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Abstract

We estimate a small open economy RBC model augmented with a simple form of financial frictions using Spanish data and Bayesian methods. The estimated model matches well with key Spanish business cycle statistics. Using the estimated model, we find that significant welfare benefits may accrue from capital controls.

Keywords: capital controls, welfare, DSGE, small open economy models, Bayesian estimation.

JEL Classification: F41

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1 Introduction

Following the recent global financial crisis, volatile international capital movements have been the subject of rigorous discussion by concerned policymakers and economists. Volatile capital flows amplify boom and bust cycles and destabilize emerging market economies. Recent crises in some European peripheral countries have further shown that massive capital inflows in boom periods can easily be reversed to become massive outflows in bust periods. Even the IMF, a former critic of capital controls, has been forced to reconsider such measures as an important policy response to volatile capital flows.[1] In fact, several countries (Brazil, Taiwan, South Korea, and Thailand) have recently responded to instability by imposing capital controls.[2] Against this background, a rapidly growing body of literature related to capital controls has emerged. For example, Jeanne and Korinek (2010) argue that some externalities are associated with capital inflows because individual market participants do not internalize their contribution to aggregate financial instability. They therefore advocate a Pigouvian tax on borrowing that may induce borrowers to internalize these externalities and increase overall welfare.[3] Kitano (2011) develops a dynamic stochastic general equilibrium (DSGE) model of a small open economy with costly financial intermediaries, and shows that if domestic financial intermediaries are less efficient, the government should impose stricter capital controls in the form of a tax on foreign

[1]For details on the IMF position, see Ostry et al. (2010) and Ostry et al. (2012).
[2]For details, see for example Jeanne et al. (2012).
[3]For related literature, see for example, Korinek (2011) and Jeanne et al. (2012).

borrowing.[4]

In this paper, we extend Kitano (2011)'s model to develop a stochastic growth model à la Aguiar and Gopinath (2007), and incorporate country premium, preference, and domestic spending shocks à la Garcia-Cicco et al. (2010). We estimate the augmented model using Spanish data and Bayesian methods. The estimated model matches key Spanish business cycle statistics. We then use the estimated model to calculate the welfare effect of capital controls. The results of our analysis show that an optimal degree of capital controls exists that achieve a higher level of welfare than obtainable under perfect capital mobility. We find that significant welfare benefits accrue from capital controls. Our simulation's results show that capital controls may improve welfare levels by approximately 3.8% of the consumption level in the case of perfect capital mobility.

The remainder of this paper is structured as follows. Section 2 presents the model of a small open economy with a simple form of financial frictions and capital controls. Section 3 estimates the model using Spanish data by Bayesian methods. Section 4 uses the estimated model to examine how capital controls affect the economy's level of welfare. Section 5 concludes.

[4]Kitano (2004) showed that capital-account restrictions can be effective measures against the capital inflow problem of emerging markets such as deterioration in the current account, real exchange rate appreciation, and inflationary pressures. However, Kitano (2007) showed that capital controls may constitute an additional burden on the government's budget, thus bringing forward the onset of a crisis.

2 The Model

We consider a small open economy with four agents: households, firms, banks, and the government. Our model is an extension of Kitano (2011) to a stochastic growth model à la Aguiar and Gopinath (2007), and we incorporate country premium, preference, and domestic spending shocks à la Garcia-Cicco et al. (2010).

Following Aguiar and Gopinath (2007), we incorporate permanent productivity shocks into a small open economy's RBC model. The production function is given by

$$Y_t = a_t K_t^{\alpha} (X_t h_t)^{1-\alpha}, \tag{1}$$

where Y_t denotes output in period t, K_t is capital, h_t is labor, α is capital's share of output, and a_t and X_t represent transitory and permanent productivity shocks, respectively. The transitory productivity shock a_t follows an AR(1) process in logs.

$$\ln a_{t+1} = \rho_a \ln a_t + \epsilon_{t+1}^a; \qquad \epsilon_t^a \sim \text{i.i.d.} \mathcal{N}(0, \sigma_a^2). \tag{2}$$

X_t is the cumulative product of "growth" shocks:

$$X_t = g_t X_{t-1} = \prod_{s=0}^{t} g_s. \tag{3}$$

The "growth" shock g_t follows

$$\ln\left(\frac{g_{t+1}}{g}\right) = \rho_g \ln\left(\frac{g_t}{g}\right) + \epsilon^g_{t+1}; \qquad \epsilon^g_t \sim \text{i.i.d.}\,\mathcal{N}(0, \sigma_g^2), \tag{4}$$

where g represents productivity's long run mean growth rate.

2.1 Households

Households seek to maximize the following utility function:

$$E_0 \sum_{t=0}^{\infty} \nu_t \beta^t \frac{\left(C_t - \theta\omega^{-1} X_{t-1} h_t^{\omega}\right)^{1-\gamma} - 1}{1-\gamma}, \quad \theta > 0, \ \omega > 1, \ \gamma > 0, \tag{5}$$

where C_t is consumption, E_0 denotes the expectations operator conditional on information available at time 0, and $\beta \in (0,1)$ denotes the discount factor. The variable ν_t represents an exogenous preference shock:

$$\ln \nu_{t+1} = \rho_\nu \ln \nu_t + \epsilon^\nu_{t+1}; \qquad \epsilon^\nu_t \sim \text{i.i.d.}\,\mathcal{N}(0, \sigma_\nu^2). \tag{6}$$

The household's flow budget constraint is given by

$$D^h_t = (1 + r^d_{t-1}) D^h_{t-1} - w_t h_t X_t - r^k_t K_t - \Omega^f_t - \Omega^b_t - \mathcal{T}_t + C_t + S_t + I_t + \frac{\phi}{2}\left(\frac{K_{t+1}}{K_t} - g\right)^2 K_t. \tag{7}$$

D^h_t is the foreign debt position of the household, r^d_t is the interest rate at which households can borrow, w_t is the real wage, r^k_t is the rental rate of capital, Ω^f_t and Ω^b_t are dividends from firms and banks, respectively, $\mathcal{T}_t$ is the government's net lump-sum transfer, I_t is investment, and ϕ is the capital adjustment cost parameter. S_t denotes a domestic spending shock:

$$\ln\left(\frac{s_{t+1}}{s}\right) = \rho_s \ln\left(\frac{s_t}{s}\right) + \epsilon^s_{t+1}; \qquad \epsilon^s_t \sim \text{i.i.d.}\,\mathcal{N}(0, \sigma_s^2), \tag{8}$$

where $s_t \equiv \frac{S_t}{X_{t-1}}$. The process of capital accumulation is given by

$$K_{t+1} = (1-\delta)K_t + I_t, \tag{9}$$

where δ denotes physical capital's depreciation rate. As given, the household takes the processes of $\{r^d_t, w_t, r^k_t\}_{t=0}^{\infty}$ as well as D^h_{-1} and K_0, and maximizes utility function (5) subject to (7) and (9) in addition to a no-Ponzi-game condition.

2.2 Firms

A firm's flow constraint is given by

$$D^f_t = (1 + r^d_{t-1})D^f_{t-1} - Y_t + w_t h_t X_t + r^k_t K_t + \Omega^f_t, \tag{10}$$

where D^f_t denotes the firm's debt position, and r^d_t is the interest rate at which firms can borrow. The firm maximizes the present discounted value of the profit stream:[5]

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0} \Omega^f_t. \tag{11}$$

[5]Following Uribe and Yue (2006), we discount the firm's profits using the household's marginal utility of wealth since households own firms.

The firm's objective is to choose paths of h_t, K_t, and D_t^f to maximize (11) subject to the firm's flow constraint (10) and a no-Ponzi-game condition.

2.3 Banks

The banking industry is assumed to be perfectly competitive and to have direct access to international financial markets. They borrow at the interest rate of $r(= r^* + e^{\mu_t - 1} - 1)$ in international financial markets and lend to domestic individuals at the rate of r_t^d. The variable μ_t represents a country premium shock:

$$\ln \mu_{t+1} = \rho_\mu \ln \mu_t + \epsilon_{t+1}^\mu; \qquad \epsilon_t^\mu \sim \text{i.i.d.}\, \mathcal{N}(0, \sigma_\mu^2). \tag{12}$$

Domestic individuals' foreign debt position is denoted by D_t:

$$D_t = D_t^h + D_t^f. \tag{13}$$

Following Edwards and Végh (1997) and Uribe and Yue (2006), we assume that financial intermediation is a costly activity and banks use resources to provide credit D_t. Formally, banks face an operation cost $\Psi(D_t)$. The bank's flow budget constraint is given by

$$D_t^b = (1+r)D_{t-1}^b + (r - r_{t-1}^d)D_{t-1} + T(D_t)D_t + \Psi(D_t)X_t + \Omega_t^b. \tag{14}$$

D_t^b is the bank's debt position. $T(\cdot)$ denotes the tax rate that the government imposes upon banks when they lend to domestic individuals. Similar to

Kitano (2011), we assume that the tax rate increases as the foreign debt position deviates from its steady state level. The bank chooses D_t to maximize the present discounted value of the profit stream (i.e., $\sum_{t=0}^{\infty}\left(\frac{\Omega_t^b}{1+r}\right)^t$). [6]

2.4 Government

As argued in the previous subsection, banks are taxed as much as $T(D_t)D_t$ when they lend to domestic individuals. Without loss of generality, we assume that the government returns the collected tax $T(D_t)D_t$ to households as a lump-sum transfer $\mathcal{T}_t$:

$$\mathcal{T}_t = T(D_t)D_t. \tag{15}$$

2.5 Equilibrium

By combining (7), (10), (13), (14), and (15), we obtain this economy's current account, CA_t, as follows:

$$CA_t \equiv -D_t + D_{t-1} = TB_t - r\,D_{t-1}, \tag{16}$$

where TB_t denotes the economy's trade balance:

$$TB_t \equiv Y_t - C_t - S_t - I_t - \phi\left(\frac{K_{t+1}}{K_t} - g\right)^2 K_t - \Psi(D_t)X_t. \tag{17}$$

[6]Following Edwards and Végh (1997) and Uribe and Yue (2006), we assume that the initial net debt is zero (i.e.,$D_{-1}^b = 0$) and banks finance their operations through retained earnings (i.e., banks do not accumulate/decumulate net debt; $D_t^b = 0$ for all t).

Note that the current account (16) is also the economy's resource constraint, meaning that an inefficient bank (i.e., a high value of $\Psi(D_t)$) implies a resource loss to this economy.

2.6 Functional forms

For the bank's operational cost, we adopt the following form:

$$\Psi(D_t) = \frac{\psi}{2}\left(\frac{D_t}{X_t} - \bar{d}\right)^2; \;\; \psi > 0, \tag{18}$$

where $\bar{d}$ is the steady-state level of foreign debt.[7] We adopt the following tax policy that formally expresses capital controls:

$$T(D_t) = \frac{\tau}{2}\left(\frac{D_t}{X_t} - \bar{d}\right)^2; \;\; \tau > 0. \tag{19}$$

3 Estimation

In this section, we estimate the model developed in the previous section using Spanish data and Bayesian methods. Some structural parameters are calibrated using their long-term data relations or common values in the related literature. The remaining structural parameters are estimated using Bayesian methods and Spanish data on output growth, consumption growth, investment growth, and trade balance to output ratio for the 1980Q1 - 2013Q1 period.[8]

[7]This form is the same as that of the portfolio (or debt) adjustment cost in Schmitt-Grohé and Uribe (2003) and Uribe and Yue (2006).

[8]Data are from the OECD's quarterly national accounts (QNA) dataset.

Table 1: Calibration

γ	ω	α	δ	β	$\bar{d}$	θ	tb/y
2	1.6	0.32	0.03	0.98	0.011	3.4	0.001

We calibrate the parameters γ, ω, α, δ, $\bar{d}$, and θ using long-run data relations as well as standard parameter values from the related literature. The steady-state value of trade balance to output ratio ($\frac{tb}{y}$) is set as equal to its data average (0.001). The steady state level of the economy's aggregate foreign debt position ($\bar{d}$) is then calibrated from current account (16) to ensure that $\frac{tb}{y}$ equals its data average.[9] We set the parameter for capital's share of output α equal to 0.32, a value commonly used in related literature. The (quarterly) depreciation rate δ is set at 0.03, which is frequently used in related business cycle studies. We set θ at 3.4 so that the steady state level of hours worked h equals 0.25. As in most studies, we set the coefficient of relative risk aversion γ to 2. The curvature of labor ω is set at 1.6, implying that the labor supply elasticity given by $\frac{1}{\omega-1}$ is about 1.7. This value of ω is similar to that given in Neumeyer and Perri (2005).

The prior distributions of parameters to be estimated are shown in columns 3 and 4 of Table 2. The prior mean and standard deviation values of g, σ_g, and σ_a are set at the estimated values for Canada given in Aguiar and Gopinath (2004).[10] We set the prior mean values of ϕ and ψ at 4 and 0.001, respectively, which are the benchmark parameter values used by Aguiar and

[9] We can obtain the steady state level of y by calibrating h/k from optimality conditions and parameter values in a similar way as in Kitano (2011).

[10] Aguiar and Gopinath (2004) estimate these parameters using GMM for Canada and Mexico (Table 4).

Gopinath (2007).[11] The priors of the autoregressive coefficients ρ_g, ρ_a, ρ_ν, ρ_s, and ρ_μ are set to be a beta distribution with a mean of 0.7 and a standard deviation of 0.1. The priors of the white noises' standard deviations of σ_ν, σ_μ, and σ_s are set at inverse gamma distributions with a mean of 0.01 and a standard deviation of ∞. Following Kollmann (2012), we set the prior means and standard deviations of the measurement errors' standard deviations to 1/4 and 1/20, respectively, of the corresponding empirical series' standard deviations.

The means and standard deviations of the posterior parameter distribution are reported in columns 5 and 6 of Table 2, respectively. The 90% posterior intervals are reported in columns 7 and 8 of Table 2. The data are informative about the estimated parameters in the sense that some of the posterior means differ noticeably from the prior means, and, in all cases, posterior parameter distributions have lower standard deviations than prior distributions.

Using the estimated parameters in Table 2, we compute theoretical moments and compare them with the data (Table 3). The model matches well with Spain's overall business cycle pattern. However, the model predicts marginally higher output and consumption volatilities than shown in the data and also marginally underestimates the autocorrelation of output compared to the data. However, the other moments implied by the model correspond fairly closely to the data.

[11] Table 3 in Aguiar and Gopinath (2007).

Table 2: Prior and posterior parameter distributions.

Parameter	Prior distribution			Posterior distribution		
	Distribution	Mean	Standard deviation	Mean	Standard deviation	90% interval
g	Gamma	1.007	0.001	1.0057	0.0001	[1.0044, 1.0070]
σ_g	Inverse gamma	0.0014	0.0006	0.0041	0.00005	[0.0027, 0.0057]
σ_a	Inverse gamma	0.0057	0.0004	0.0048	0.00003	[0.0044, 0.0053]
ϕ	Gamma	4	3	8.3592	0.3028	[5.2828, 13.7687]
ψ	Gamma	0.001	0.0005	0.0015	0.00004	[0.0001, 0.0037]
ρ_g	Beta	0.7	0.1	0.7828	0.0113	[0.7010, 0.8698]
ρ_a	Beta	0.7	0.1	0.8936	0.0103	[0.8602, 0.9268]
ρ_ν	Beta	0.7	0.1	0.9152	0.0115	[0.8627, 0.9681]
ρ_s	Beta	0.7	0.1	0.7415	0.0190	[0.6087, 0.8838]
ρ_μ	Beta	0.7	0.1	0.4791	0.0105	[0.2845, 0.9128]
σ_ν	Inverse gamma	0.01	∞	0.0455	0.0081	[0.0354, 0.0552]
σ_μ	Inverse gamma	0.01	∞	0.0027	0.0006	[0.0016, 0.0037]
σ_s	Inverse gamma	0.01	∞	0.0052	0.0063	[0.0025, 0.0079]
			Measurement errors			
σ_y^{me}	Inverse gamma	0.002	0.0004	0.0022	0.00003	[0.0016, 0.0029]
σ_c^{me}	Inverse gamma	0.002	0.0004	0.0027	0.00006	[0.0019, 0.0034]
σ_i^{me}	Inverse gamma	0.006	0.0012	0.0084	0.00007	[0.0072, 0.0095]
σ_{tby}^{me}	Inverse gamma	0.008	0.0016	0.0041	0.00016	[0.0036, 0.0046]

Note) Estimation is based on Spain data from 1980 Q1 to 2013 Q1. The posterior distribution was obtained using the Metropolis-Hastings algorithm. A sample of 1,000,000 draws was created and the first 500,000 were discarded. Brooks and Gelman's (1998) measure was used to verify the convergence of parameters.

Table 3: Comparing model with data: Second moments

	g^Y	g^C	g^I	tby
	Standard deviation (%)			
data	0.80	0.86	2.45	3.28
model	1.03	1.15	2.54	3.46
	Standard deviation relative to g^Y			
data	1.00	1.08	3.06	4.09
model	1.00	1.12	2.47	3.36
	Autocorrelation	*Correlation with g^Y*		
data	0.20	0.59	0.69	-0.01
model	0.07	0.78	0.68	-0.04

Note) g^Y, g^C, and g^I denote the growth rates of output, consumption, and investment, respectively. tby denotes the trade balance to output ratio. Spain data from 1980 Q1 to 2013 Q1. Data source: the OECD's quarterly national accounts (QNA) dataset.

4 Welfare effects of capital controls

We use perturbation methods to compute second-order accurate solutions in Schmitt-Grohé and Uribe (2004) to measure lifetime utility levels.[12] We compare the measured welfare levels under different degrees of capital controls with the welfare level existing under perfect capital mobility to conduct policy evaluations of capital controls.

We define lifetime utility under perfect capital mobility (i.e., no capital controls) as

$$V_0^b \equiv E_0 \sum_{t=0}^{\infty} \beta^t U(c_t^b, h_t^b),$$

[12] Kim and Kim (2003) show that second-order solutions are necessary because the conventional linearization can generate spurious welfare reversals.

where $c_t^i \equiv \frac{C_t^i}{X_{t-1}}(i = a \text{ or } b)$. We define life time utility under capital controls as alternative policy regimes:

$$V_0^a \equiv E_0 \sum_{t=0}^{\infty} \beta^t U(c_t^a, h_t^a).$$

Moreover, we define λ^c as the welfare benefit of adopting policy regime a rather than policy regime b. Formally, λ^c is defined as

$$V_0^a = E_0 \sum_{t=0}^{\infty} \beta^t U((1+\lambda^c)c_t^b, h_t^b).$$

In other words, λ^c is the fraction of regime b's consumption process that compensates the household to a level considered as well off under regime b as under regime a.[13]

Using the economy possessing the parameters estimated in the previous section, we examine how capital controls influence the welfare level. We compute the life-time utility level associated with different values of τ. Figure 1 indicates the corresponding welfare benefits obtained by adopting different values of τ instead of the benchmark case of $\tau = 0$. Although not shown in Figure 1, the welfare-benefit measure turns negative if the value of τ continues to increase. We can therefore say that a range of $\tau\,(> 0)$ exists that improves welfare levels compared to the perfect capital mobility case ($\tau = 0$). In Figure 1, the economy's welfare curve indicates a hump shape.

[13] We obtain λ^c as follows. We first measure the percentage change from the deterministic steady-state consumption level that would in each case give households the same expected utility in the stochastic economy. Using the measured percentage change in each case, we calculate the welfare benefits of adopting different τ values instead of the benchmark case of $\tau = 0$.

The optimal value of τ (0.022) maximizes the value of the welfare benefit (3.79%).

The intuition behind these results is similar to that in Kitano (2011). Capital controls exert two opposite effects on welfare levels. On one hand, capital controls have an intertemporal distortion effect on the equilibrium path.[14] As indicated in the upper panel of Figure 2, the larger τ value increases the tax rate level of $T(D_t)$, causing evidently larger distortions. On the other hand, capital controls limit the deviation of foreign borrowings. Since banking is costly, as banks borrow more from abroad, their operations suffer increasing resource losses. As shown in the lower panel of Figure 2, operational costs can be halved if we compare the optimal τ case (i.e., 0.022) to the $\tau = 0$ case. If the beneficial effect in limiting foreign borrowing outweighs the intertemporal distortion effect, imposing capital controls improves welfare. However, if capital controls are too strict, the latter would dominate the former. Imposing an appropriate level of restriction enables the government to improve welfare compared to the perfect capital mobility case.

[14] If banks are highly efficient, the imposition of capital controls only results in a deterioration of welfare as shown in Kitano (2011).

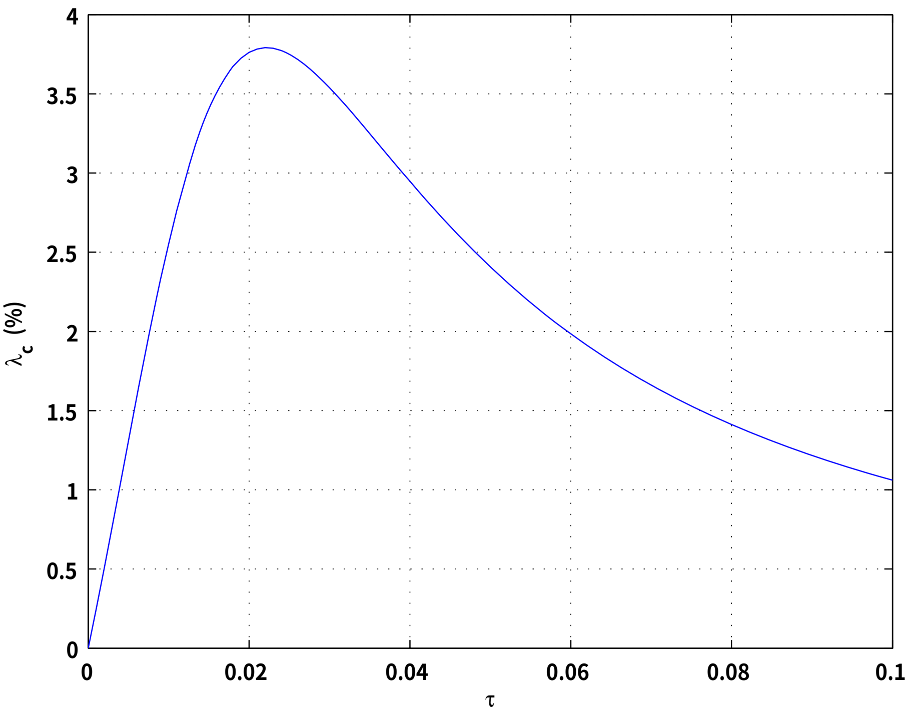

Figure 1: Welfare levels - varying τ

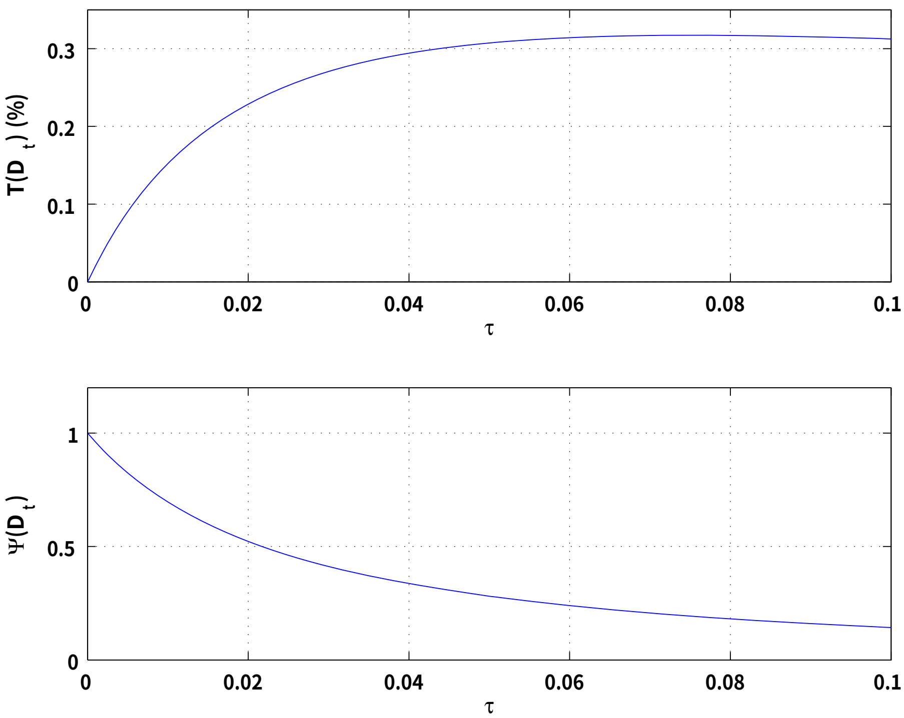

Figure 2: Tax rate $T(D_t)$ and operational cost $\Psi(D_t)$ - varying τ; $\Psi(D_t)$ is normalized to 1 when $\tau = 0$.

5 Conclusion

We have computed the potential welfare benefit of capital controls using Bayesian methods and Spanish data from 1980Q1 to 2013Q1. The estimated model replicates key Spanish business cycle statistics with a high degree of accuracy. We have shown that perfect capital mobility may not be optimal and that capital controls may enhance the economy's welfare level. Our simulation based on parameters estimated using Bayesian methods indicates that an optimal degree of capital restrictions may improve the welfare level by 3.79% of the consumption level in the perfect capital mobility case.

Our analysis is based on a simple real business cycle model. However, in reality, the direct effect of capital inflows on the economy's productivity should be incorporated. Different types of capital flows, such as foreign direct investment and short-term borrowing, could be introduced into the model, along with an examination of the effects of different tax rates on these factors and overall welfare. We leave these extensions for our future work.

Appendix (Not for publication)

Optimality conditions of the household's problem

The optimality conditions associated with the household's maximization problem are given by

$$\nu_t \left(C_t - \theta\omega^{-1} X_{t-1} h_t^{\omega}\right)^{-\gamma} = \Lambda_t, \tag{20}$$

$$\nu_t \left(C_t - \theta\omega^{-1} X_{t-1} h_t^{\omega}\right)^{-\gamma} \theta X_{t-1} h_t^{\omega-1} = \Lambda_t w_t X_t, \tag{21}$$

$$\Lambda_t = \beta(1 + r_t^d) E_t \Lambda_{t+1}, \tag{22}$$

$$\begin{aligned} &\Lambda_t \left\{1 + \phi\left(\tfrac{K_{t+1}}{K_t} - g\right)\right\} \\ &= \beta E_t \Lambda_{t+1} \left\{1 + r_{t+1}^k - \delta - \tfrac{\phi}{2}\left(\tfrac{K_{t+2}}{K_{t+1}} - g\right)^2 + \phi\left(\tfrac{K_{t+2}}{K_{t+1}} - g\right)\tfrac{K_{t+2}}{K_{t+1}}\right\}, \end{aligned} \tag{23}$$

and

$$\lim_{j\to\infty} E_t \frac{D_{t+j}^h}{\prod_{s=1}^{j}(1 + r_s^d)} = 0. \tag{24}$$

Optimality conditions of the firm's problem

The optimality conditions associated with the firm's maximization problem are given by (22),

$$r_t^k = \alpha a_t K_t^{\alpha-1}(X_t h_t)^{1-\alpha}, \tag{25}$$

$$w_t = (1-\alpha) a_t \left(\frac{K_t}{X_t h_t}\right)^{\alpha}, \tag{26}$$

and

$$\lim_{T\to\infty} \frac{d_T^f}{R_{0,T}^d} = 0. \tag{27}$$

Optimality conditions of the bank's problem

Integrating (14), we obtain the present discounted value of the bank's profits as follows:

$$\sum_{t=0}^{\infty} \left(\frac{\Omega_t^b}{1+r}\right)^t = \sum_{t=0}^{\infty} \left(\tfrac{1}{1+r}\right)^t \left[(r_{t-1}^d - r)D_{t-1} - T(D_t)D_t - \Psi(D_t)X_t\right] \\ -(1+r)D_{-1}^b + \lim_{T\to\infty} \frac{D_T^b}{(1+r)^{T-1}}. \tag{28}$$

The bank chooses D_t to maximize the present discounted value of its profit stream, which is given by the right-hand side of (28), for a given initial stock of debt, D_{-1}^b. A first-order condition of the bank's maximization problem is given by

$$r_t^d = r + (1+r)\left\{T(D_t) + T'(D_t)D_t + \Psi'(D_t)\right\}. \tag{29}$$

Following Edwards and Végh (1997) and Uribe and Yue (2006), we assume that initial net debt is zero (i.e.,$D_{-1}^b = 0$), and banks finance their operations through retained earnings (i.e., banks do not accumulate/decumulate net debt; $D_t^b = 0$ for all t). Therefore we can identify the time path of profits Ω_t^b as follows.

$$\Omega_t^b = (r_{t-1}^d - r)D_{t-1} - T(D_t)D_t - \Psi(D_t)X_t. \tag{30}$$

Equilibrium conditions

Let $\lambda_t \equiv \Lambda_t X_{t-1}^{\gamma}$, $y_t \equiv \frac{Y_t}{X_{t-1}}$, $c_t \equiv \frac{C_t}{X_{t-1}}$,$i_t \equiv \frac{I_t}{X_{t-1}}$, $k_t \equiv \frac{K_t}{X_{t-1}}$, and $d_t \equiv \frac{D_t}{X_t}$. Then, we have equilibrium conditions of this economy expressed in terms of stationary variables as follows.

$$y_t = a_t k_t^{\alpha} h_t^{1-\alpha} g_t^{1-\alpha}, \tag{31}$$

$$d_t g_t = (1 + r_{t-1}^d)d_{t-1} - y_t + c_t + s_t + i_t + \frac{\phi}{2}\left(\frac{k_{t+1}}{k_t}g_{t+1} - g\right)^2 k_t + \frac{\psi}{2}\left(d_t - \bar{d}\right)^2. \tag{32}$$

$$k_{t+1}g_t = (1-\delta)k_t + i_t, \tag{33}$$

$$\nu_t \left(c_t - \theta\omega^{-1}h_t^{\omega}\right)^{-\gamma} = \lambda_t, \tag{34}$$

$$\theta h_t^{\omega-1} = w_t g_t, \tag{35}$$

$$\lambda_t = \frac{\beta}{g_t^{\gamma}}(1+r_t^d)E_t\lambda_{t+1}, \tag{36}$$

$$\lambda_t \left\{1+\phi\left(\tfrac{k_{t+1}}{k_t}g_t - g\right)\right\}$$
$$= \tfrac{\beta}{g_t^{\gamma}}E_t\lambda_{t+1}\left\{1+r_{t+1}^k-\delta-\tfrac{\phi}{2}\left(\tfrac{k_{t+2}}{k_{t+1}}g_t-g\right)^2+\phi\left(\tfrac{k_{t+2}}{k_{t+1}}g_{t+1}-g\right)\tfrac{k_{t+2}}{k_{t+1}}g_{t+1}\right\}, \tag{37}$$

$$r_t^k = \alpha a_t k_t^{\alpha-1}h_t^{1-\alpha}g_t^{1-\alpha}, \tag{38}$$

$$w_t = (1-\alpha)a_t {k_t}^{\alpha} {h_t}^{-\alpha} g_t^{-\alpha}, \tag{39}$$

and

$$r_t^d = r + (1+r)\left\{\frac{\tau}{2}\left(d_t-\bar{d}\right)^2 + \tau\left(d_t-\bar{d}\right)d_t + \psi\left(d_t-\bar{d}\right)\right\}. \tag{40}$$

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