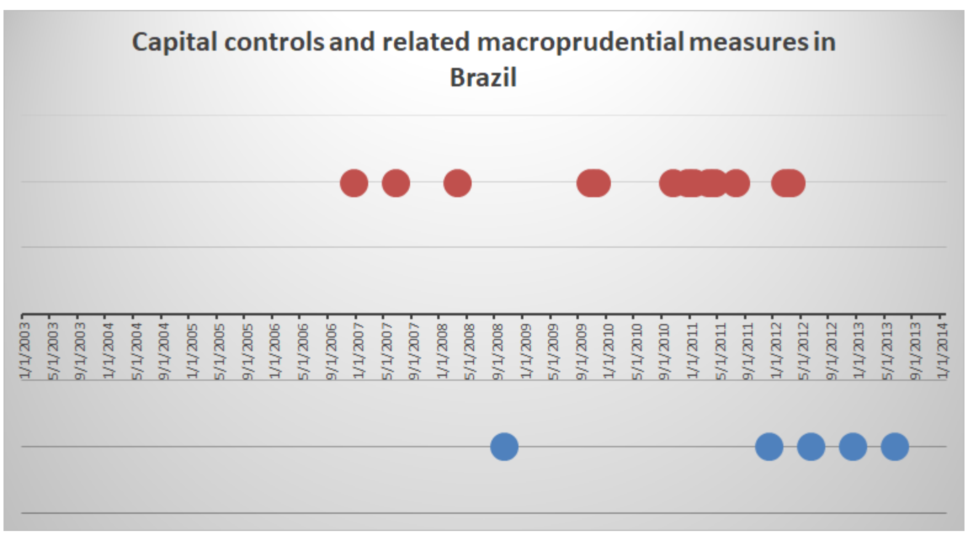
5 Measuring the information content of capital controls

My theoretical model assumes that private agent learns about economic fundamentals from capital controls. In the empirical section, I present two complementary sets of empirical evidence on the relationship between capital controls and expectations of fundamentals to justify this assumption. The first set of evidence comes from Brazilian survey data of expectations, a direct measure of market participant's expectations of fundamentals, where the daily frequency of the data allows for relatively clean identification. However, the survey data is an average of expectations of many forecasters using different methodologies, and hence hard to interpret in more details. Therefore, my second set of empirical evidence takes a stand on the methodology used to form expectations. I use a standard econometric model to construct nowcasts for real GDP growth and examines whether capital control announcements help improve nowcast of Brazilian real GDP. Empirical evidence coming from both exercises show that capital controls convey valuable information about economic fundamentals agent uses in their forecasts. The empirical section starts with a brief description of Brazil's experience with capital controls between 2006 and 2013 and proceeds to the two sets of empirical evidence.

5.1 Capital controls in Brazil after the Global Financial Crisis

In the empirical section, I focus on Brazil's experience with capital controls after the global financial crisis. Between 2006 and 2013, Brazil adopted a series of well-known capital control measures discussed in many sources (Holland(2013), Chamon and Garcia(2014), Forbes et al.(2016), to name only a few). Most notably, in response to the large capital inflows into emerging markets following the U.S. Federal Reserve's Quantitative Easing programs, the country imposes taxes on short-term portfolio inflow coupled with related macroprudential measures. These efforts are widely considered successful by most policymakers in ensuring financial stability and are promoted by the International Monetary Fund(IMF) as an example to learn from.

Figure 6: Capital controls and related macroprudential measures in Brazil: 2006 - 2013



To study the relationship between capital controls and expectations of fundamentals, I construct a daily dummy variable of policy stance containing all capital controls and related macroprudential measures in my sample[7]: 1 represents the introduction or a

[7] Table 6 and 7 in appendix A contain details of what these measures actually are and their announcement dates, as well as sources.

tightening of a policy measure, -1 removal or loosening and 0 if no action was pursued. Figure 6 visualizes the policy stance variable, where a red(blue) dot represents a tightening(loosening) measure. Between 2006 and 2013, there are 18 such policy measures in total, but the majority of these measures are announced between 2010 and 2012. Most of these policy measures were actually implemented at or shortly after the announcement, allowing me to focus on announcement dates alone.

5.2 Identification assumption

My empirical findings that capital controls convey negative information about economic fundamentals relies on the identification assumption that a tightening of capital controls does not negatively affect real GDP within the current quarter. Hence, my empirical results are not immune to the criticism that forecasters expect capital controls to decrease real GDP and they are simply incorporating this mechanism into their forecasts. I state several reasons to support my assumption. First, there is no academic consensus on how capital controls affect real output. By improving financial stability, a primary function emphasized by the current literature, capital controls can actually be expected to increase output by avoiding the output cost of a financial crisis. Klein(2012) finds not empirical relationship between capital controls and real output. Second, the Brazilian capital controls considered here focuses on short-term portfolio inflows instead of Foreign Direct Investment(FDI) in the hope of retaining productive capital inflows to the economy. This institutional background mitigates concerns that capital controls negatively affect real GDP by decreasing foreign investment which would help improve the economy's productive capacity. Last, capital controls and output are unrelated in the model: tradable and nontradable outputs are endowment driven by an exogenous process, and capital controls improve welfare through better intertemporal consumption smoothing.

5.3 Capital controls and high-frequency expectations of fundamentals

My empirical evidence from high-frequency Brazilian survey data suggest that expectations of economic fundamentals respond to capital control announcements. Below, I discuss the nature of the survey data used in this section, conduct event studies on six major capital control announcements in Brazil and measure the revisions of expectations in response to these announcements.

5.3.1 Data

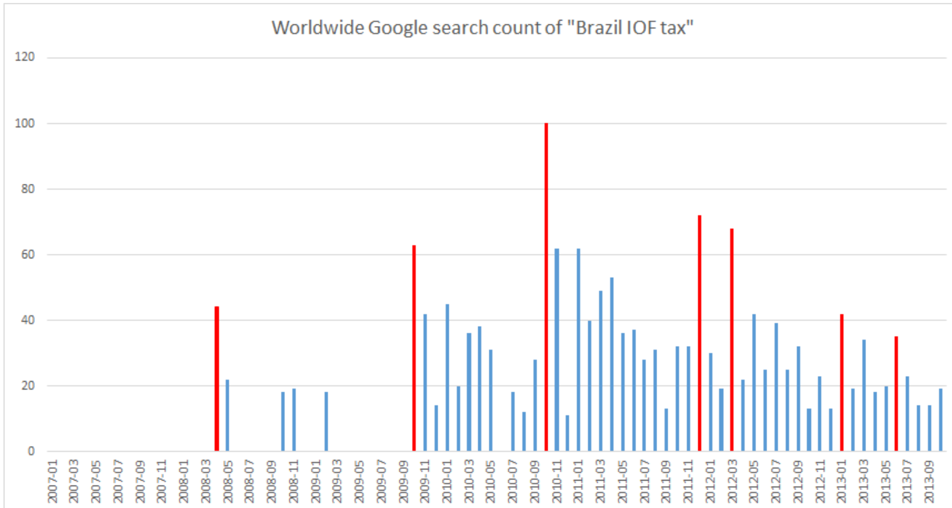
Survey data of market expectations used in this section comes from the Brazilian central bank's Market Expectations Systems (MES). Since 1999, the MES collects forecasts of inflation, output growth, industrial production and the policy interest rate at different horizon from around 120 professional forecasters, most of whom are financial institutions or real-sector companies with a forecasting team. The MES only reports summary statistics of the distribution of forecasts. Individual forecasts are not publicly available.

I focus on daily median expectation of Brazilian quarterly real GDP growth for the current quarter, although median expectations for the previous quarter and the next three quarters are also analyzed. Individual forecasters do not submit their forecasts on a daily basis, so daily variation in the expectations data comes from the fact that different forecasters report to the MES system at different points in time. On average, the median daily expectation of quarterly GDP growth changes every 2-3 days.

5.3.2 Empirical methodology

I use event study to measure the revisions to median quarterly GDP growth expectation in response to six major capital control news events highlighted in Table 6 and Table 7 in the appendix. Five out of the six events involve the use of tax on portfolio inflows. Announcement of these events are unexpected to market participants. Figure 7 shows Google search counts for the phrase *Brazil IOF tax* between 2006 and 2013, and hikes in search counts are highlighted in the figure. A hike usually comes on or after the announcement date of a major capital control event, suggesting the unexpected nature of these announcements. A search of news on or near the six announcement dates yields no information of any other major economic policy announcements on these dix dates, which would confound the event study results.

Figure 7: Google search count of Brazil's IOF tax



Detailed steps of my event studies are described below:

Step 1. Identify an event window consisting of the day of the announcement of an event(T) and two days prior($t_1 \equiv T-2$) and after($t_2 \equiv T+2$) the announcement.
Step 2. Estimate an AR (1) model($y_t = \alpha + \rho y_{t-1} + \epsilon_t$) for real GDP growth expectations using 30 days of data prior to the event window (these 30 days are called the estimation window).
Step 3. Use the model to predict GDP growth expectations during the event window($t \in [t_1, t_2]$). These predictions are called counterfactual growth expectations($CE[y_t]$).
Step 4. Calculate abnormal growth expectations during the event window($t \in [t_1, t_2]$) as the difference between actual and counterfactual growth($AE_t = E[y_t] - CE[y_t]$).
Step 5. Calculate mean abnormal growth expectations over the event window($MAE = \frac{1}{t_2 - t_1} \Sigma_{t=t_1}^{t_2} AE_t$).
Step 6. Calculate T-statistic for the hypothesis that mean abnormal growth expectations is zero.

5.3.3 Results

Table 4 presents the main empirical findings using high-frequency survey data of expectations. Four out of the six major capital control events are associated with statistically significant revisions of growth expectations. The magnitudes of these revisions are economically meaningful and close to the usual adjustments made by a professional forecaster in response to the release of a major news event. On average, an announcement of a tightening(loosening) of capital controls is associated with a downward(upward) revision of growth expectation of around 0.23 percent. This is supportive of the countercyclical capital control policy rule used in my theoretical model. The exception is the tightening announcement in March 2008, when market participants actually revise their growth expectations upward. To sum up, empirical evidence from high-frequency survey data suggests that expectations of fundamentals do respond to capital control measures. However, these results are based on mean expectations of 120 forecasters using different forecasting methodologies, and can be hard to interpret in greater details. Hence, in the next section, I take a stand on the forecasting methodology used to form expectations.

Table 4: Event study: capital controls and revisions to GDP growth expectations

Event date	Type	Mean growth forecast revision(%)	T-statistic
3/12/2008	tightening	-0.05**	2.12
10/20/2009	tightening	0.02	-1.40
10/04/2010	tightening	0.70***	-72.79
12/01/2011	loosening	0.02	0.19
03/09/2012	tightening	0.03**	-1.98
06/04/2013	loosening	0.16***	4.77

Coefficient is positive if it has the expected sign. T-statistic reported here are for a statistical test of the hypothesis that mean abnormal growth expectations is zero.

5.4 Using capital controls to improve GDP nowcast

In this section, I use a conventional econometric model to nowcast Brazilian quarterly real GDP between 2006 and 2013. The GDP-nowcasts are my preferred measure of the expectation of economic fundamentals and the data series used to produce the nowcasts are my preferred measure of the forecaster's information set. To my knowledge, this methodology is new to the empirical literature of capital controls. I add the dummy variable of policy stance and show that it improves the precision of the GDP-nowcast.

5.4.1 Data

I briefly discuss time-series data used to form nowcasts of Brazilian quarterly real GDP growth. All categories of economic data typically included in a GDP-nowcasting model are used here and divided into eight blocks: labor, trade, industrial production, survey, GDP and income, monetary and credit, financial and interest rate, and government finance.[8] All series are monthly data from January 2004 to December 2013. There are capital controls in most of the years in the sample period except 2004 and 2005. These two years are included to have a long enough sample period to train the forecasting model.

5.4.2 Empirical methodology

I adopt the econometric framework in Giannone, Reichlin and Small(2008), widely used by central banks in advanced economies, to produce real-time nowcasts of quarterly Brazilian real GDP growth in a ten-year period between 2004 and 2013. Capital control measures are then added to my information set and they are shown to improve the precision of my nowcasts. I briefly describe the econometric framework below and refer interested readers to the original paper for more detail.

Let Ω_{v_j} be the available information set of data vintage v_j following release j in month v. The information set consists of:

$$\Omega_{v_j} = x_{it|v_j}; t = 1, ..., T_{v_j}, i = 1, ..., n \tag{44}$$

where $x_{it|v_j}$ is a generic data series in the information set Ω_{v_j} used to form the nowcast, $i = 1, ..., n$ indexes individual time series (exports, unemployment, etc...), $t = 1, ..., T_{v_j}$ indexes dates a series in vintage v_j is observed (T_{v_j} the period in which series i in vintage v_j is last observed). Assuming no data revisions, the information set is expanding with each release. Let $k = 1, 2, 3, ...$ index quarters, and hence $3k$ represents the third month of a quarter ($3k - 1$ the second month of a quarter and $3k - 2$ the first month). Let y_{3k} be quarterly GDP at the end of the third month of a quarter

[8] Table 8 in the appendix provides details of the data series. Each series is typically released at the same point in time in a given month. Table 8, as a calendar of data release, also gives the order in which data enters into the nowcast model.

and M the underlying econometric model. The nowcast of quarterly GDP and the uncertainty of the nowcast conditioning on information set Ω_{v_j} and the underlying model are given by:

$$\hat{y_{3k|v_j}} = E[y_{3k|\Omega_{v_j}}; M] \tag{45}$$

$$V(y_{3k|v_j}) = E[(\hat{y_{3k}} - y_{3k})^2; M] \tag{46}$$

M is a Dynamic Factor Model(DFM) estimated with a Kalman filter:

$$x_{t|v_j} = \mu + \Lambda F_t + \xi_{t|v_j} \tag{47}$$

$$F_t = AF_{t-1} + Bu_t \tag{48}$$

where equation 47 is the measurement equation and equation 48 the transition equation. $x_{t|v_j} = (x_{1t|v_j}, ..., x_{nt|v_j})'$ is a vector of individual monthly data appropriately transformed to induce stationarity, F_t common factors to be extracted, Λ the corresponding factor loadings, $\xi_{t|v_j} = (\xi_{1t|v_j}, ..., \xi_{nt|v_j})'$ a vector of the idiosyncratic component driven by variable-specific shocks and u_t a white noise shock to the common factors. I also assume that $\xi_{t|v_j}$ are cross-sectionally orthogonal white noises, and they are also orthogonal to the common shocks u_t.

After the monthly factors, F_t, are estimated for all months in the quarter, I proceed to obtain monthly GDP nowcasts based on these factors. The following regression is used to obtain coefficients in the nowcasting regression:

$$y_{3k|v_j} = \alpha + \beta F_{3k|v_j} + \epsilon_t \tag{49}$$

where $\hat{F}_{3k|v_j}$ is factor estimate at the end of the third month of a quarter. The GDP nowcast at the same point in time is then $\hat{y_{3k|v_j}} = \hat{\alpha} + \hat{\beta}\hat{F}_{3k|v_j}$. GDP-Nowcasts at the end of the 1st and 2nd months can be obtained in a similar way, by projecting quarterly GDP on factor estimates at the end of the corresponding month.

In this framework, the nowcast and the uncertainty of the nowcast change as new data comes into the forecaster's information set. The information content of the news contained in data vintage j+X can be measured as revision of the nowcast $E[y_{3k|\Omega_{v_{j+X}}};M] - E[y_{3k|\Omega_{v_j}};M]$ or as the reduction in mean-squared forecast error(MSFE) of the nowcast in response to the release of X:

$$MSFE(\Omega_{v_j}) = E[(\hat{y_{3k}} - y_{3k})^2|\Omega_{v_j};M] \quad (50)$$

$$MSFE(\Omega_{v_{j+X}}) - MSFE(\Omega_{v_j}) = E[(\hat{y_{3k}} - y_{3k})^2|\Omega_{v_{j+X}};M] - E[(\hat{y_{3k}} - y_{3k})^2|\Omega_{v_j};M] \quad (51)$$

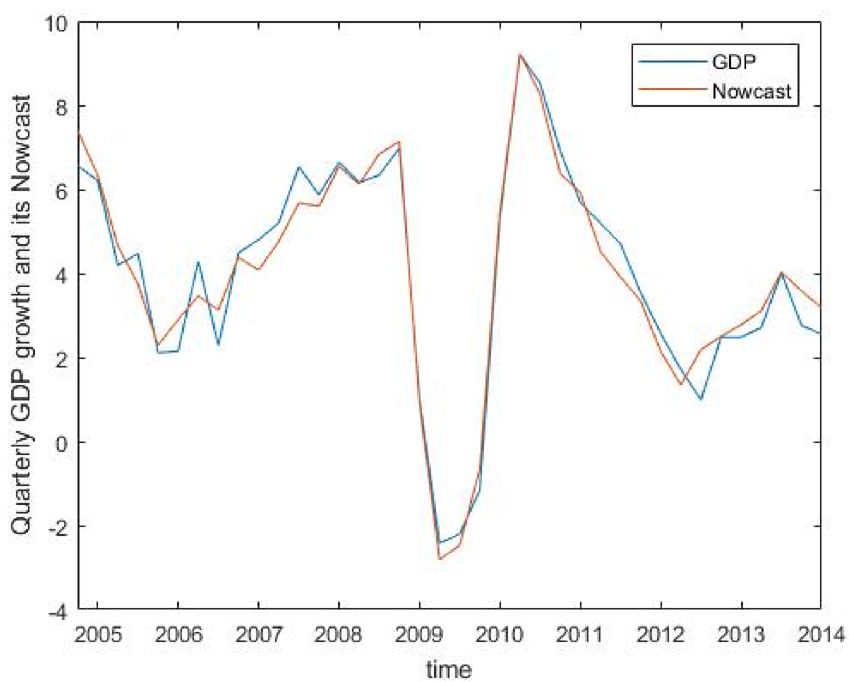
Let Ω_{v_j} be the information set available to the forecaster before capital controls are announced, CC the capital control dummy and $\Omega_{v_{j+CC}}$ the information set after capital controls are announced. The information content of capital controls is given by:

$$MSFE(\Omega_{v_{j+CC}}) - MSFE(\Omega_{v_j}) \quad (52)$$

and I estimate the empirical object above by using its sample counterpart.

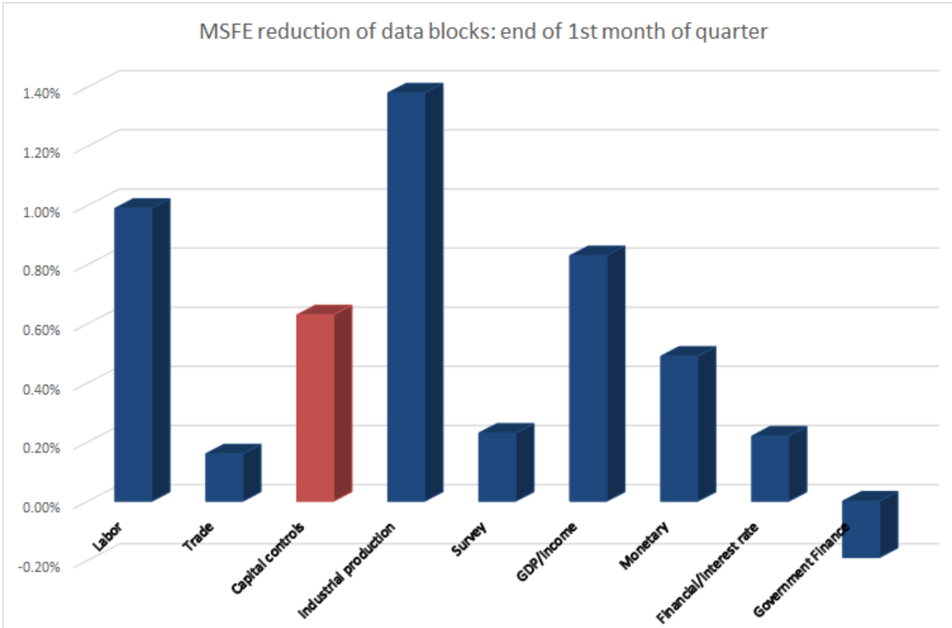
5.4.3 Results

Figure 8: Nowcasting Brazilian real GDP growth



When international capital flows is a major concern for the Brazilian economy, the

Figure 9: Mean forecast error reduction of different economic data series



forecaster obtains a more precise estimate of GDP growth by using capital controls in her information set. Figure 8 plots actual Brazilian quarterly GDP growth rates alongside its nowcast at the end of the current quarter. As can be seen, the econometric model does reasonably well in delivering real-time estimates of quarterly GDP. Figure 9 proceeds to show the mean forecast error reduction of each data block (at the end of the first month of the quarter)[9]. This exercise allows for the measurement of the information content of capital controls relative to other economic data series. In terms of forecast error reduction, industrial production contains the most important information, followed by income, capital controls and monetary statistics. Financial market variables and government finance data have negligible effects on the nowcast.

Table 5 puts the magnitude of the information conveyed by capital controls in context. During my sample period, Brazilian real GDP growth averages 4% with a standard deviation of 2.7%. After capital control measures are included in the forecaster's information set, the nowcast of current quarter real GDP growth at the end of

[9]Here, I present the forecast error reduction in percentage of GDP growth rate to allow for a more intuitive interpretation. The forecasting literature usually reports these numbers as Mean-Squared Forecast Error(MSFE) normalized by the variance of the series, and I follow this convention in the appendix.

Table 5: Capital control announcement and forecast error reduction(FER)

Mean GDP growth	std. GDP growth	FER,1st month	FER,2nd month	FER,3rd month
3.99%	2.67%	0.63%	0.57%	0.69%

My sample period is between 2004Q1 and 2013Q4.

a given month becomes more accurate by about 0.55%-0.7% in real-time, depending on which month in the quarter is considered.

A caveat of the above result is that unlike other economic data used, capital control announcements can be made at different points in time in a given month instead of at a given time. To use these announcements in the current framework, I need to make a decision where to put them in the calendar of data release. I position capital control announcements such that this decision does not exaggerate the information conveyed by them. For instance, if half of the announcements were made on November 20th in 2009 and the other half made on December 10th 2009, capital controls would come into the forecasting model on the 10th of a month and the November 20th announcements would be treated as if they were made on December 10th.

5.4.4 Robustness checks

I complete two robustness checks of my nowcasting results: first, my empirical results are robust to the month I consider. When quarterly GDP is projected on factor estimates of the second month or the third month of the current quarter, capital controls is still helpful in obtaining a more precise nowcast[10]. Second, I compare my results for the capital controls dummy against random dummies of similar structure. For this purpose, I generate 500 random dummies of the same length and the same proportion of -1s and 1s in simulation. In each iteration, a random dummy is placed in exactly the same place as the capital control dummy and used alongside the same macroeconomic data to generate a GDP-nowcast. The capital control dummy outperforms 81% of random dummies in terms of MSFE reduction. [11] These exercises show that

[10]Table 9 in the appendix presents these results in detail.

[11]Figure 10 in the appendix plots the distribution of MSFE reduction of random dummies alongside that of capital controls, shown with the solid red line. It is not surprising that some randomly generated dummies does better than the capital control dummy for this particular sample period.

my finding that capital controls help predict real GDP better is robust to timing and isn't due to spurious correlation.

5.4.5 Nowcasting and calibration of theoretical model

The magnitude of the MSFE reduction from capital controls provides a key moment to target in calibration of the theoretical model with learning from policy. In the model, the representative agent completes a Bayesian updating of her information set when she observes capital controls. Certain parameters influence how much the agent learns about fundamentals from policy. I calibrated these parameters such that the MSFE reduction from capital controls in the model matches what I find in the nowcasting exercise in this section.

6 Conclusion

This paper contributes to our understanding the role of capital controls in conveying important information about economic fundamentals and the implications of such informational channel for the efficacy of capital controls. I incorporate learning from capital controls in a small open economy model with a collateral constraint and associated pecuniary externality. Capital controls could be less efficient in reducing borrowings and mitigating the severity of a financial crisis when the agent learns from policy and saves less for precautionary reasons. To justify my modeling assumption, I provide empirical evidence that capital controls contain useful information about economic fundamentals people use in their forecasts. The findings of this paper could have important implications for policymakers: in designing capital controls, policymakers have to consider that the environment in which she operates is not invariant to policy itself: it changes as information about the environment is being transmitted through policy actions.

The finding that learning from capital controls undermines its efficacy is a result of

Using one of these in future nowcasting exercises, however, constitutes exactly what one calls data-mining.

the current modeling environment of over-borrowing relative to the socially-optimal level. In such a setting, learning and information revelation reduces precautionary savings precisely when such savings mitigates the pecuniary externality. Schmitt-Grohe and Uribe(2018) have pointed out that under certain conditions, fear of self-fulfilling crisis may lead to under-borrowing in this class of model. In such an alternative setting, learning and information revelation reduces precautionary savings when the agent saves too much. Therefore, learning from policy is instead expected to enhance policy efficacy by reducing the size of the capital control tax necessary to rule out self-fulfilling crisis and multiple-equilibria. This extension is planned for future research.

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A. Additional tables

Table 6: Capital control and related prudential measures in Brazil, 2006 - 2013

Measure	Announcement date	Source(s)
Limit on banks' foreign exchange exposure was increased to 60% (from 30%)	12/05/2006	F
Bank's capital requirement on forex exposure increased from 50% to 100%	06/11/2007	F
Introduced IOF of 1.5% on fixed income	03/12/2008	F,J
Reduced IOF on fixed income to 0%	10/23/2008	F,J
Introduced IOF of 2% on fixed income and equities	10/20/2009	F,J,CG
Introduced 1.5% tax when foreigners convert ADRs into receipts for local shares	11/18/2009	F,CG
Increased IOF to 4% on fixed income	10/04/2010	F,J,CG
Increased IOF to 6% on fixed income	10/18/2010	F,J,CG
Introduced tax on the cancellation of Depository receipts	12/30/2010	F,CG
Reducing IOF from 6% to 4%	01/03/2011	J
Introduced 60% URR on banks' short FX position > 3bn USD in the spot market	01/06/2011	F,CG
Introduced 2% tax on local corporate offshore borrowing and a 6% IOF on FX loans greater than one year	03/28/2011	F,CG

F: Forbes et al.(2016). CG: Chamon and Garcia(2014). J: Jinjarak et al.(2012)

Table 7: Capital control and related prudential measures in Brazil, 2006 - 2013, continued

Measure	Announcement date	Source(s)
Extended the IOF on FX loans to over two years	04/06/2011	F,CG
Introduced 60% URR on banks' short FX position > 1bn USD in the spot market	07/08/2011	F,CG
Introduced 1% tax on notional amount of currency derivatives	07/26/2011	F,CG
Reduced IOF on equities to 0%	12/01/2011	F,CG
Tax on borrowing abroad extended to maturity below 3 years	02/29/2012	CG
Tighten restrictions on anticipation of exporter payments for up to 1 year	03/01/2012	F,CG
Tax on borrowing abroad extended to maturity below 5 years	03/09/2012	CG
Tax on derivatives for hedging by exporters set to 0%	03/15/2012	CG
Tax on borrowing abroad restricted to maturity below 2 years	06/14/2012	CG
Anticipation of payments to exporters can be done by financial institutions	06/28/2012	CG
Anticipation of payments to exporters allowed between 1-5 years	12/04/2012	CG
Tax on borrowing abroad restricted to maturity below 1 years	12/05/2012	CG
URR on bank's gross FX position applies only after USD 3 billion	12/18/2012	CG
Reduced IOF on fixed income to 0%	06/04/2013	F,CG
Tax on notional amount of derivatives eliminated	06/12/2013	CG

F: Forbes et al.(2016). CG: Chamon and Garcia(2014). J: Jinjarak et al.(2012)

Table 8: Brazil: calendar of data releases within the month

Block name	Series	Timing	Publishing lag
Labor	Employment	20th month	20 days
Trade	Exports	first days	2 days
Trade	Imports	first days	2 days
Capital control	Capital control policy dummy	same day	current month
Industrial Production	Industrial Production: total	first days	one month
Industrial Production	Industrial Production: Consumer goods	first days	one month
Industrial Production	Industrial Production: Capital goods	first days	one month
Industrial Production	Industrial Production: Intermediate goods	first days	one month
Industrial Production	Capacity utilization	first weeks	one month
Survey	Consumer confidence	last week	current month
GDP/Income	Monthly GDP	end	one month
GDP/Income	Retail sales volume	middle	1-2 month
GDP/Income	Amplified retail sales volume	middle	1-2 month
Monetary/Credit	M1	last week	1-2 month
Monetary/Credit	M2	last week	1-2 month
Monetary/Credit	M3	last week	1-2 month
Monetary/Credit	Monetary Base	last week	1-2 month
Monetary/Credit	Total bank reserve	last week	1-2 month
Monetary/Credit	Total loans	last week	1-2 month
Financial/Interest rate	Effective exchange rate index	last day of month	current month
Financial/Interest rate	USD/REAL spot rate	last day of month	current month
Financial/Interest rate	IMF Brazil share price index	last day of month	current month
Financial/Interest rate	OECD Brazil share price index	last day of month	current month
Financial/Interest rate	Brazil central bank Selic policy rate	last day of month	current month
Government Finance	Central Government Budget Balance	last day of month	one month
Government Finance	Primary Balance	last day of month	one month
Government Finance	Net debt % of GDP	last day of month	one month

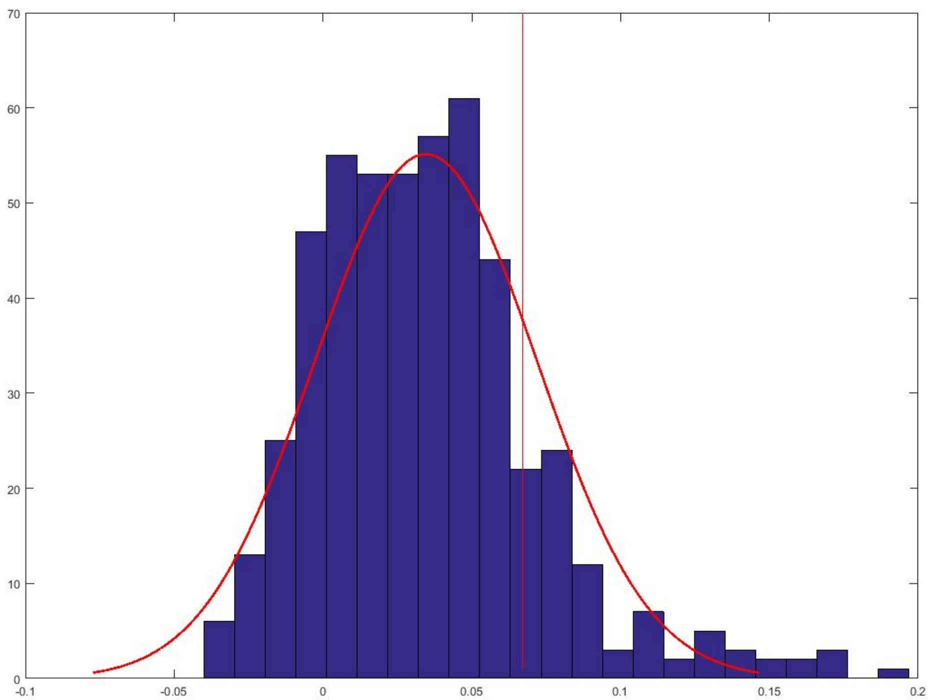
Table 9: Brazil: MSFE of nowcast after a block has been included

Block name	MSFE:1st month	MSFE:2nd month	MSFE:3rd month
Labor and trade	0.6034	0.6495	0.7078
Capital control dummy	0.5479	0.6038	0.6406
Industrial production	0.2791	0.3664	0.4562
Survey	0.2712	0.3676	0.4718
GDP/Income	0.1707	0.2326	0.3606
Monetary/Credit	0.1374	0.1057	0.091
Financial/interest rate	0.1307	0.0946	0.0779
Government finance	0.1366	0.1001	0.0809

MSFE reported here are normalized by the variance of GDP growth during the sample period.

B. Additional figures

Figure 10: Compare MSFE reduction of capital control and of random dummies



C. Computational Appendix

The Matlab code is an extension of the programs used in Bianchi, Liu and Mendoza(2016). The code named "Modelupdate.m" solves the model and is divided into five sections.

Section 1. Parameter Values set the parameter values shown in Table 3. We use 100 points in the grid for bonds, three states for y_T shocks, three states for news shocks, four states for observable tax rates, two states for the random component of the tax rule last period and two states for interest rate shocks. In the decentralized equilibrium, there is no tax imposed and none observed, so the number of states is 18, as in the original paper. In the equilibrium with tax rule and Bayesian updating, the number of states is $18 \times 8 = 144$. The convergence tolerance level for the solution of decision rules is set to $\epsilon = 1e^{-5}$.

Section 2. Construction of Markov Chain discretizes y_T shocks and v_t shocks using Tauchen and Hussey's method. News shocks are incorporated as in the original paper(briefly described on page 17 in section 4.3). Agent's Bayesian updating after observing a capital control tax is incorporated according to formulas in page 18 and 19 in section 4.3 of the paper. On top of y_T, s_t, τ_t and v_{t-1}, I add global liquidity shocks to construct the entire transition probability matrix, assuming independence between y_T shocks, interest rate shocks and v_t shocks.

Section 3. Decentralized equilibrium solves the decentralized equilibrium using the time iteration method described. The solution method is described in detail in Appendix A of Bianchi, Liu and Mendoza(2016). For the state vector $z = (y_t^T, s_t, R_t)'$, the algorithm solves for the recursive functions $c^T(b, z)$, $p^N(b, z)$ and $B(b, z)$ such that the following four conditions are satisfied.

$$p^N(b,z) = (\frac{1-\omega}{\omega})(\frac{c^T(b,z)}{c_t^N})^{\eta+1} \tag{53}$$

$$u_T(c^T(b,z), y^N) \geq \beta R(z) E_z[u_T(c^T(B(b,z), z'), y^N)] \tag{54}$$

$$B(b,z) \geq -(\kappa^N p^N(b,z) y^N + \kappa^T y^T(z) \tag{55}$$

$$B(b,z) + c^T(b,z) = b(1 + R(z)) + y^T(z) \tag{56}$$

Section 4. Equilibrium with tax rule and Bayesian updating solves the equilibrium when a tax rule is imposed by a macroprudential regulator(as in section 4.2 in this paper) and agent completes a Bayesian updating(as in section 4.3 in this paper) using the time iteration method described. I avoid calling this the social planner's equilibrium because the regulator is not imposing an optimal tax. The solution method is identical to the last section. For the state vector $z_t = (y_t^T, s_t, R_t, \tau_t, v_{t-1})'$, the algorithm solves for the recursive functions $c^T(b,z)$, $p^N(b,z)$ and $B(b,z)$ such that equations 54, 56 and 57 and the following replacement for equation 55 are satisfied.

$$u_T(c^T(b,z), y^N) \geq \beta R(z)(1+\tau_t) E_z[u_T(c^T(B(b,z), z'), y^N)] \tag{57}$$

Section 5. Welfare Calculation takes the optimal policy functions derived from section 3 and section 4 of the code, and iterates until convergence to get value functions of the private agent in the decentralized economy and in the economy with tax and updating. Welfare gains are then calculated as in Bianchi(2011). Since the two economies have different state space, I compare, for each of the 8 different combinations of τ_t and v_{t-1}, the value function in the second economy against the value function in the first economy.

The Matlab code "Simulation.m" simulates the model and is divided into two sections.

Section 1. Simulation simulates the model for 201,000 periods. The first 1,000 periods are discarded to eliminate initial condition dependence. The initial bond position is set as mid point of the bond grid for both economies.

Section 2. Event analysis identifies sudden stop events, and finds the surrounding three periods before and after the event. Crisis is defined as 1) current account goes beyond two standard deviation of the ergodic distribution of debt in decentralized equilibrium and 2) collateral constraint binds. The crisis moments are obtained by taking average across all crisis episodes.