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Juan Herreño
Carlos Rondón-Moreno

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Overborrowing and Systemic Externalities in the Business Cycle Under Imperfect Information*

Juan Herreño
University of California, San Diego

Carlos Rondón-Moreno
Banco Central de Chile

Abstract

We study the interaction between imperfect information and financial frictions and its role in financial crises in small open economies. We use a model where households observe income growth but do not perceive whether the underlying shocks are permanent or transitory, and borrowing is subject to a collateral constraint. We show that the combination of imperfect information and a borrowing constraint is a significant source of economic instability. The optimal macroprudential policy helps stabilize the economy by actively taxing debt, but its implementation is complex. The interaction between the collateral constraint and the information friction changes the cyclicality of the optimal tax. We show that a simple fixed-tax rule intervention is effective, and welfare benefits are close to the second-best.

Resumen

Estudiamos la interacción entre la información imperfecta y las fricciones financieras y su papel en las crisis financieras en economías pequeñas y abiertas. Utilizamos un modelo en el que los hogares observan el crecimiento de los ingresos, pero no perciben si los choques subyacentes son permanentes o transitorios, y el endeudamiento está sujeto a una restricción de colateral. Mostramos que la combinación de información imperfecta y una restricción de endeudamiento es una fuente significativa de inestabilidad económica. La política macroprudencial óptima ayuda a estabilizar la economía al gravar activamente la deuda, pero su implementación es compleja. La interacción entre la restricción de colateral y la fricción de información cambia la ciclicidad del impuesto óptimo. Mostramos que una intervención con una regla simple de impuesto fijo es efectiva, y los beneficios en términos de bienestar están cerca del second-best.

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1 Introduction

Three empirical regularities distinguish business cycles in emerging economies: consumption volatility is higher than income volatility, the current account exhibits a strong countercyclical pattern, and the economy experiences recurring macro-financial crises (often called Sudden Stops). These crises carry significant macroeconomic implications. They entail sharp reversals of capital inflows, corrections in asset prices, lower economic growth, and, in some cases, exclusion from international credit markets (Calvo, 1998; Mendoza, 2010).[1]

The literature has put forth two main mechanisms to explain these phenomena. One mechanism suggests that more stringent financial constraints characterize emerging economies and that adverse shocks may create debt-deflation episodes amplified by a decline in relative prices (Mendoza, 2010; Bianchi, 2011). Another mechanism proposes that the stochastic nature of shocks in emerging economies is different, and economic agents might not perfectly observe the persistence of the shocks they face. This uncertainty about the fundamentals leads to a more volatile cycle and makes the economy more vulnerable to sudden changes in economic conditions (Aguiar and Gopinath, 2007; Boz et al., 2011; Blanchard et al., 2013).

We contribute to the existing literature by examining the macroeconomic implications of imperfect information regarding an economy's fundamentals and its interplay with borrowing constraints. Specifically, we explore how imperfect information can trigger Sudden Stops in a small open economy model characterized by financial frictions. Additionally, we analyze how the interaction between financial and informational frictions influences the dynamics of optimal macroprudential policies aimed at reducing the frequency and severity of financial crises.

Our main result shows that the perfect information assumption in standard models

[1] For the simulations presented in this paper, we define a *Sudden Stop* as an episode in which the current account improves (i.e., it becomes less negative or even positive) by more than one-standard-deviation above its long-term average, and a financial constraint, which in this paper takes the form of a collateral constraint, is binding. From this point onward, we will use the terms *Sudden Stop* and *financial crisis* interchangeably.

of collateral constraints leads to an underestimation of the welfare losses stemming from the externality that emerges when households pledge collateral goods or assets at market prices (Bianchi, 2011). Notably, assuming perfect information also leads to underestimating the effectiveness of the optimal tax policy in mitigating the effects of the pecuniary externality. Moreover, we find that incorporating imperfect information reshapes the cyclicality of the tax with respect to each of the individual components of income.

In order to incorporate imperfect information into a standard small open economy model with an occasionally binding collateral constraint, our approach draws upon the contributions of Bianchi (2011) and Seoane and Yurdagul (2019). In our model economy, households receive stochastic income endowments from tradable and nontradable sectors. These endowments are subject to sector-specific transitory shocks and a common-trend shifter (representing the cumulative effect of current and past growth shocks) to both sectors.

Due to imperfect information, households cannot directly observe the underlying components of each endowment; instead, they form beliefs about the fundamentals using the Kalman filter to solve a signal extraction problem. When new information becomes available, households optimally adjust their consumption decisions based on their updated beliefs about the unobservable components of income while also considering potential past mistakes. Assuming this type of Bayesian updating means that, in response to an income shock, households will formulate beliefs that assign a positive probability to the income shift being explained by changes in both transitory and permanent components. In other words, as shown by Boz et al. (2011), the economy will respond to purely transitory shocks as if they were more persistent, and to permanent shocks as if they were more transitory.

We assume an incomplete credit market environment where households have access only to a one-period, non-state-contingent bond denominated in units of tradable goods. A collateral requirement restricts the household's borrowing to a fraction of their total income, which is defined as the sum of their tradable income and their non-tradable endowment, both in units of tradable goods. Since the value of collateral is a function of

market prices,in particular, of the relative price of non-tradable goods, a pecuniary externality emerges due to private households failing to internalize how their decisions, once properly aggregated, impact the relative price of nontradable goods and their borrowing capacity. This leads them to choose inefficient levels of consumption and debt. This effect, referred to in the literature as a Fisherian debt-deflation, has been studied as a potential cause of large reversals in credit during times of financial distress and as a motivation for the implementation of macroprudential policies aimed at restoring efficiency in credit markets.

We find that under imperfect information, both the decentralized economy and the Social Planner increase their average debt-to-GDP ratios by about two percentage points relative to their perfectly informed counterparts. More importantly, under both perfect and imperfect information, the pecuniary externality causes private households to borrow about one percentage point of GDP more than the constrained Planner.

The interaction between information frictions and the pecuniary externality, while not causing a significant change in the level of overborrowing, results in substantial macroeconomic consequences. First, financial crises become more frequent. Specifically, the frequency of crises increases by 1.4 percentage points for the decentralized equilibrium compared to the same economy under perfect information. In contrast, the uninformed Planner experiences 0.25 percentage points fewer Sudden Stops than under perfect information. This result underscores the importance of studying the nonlinearity involved in the interaction between imperfect information and the pecuniary externality.

More importantly, we find that the information friction amplifies the associated welfare costs of the externality despite creating about the same level of overborrowing as in a perfectly informed economy. Specifically, the welfare loss more than doubles under imperfect information. These results stem from the asymmetric impact of the information friction on how the Social Planner values wealth and future consumption. Both the Planner and the households recognize that higher uncertainty increases the likelihood of facing a binding collateral constraint, leading to increased precautionary savings by both parties. However, the constrained Planner can adjust its marginal utility of wealth

to reflect the impact of uncertainty on changes in the collateral's value with consumption, resulting in more cautious behavior. The relevance of this mechanism arises when the economy's debt allocation is close to the limit allowed by the collateral constraint. Consequently, the effects of this mechanism become evident primarily during periods of financial distress.

The interaction between information and financial frictions has important implications for the shape and efficiency of macroprudential policies in preventing and mitigating the risk of financial crises. First, we find that under imperfect information, the average tax on foreign borrowing is 11.4 percent, which is about 1.7 percentage points higher than under perfect information. Second, our results show that implementing the optimal capital control policy decreases the frequency of financial crises in the uninformed economy—from 5.5 crises to 1.7 every 100 years—and mitigates their severity. Specifically, the average drop in consumption during a Sudden Stop decreases from 25 to 21 percent of their pre-crisis level due to the optimal tax policy. In contrast, the informed Planner's optimal tax reduces the frequency of financial crises from 4.1 to 2 percent, and the average drop in total consumption is mostly unaffected, changing from from 25 to 24.5 percent.

Moreover, we find that the information friction has a more noticeable impact on conditional moments rather than on unconditional averages. For instance, the informed and uninformed constrained Planners adjust the optimal tax differently around episodes of financial stress. While both Planners set taxes to zero during crises, the uninformed Planner raises its tax by four percentage points in the year before the event, whereas the informed Planner does so by 1.3 percentage points.

In our simulations, Sudden Stops materialize after the economy suffers a series of successive negative permanent income shocks, which agents perceive as partially transitory. In response, uninformed households increase their borrowing to smooth consumption without internalizing that their behavior also increases the economy's vulnerability to a capital flow reversal. The imperfectly informed Planner aims to counter this risk by raising the taxes on foreign debt by more than would be necessary in a perfectly informed economy. Even though the Sudden Stop still materializes due to the arrival of

new shocks, which is by design as we are conditioning on these events occurring, the Planner successfully mitigates its impact on consumption.

Our results also show that considering the information friction changes the cyclicality of the optimal policy.[2] In particular, when measured relative to individual components rather than total income, the policy's cyclical behavior changes between perfect and imperfect information. For instance, a permanent shock to income, which we denote by g_t, generates a relatively acyclical optimal policy under perfect information and a procyclical tax under imperfect information. In contrast, the optimal tax is procyclical in response to transitory shocks to nontradable income under perfect information, Z_t^N, and countercyclical in the imperfectly informed economy. Finally, we show that under both information sets, the Planner finds it optimal to reduce taxes in response to positive transitory shocks to tradable income, Z_t^T, and to raise them during negative shocks.[3]

These changes in the cyclical behavior of the optimal policy are a direct result of the interaction between information and financial frictions. Despite assuming that agents produce optimal forecasts (by using the Kalman filter), the forecast errors present in the imperfectly informed economy and their effect on the collateral constraint change the dynamics of the Planner's optimal tax policy. For instance, when an uninformed household faces a negative transitory shock to nontradable income, her forecast about the fundamentals will consider that each of the following scenarios is likely: a negative shock to Z_t^N, a positive shock to Z_{t-1}^T that went unnoticed, and a negative shock to the permanent component g_t.

As nontradable income decreases, the relative price of nontraded goods increases, prompting households to shift consumption towards the tradable sector. This higher demand for tradable goods is reinforced by the household's expectation that she might have missed a positive shock to Z_{t-1}^T, which in turn stimulates the uptick in relative

[2] We define the cyclicality of the optimal tax as in Schmitt-Grohé and Uribe (2017). A *countercyclical tax* is a capital control policy that increases during booms and decreases during economic recessions (i.e., exhibits a positive correlation relative to a particular component of income).

[3] Relative to total GDP, the cyclicality of the optimal policy under perfect and imperfect information aligns with the findings of Schmitt-Grohé and Uribe (2017). To resolve the trade-off between the desire of impatient households to increase debt for smoothing consumption and the necessity of preventing financial crises, the Planner raises taxes on foreign debt when total income is low, and crises are more likely to occur.

prices. This dynamic increases the collateral value and relaxes the household's borrowing constraint. However, relative to a perfectly informed economy, uninformed households do not increase their borrowing as much because they believe there is a chance they are facing a permanent negative shock to income. The combination of lower debt and a more relaxed financial constraint leads the Planner to reduce the tax in bad times, therefore adopting a countercyclical macroprudential tax in response to shocks to nontradable income.[4]

Finally, we analyze implementation issues of the optimal macroprudential policy under imperfect information. As mentioned earlier, the uninformed, constrained Planner chooses a highly nonlinear state-contingent tax policy, adjusting debt taxes more frequently than the informed Planner. However, empirical data suggests that policymakers prefer 'stickier' policy rules. For example, in a study of 21 emerging countries, Acosta et al. (2020) found that authorities infrequently adjust capital controls; once a tax is applied, it remains unchanged for an extended period.

To contribute to this ongoing debate, we assess whether a simplified implementation of our predicted optimal tax policy effectively offsets the welfare costs arising from the pecuniary externality. Following the approach of Bianchi (2011), we analyze the welfare benefits of optimizing, at time 0, the fixed tax that brings the Planner closer to the second-best solution.

Our findings indicate that a fixed tax rate equal to 10 percent (about 88% of the ergodic mean from the optimal tax distribution) yields a welfare cost of 0.06 percent of lifetime consumption, about one-forth the welfare loss in the decentralized solution. Under the optimal implementable fixed tax rate regime, the likelihood of crises drops from 5.5 percent to 2.4 percent, and the decentralized economy borrows about 0.4 percentage points of GDP more than the constrained Planner.

[4]Section 4.3.1.1 presents the analysis explaining the changes in the cyclicality of the optimal tax relative to shocks to the permanent component of income, g_T, and the transitory component of tradable income, Z_t^T.

1.1 Related Literature.

This paper contributes to various dimensions of the literature that explore small open economy macroeconomics by examining the interaction between information and financial frictions.

First, we contribute to the literature studying the cyclical properties of emerging economies. The ongoing debate primarily revolves around determining the key factor driving the business cycle—whether it is trend (or growth) shocks, as argued by Aguiar and Gopinath (2007), or if permanent shocks play a secondary role due to the presence of financial frictions, as proposed by Neumeyer and Perri (2005) and Garcia-Cicco et al. (2010). According to the latter strand of the literature, properly calibrated models incorporating transitory and trend shocks require either financial frictions or interest rate shocks to replicate fundamental features of the business cycle in emerging countries. However, Boz et al. (2011) and Blanchard et al. (2013) validate the significance of trend shocks by considering the impact of imperfect information on the cycle. In particular, they show that by incorporating a learning process related to the nature of shocks, models where income depends on permanent and transitory components can effectively reproduce the volatility of consumption and vulnerability to crises typical of emerging economies. We contribute to this body of literature by showing that a model featuring information and financial frictions can also replicate the empirical regularities found in the business cycles in emerging economies.

Second, our work is related to a growing body of literature studying the macroeconomic implications of financial frictions and macroprudential policy in emerging economies. Our work stems from the seminal contribution of Mendoza (2002) and Mendoza (2010), who introduced a theoretical dynamic general equilibrium model with an endogenous collateral constraint capable of generating Sudden Stops within regular business cycles. Using a quantitative framework, Bianchi (2011) demonstrated that partially leveraging external debt against domestic income introduces a pecuniary externality in the credit market, thereby quantifying the welfare improvements of implementing macroprudential

policy.

We contribute to this literature by examining the desirability and implementation of macroprudential policy in a model with both financial and information frictions. Standard models in this literature analyze optimal tax policy in economies impacted by standard transitory shocks (e.g., productivity, terms-of-trade, or interest rate shocks) under the assumption of perfect information (Arce et al., 2023; Benigno et al., 2013, 2016; Jeanne and Korinek, 2019; Korinek, 2011, 2018; Ottonello, 2021; Schmitt-Grohé and Uribe, 2017, 2020). However, research has shown that alternative sources of financial volatility, such as news or trend shocks, have important implications for formulating capital control policy.[5]

Within this literature strand, our paper is closely related to Bianchi et al. (2012), Bianchi et al. (2016), Flemming et al. (2019), and Seoane and Yurdagul (2019). For instance, in a model centered on the interplay between financial innovation, credit frictions, and imperfect information within the financial transmission mechanism, Bianchi et al. (2012) study a scenario where Bayesian learning and information crucially shape macroprudential policy. Like our approach, they depart from the standard assumption of perfect information about the stochastic process driving fluctuations in credit conditions. Differing from our work, the information friction in their model centers around optimistic (pessimistic) beliefs regarding financial innovation.

Bianchi et al. (2016) studies an economy characterized by regime changes in world interest rates and news shocks about future fundamental realizations. They show that as the precision of news shocks increases, the efficacy of implementing capital controls lowers. Furthermore, consistent with our findings, they establish that the optimal tax policy is highly nonlinear and requires significant variation across capital-market regimes and news shocks.

Finally, our research is strongly connected to the works of Flemming et al. (2019) and Seoane and Yurdagul (2019). These studies extend the standard model with occasionally binding collateral constraints to include permanent income (trend) shocks but abstract from relaxing the perfect information assumption. Moreover, except for some

[5]See, among others, Akinci and Chahrour (2018), Bianchi et al. (2012), Bianchi et al. (2016), Flemming et al. (2019), and Seoane and Yurdagul (2019).

minor differences, our benchmark model in the perfect information limit collapses to the model used by these papers, where the economy is affected by permanent and transitory shocks, but agents can perfectly observe them. Our main contribution to this literature is studying how the interaction between collateral constraints and imperfect information affects borrowing decisions and induces friction to a consumption-savings problem. More importantly, we study how introducing imperfect information reshapes the optimal policy needed to restore market efficiency.

The remainder of the paper is organized as follows. Section 2 provides the model and explains the household problem, the endowment properties, and the information structure. Section 3 describes the equilibrium and presents the optimal conditions for the decentralized economy and the constrained Planner. Section 4 presents our quantitative results, and Section 5 concludes.

2 Theoretical Framework

For our modeling framework, we adopt the standard model of a small open economy with occasionally binding collateral constraints proposed by Bianchi (2011) and widely used in the related quantitative literature. Similar to Seoane and Yurdagul (2019), we modify the endowment structure of Bianchi's model to include trend (permanent) and transitory shocks, and the main innovation is to relax the full information assumption. These endowments are the only source of uncertainty in the model and provide the structure through which we relax the perfect information in the model. The following sections explain each block of the model in detail.

2.1 Households

Household intertemporal preferences are given by a standard constant relative risk aversion (CRRA) function:

$$\mathbb{E}_0^j \left[\sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} \right) \right], \quad \sigma > 0 \tag{1}$$

where β is the discount factor, and σ denotes the inverse of the intertemporal elasticity of substitution. Expectations are taken over the information set j, where $j \in \{ii, uu\}$. In this set, uu denotes an economy experiencing information frictions (i.e., households are uninformed), and ii denotes an economy populated by perfectly informed households.

Total consumption (C_t) is an aggregate bundle of the consumption of tradable (C_t^T) and non-tradable (C_t^N) goods given by a CES aggregator with ϵ as the elasticity of substitution between tradable and non-tradable goods. The aggregator function is defined by:

$$C_t = \left[\omega \left(C_t^T \right)^{\frac{\epsilon-1}{\epsilon}} + (1-\omega) \left(C_t^N \right)^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}}$$

where $1-\omega$ is the weight given to non-tradable goods, and $0 \leq \omega \leq 1$. At the beginning of period t, households receive their endowments, repay their debt, and choose their

consumption and borrowing. The budget constraint is given by:

$$B_{t+1} = (1+r)B_t + Y_t^T + p_t Y_t^N - C_t^T - p_t C_t^N \tag{2}$$

Y_t^s is the income endowment from sector s where $s \in \{T, N\}$ denotes the tradable and non-tradable sectors. Borrowing occurs through choosing the amount of foreign bonds (B_{t+1}) to be repaid next period at the international interest rate r. Bonds are non-state-contingent and denominated in units of tradable goods. p_t is the relative price of non-tradable goods in terms of tradable goods, and the price for tradable goods is the numeraire.

Beyond the non-availability of a state-contingent bond, credit markets are also imperfect due to a borrowing constraint that limits the amount of debt (defined as a negative nominal value of bonds) a household can hold. In particular, borrowing must be less than a given fraction κ of total current income (measured in tradable units):

$$B_{t+1} \geq -\kappa \left(Y_t^T + p_t Y_t^N\right) \tag{3}$$

Equation (3) has two characteristics that are worth noting. First, the constraint is consistent with empirical evidence showing that income is one of the key determinants of access to credit markets (Jappelli, 1990; Lian and Ma, 2021). Second, international creditors require short-term external debt (denominated in units of tradable goods) to be partially leveraged by the endowment of the non-tradable sector, a common observation in emerging countries.

The relationship between the relative price of tradable goods, p_t, and the value of the collateral implied by the borrowing constraint introduces a debt-deflation mechanism like the one proposed by Fisher (1933) into the model. In good times, when income is high, the value of the collateral increases, incentivizing borrowing and consumption. As a result, the price of non-tradable goods also increases, relaxing the collateral constraint even further and reinforcing the initial response of borrowing. In bad times, lower income reduces consumption and borrowing. In response, the price of non-tradable goods will

fall, as will the value of the collateral. As the constraint tightens, the household must further reduce its consumption, reducing the value of its collateral again and forcing even more deleverage. This downward spiral can move the collateral constraint to the point where it binds, shutting off access to credit markets and triggering a Sudden Stop.

Since households take prices as given, they do not internalize how their choices affect the relative price of non-tradable goods in general equilibrium. As pointed out by Bianchi (2011), the household's equilibrium decisions on consumption and borrowing will be inefficient compared to those made by a constrained Planner who internalizes the feedback between prices and the collateral value.

As we will show in the following sections, introducing imperfect information significantly amplifies the implications of this type of pecuniary externality.

2.2 Endowment Properties

Each period, households receive two endowments from the tradable and non-tradable sectors. Each endowment is composed of a sector-specific transitory component and a common permanent (or trend) component.[6] We assume that households cannot directly observe the underlying drivers of income, only its realized value.

In particular, we assume that each endowment is given by:

$$Y_t^s = \Gamma_t e^{z_t^s}, \quad \forall\, s \in \{T,\, N\}, \tag{4}$$

where z_t^s denotes the transitory component of the endowment coming from sector s. The trend component is given by Γ_t, defined as the cumulative product of current and previous realizations of economic growth shocks. Formally

$$\Gamma_t = \Gamma_{t-1} e^{g_t} = \prod_{j=0}^{t} e^{g_j}, \tag{5}$$

where g_t is the stochastic growth rate of the permanent component and follows an AR(1)

[6] See Aguiar and Gopinath (2007), Gertler et al. (2007), and Boz et al. (2011) for a discussion on the relevance of permanent shocks to explain unconditional business cycle moments in emerging economies.

process given by:

$$g_t = (1 - \rho_g)\mu_g + \rho_g g_{t-1} + \epsilon_t^g. \tag{6}$$

The long-run mean growth rate of the permanent component of income is denoted by μ_g, and the autocorrelation of g satisfies the constraint $|\rho_g| < 1$. The stochastic term ϵ_t^g is an independent and identically distributed random variable that follows a normal distribution with mean zero and variance σ_g^2.

Equations (4) and (5) imply that both sectors share the same trend component but are exposed to different transitory shocks. Moreover, we assume independence between g_t and z_t^s. In particular, z_t^T and z_t^N are determined by the vector autoregression:

$$z_t = \begin{bmatrix} z_t^T \\ z_t^N \end{bmatrix} = \begin{bmatrix} \rho_{z^T, z^T} & \rho_{z^T, z^N} \\ \rho_{z^N, z^T} & \rho_{z^N, z^N} \end{bmatrix} \begin{bmatrix} z_{t-1}^T \\ z_{t-1}^N \end{bmatrix} + \begin{bmatrix} \epsilon_t^T \\ \epsilon_t^N \end{bmatrix} \tag{7}$$

$$= \mathbf{A} z_{t-1} + \varepsilon_t^z \tag{8}$$

where ε_t^s follows a bivariate normal distribution with mean zero and a variance-covariance matrix Σ.

2.2.1 Information Friction and Learning Problem

As explained above, households in our economy are not able to directly observe the underlying permanent and transitory components of income. Instead, in each period households must form beliefs about the unobserved components by using the information available in the economy.

To model this belief-formation process, we make two assumptions. First, at any given time t, households in our economy know the complete history of endowment realizations and the properties of the stochastic processes that generate them. Second, because the endowments are informative about the underlying components, linear in differences, and with Gaussian innovations, we assume households use the Kalman filter to form their beliefs. Moreover, as the Kalman filter chooses the decomposition that minimizes the mean square error between the observed and predicted signals, we implicitly assume

that households use all of the available information to produce optimal beliefs about the unobservable components of income. Because income is given by an endowment, that households use only endowment information for their signal-extraction problem is not a restrictive assumption.

The Kalman Filter

To implement the Kalman filter, first, we define the information set that is available to the household at any given time t. Let $\mathbb{I}_t$ denote this set, and be defined as:

$$\mathbb{I}_t \equiv \left\{ \left\{ Y_{t-s}^i \right\}_{s=0}^{\infty}, f\left(\epsilon_t^T, \epsilon_t^N\right), f\left(\epsilon_t^g\right) \right\}, \quad \forall i \in [T, N], \tag{9}$$

where $\left\{Y_{t-s}^i\right\}_{s=0}^{\infty}$ is the full stream of current, and past realizations of income, $f(\epsilon_t^T, \epsilon_t^N)$ and $f(\epsilon_t^g)$ are the underlying probabilistic distributions of z^T, z^N, and Γ, respectively.

Second, we need to find a relationship between observable signals (i.e., elements in $\mathbb{I}_t$) and the underlying exogenous states. Let the growth rate of the tradable income (g_t^T) and the growth rate of the non-tradable component relative to tradable income (g_t^N) be given by:

$$\Delta_t^T = \ln\left(\frac{Y_t^T}{Y_{t-1}^T}\right) = \ln\left(\frac{\Gamma_{t-1}e^{g_t}e^{z_t^T}}{\Gamma_{t-1}e^{z_{t-1}^T}}\right) = z_t^T - z_{t-1}^T + g_t, \tag{10}$$

$$\Delta_t^N = \ln\left(\frac{Y_t^N}{Y_{t-1}^T}\right) = \ln\left(\frac{\Gamma_{t-1}e^{g_t}e^{z_t^N}}{\Gamma_{t-1}e^{z_{t-1}^T}}\right) = z_t^N - z_{t-1}^T + g_t. \tag{11}$$

By observing the growth rates Δ_t^T and Δ_t^N the households also perceive a linear combination of the unobservable exogenous states $\left\{z_t^T, z_t^N, g_t\right\}$. By rewriting the learning problem into its state-space form, we reduce it to a set of two fundamental equations.

The first one is obtained by writing (10) and (11) as a system of equations:

$$s_t = \begin{bmatrix} \Delta_t^T \\ \Delta_t^N \end{bmatrix} = \mathbf{Z}\alpha_t = \begin{bmatrix} 1 & 0 & 1 & -1 \\ 0 & 1 & 1 & -1 \end{bmatrix} \begin{bmatrix} z_t^T \\ z_t^N \\ g_t \\ z_{t-1}^T \end{bmatrix}, \tag{12}$$

where s_t denotes a vector of observable signals, and α_t is the vector of exogenous states. Equation (12) is known as the observation (or measurement) equation, and it relates the observable signals to the underlying unobservable states.

The second fundamental equation of the state-space specifies how the underlying variables evolve over time. This equation is called the transition equation and is given by:

$$\begin{bmatrix} z_t^T \\ z_t^N \\ g_t \\ z_{t-1}^T \end{bmatrix} = \begin{bmatrix} \rho_{z^T,z^T} & \rho_{z^T,z^N} & 0 & 0 \\ \rho_{z^N,z^T} & \rho_{z^N,z^N} & 0 & 0 \\ 0 & 0 & \rho_g & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} z_{t-1}^T \\ z_{t-1}^N \\ g_{t-1} \\ z_{t-2}^T \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ (1-\rho_g)\mu_g \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \epsilon_t^T \\ \epsilon_t^N \\ \epsilon_t^g \end{bmatrix}. \tag{13}$$

The equation, in compact form, is:

$$\alpha_t = \mathbf{c} + \mathbf{A}\alpha_{t-1} + \mathbf{R}\eta_t, \quad \text{with} \quad \eta_t \sim N(0, \mathbf{Q}), \ \mathbf{Q} = \begin{pmatrix} \sigma^2_{z^T,z^T} & \sigma_{z^T,z^N} & 0 \\ \sigma_{z^N,z^T} & \sigma^2_{z^N,z^N} & 0 \\ 0 & 0 & \sigma_g^2 \end{pmatrix}, \tag{14}$$

where $\mathbf{c}$ denotes a vector containing the mean of each variable, $\mathbf{A}$ is the matrix containing the autocorrelation parameters and, $\mathbf{R}\eta$ is the error term. Errors come from a normal distribution with mean zero and variance-covariance $\mathbf{Q}$.

Let $\mathbf{a}_t$ be the optimal estimator of α_t. Therefore, the expectation of the underlying exogenous state variables conditional on current and past information sets is given by $\mathbf{a}_t = \mathbb{E}[\alpha_t|\mathbb{I}_t]$ and $\mathbf{a}_{t|t-1} = \mathbb{E}[\alpha_t|\mathbb{I}_{t-1}]$. The Kalman filter states that the posterior beliefs $\mathbf{a}_t$ will be a convex combination of the prior $\mathbf{a}_{t-1}$ and the new information added by the

vector of signals s_t. The system given by the filter is:

$$\mathbf{a}_{t|t-1} = \mathbf{c} + \mathbf{A}\mathbf{a}_{t-1} \tag{15}$$

$$\mathbf{a}_t = k_1\mathbf{a}_{t|t-1} + k_2 s_t \tag{16}$$

where k_1 and k_2 in equation (16) are the Kalman gains and are defined as:

$$k_1 = \mathbf{I} - \mathbf{PZ}(\mathbf{ZPZ})^{-1}\mathbf{Z}$$

$$k_2 = \mathbf{PZ}'(\mathbf{ZPZ}')^{-1}$$

and where $\mathbf{P}$ is the variance-covariance matrix that solves the Riccati equation:

$$\mathbf{P} = \mathbf{APA}' - \mathbf{APZ}'(\mathbf{ZPZ}')^{-1}\mathbf{ZPA}' + \mathbf{RQR}' \tag{17}$$

In summary, the forecast $\mathbf{a}_t$ will be determined by the weight k_1 given to the forecast of $\mathbf{a}_{t|t-1}$ based only on information available at time $t-1$, and the weight k_2 attached to the new information about α_t contained in the current signals.

3 Equilibrium

The household's decisions about consumption and borrowing and its beliefs about the permanent and transitory components of income determine the household's intertemporal flow of utility. Therefore, the household's problem at time t consists of choosing the optimal sequence of consumption and borrowing subject to the budget and borrowing constraints and a given set of information $\mathbb{I}_t$. The recursive maximization problem is:

$$V(B, \mathbf{a}, \mathbf{y}) = \underset{C^T, C^N, B'}{max}\, U\left(C(C^T, C^N)\right) + \beta\mathbb{E}\left[V\left(B', \mathbf{a}', \mathbf{y}'\right)\right] \tag{18}$$

subject to

$$B' = (1+r)B + Y^T + pY^N - C^T - pC^N \tag{19}$$

$$B' \geq -\kappa \left(Y^T + pY^N\right) \tag{20}$$

where variables without a subscript correspond to the current period, and variables with a prime superscript correspond to the next period. Moreover, $\mathbf{a}$ is a vector that contains the household's beliefs about the transitory and permanent components of the endowments, and $\mathbf{y} = \left\{Y^T,\, Y^N\right\}$. Then, a competitive equilibrium is a set of allocations $\left\{C^T, C^N, B'\right\}$, a set of beliefs $\mathbf{a}_t = \mathbb{E}[\alpha_t|\mathbb{I}_t]$, and the pair of prices $\{r,\, p\}$, such that households maximize their intertemporal flow of consumption, all of the constraints are satisfied, and the market for bonds and goods both clear.

3.1 Decentralized Economy

To develop more intuition about the role of the borrowing constraint in a competitive economy, we focus our attention on the solution of the sequential version of (18). We denote Λ_t and μ_t, the Lagrange multipliers correspond to the budget and borrowing constraints. Since tradable and non-tradable income are permanently growing, we need to transform the dynamic system described by our economy to make it stationary. In general, the literature normalizes by Γ_{t-1}; however, because in our environment, households do not observe Γ_{t-1}, we will use the endowment of tradable income in the previous period, Y^T_{t-1}. Let $\lambda_t = \Lambda_t \left(Y^T_{t-1}\right)^\sigma$, and $\hat{x}_t = X_t/Y^T_{t-1}$ for each variable X_t. The normalized optimality conditions are:

$$\lambda_t = \omega \hat{c}_t^{-\sigma+\frac{1}{\epsilon}} (\hat{c}_t^T)^{-\frac{1}{\epsilon}} \tag{21}$$

$$p_t = \frac{(1-\omega)}{\omega} (\frac{\hat{c}_t^N}{\hat{c}_t^T})^{-\frac{1}{\epsilon}} \tag{22}$$

$$\lambda_t \left[1 - \mu_t\right] = (1+r)\beta e^{(-\sigma\Delta_t^T)} \mathbb{E}_t \lambda_{t+1} \tag{23}$$

$$e^{g_t^T} \hat{b}_{t+1} = \hat{b}_t(1+r) + e^{\Delta_t^T} - \hat{c}_t^T \tag{24}$$

$$\hat{b}_{t+1} \geq -\kappa \left(1 + p_t \frac{e^{\Delta_t^N}}{e^{\Delta_t^T}}\right) \tag{25}$$

$$\mu_t \geq 0; \;\; \mu_t \left[\hat{b}_{t+1} + \kappa \left(1 + p_t \frac{e^{\Delta_t^N}}{e^{\Delta_t^T}}\right)\right] = 0 \tag{26}$$

Equation (23) represents the Euler equation for bond holdings. When the borrowing constraint is not binding (i.e., $\mu_t = 0$), the solution to the problem is to equalize the marginal benefit of increasing one unit of consumption today to the discounted cost of sacrificing one unit of future consumption. Whenever the constraint binds, the marginal utility of current consumption is adjusted by the shadow value of relaxing the collateral constraint μ_t.

The market clearing condition of this economy implies the non-tradable endowment is fully spent on non-tradable goods $Y_t^N = C_t^N$. Therefore, the equilibrium price of non-tradable goods relative to tradable goods is given by:

$$p_t = \frac{1-\omega}{\omega} \left(\frac{Y_t^N}{C_t^T}\right)^{-\frac{1}{\epsilon}} \tag{27}$$

Equation 27 explains intuitively the nature of the pecuniary externality. In equilibrium, changes in C_t^T will affect p_t proportionately and, more importantly, the collateral constraint's value. Households know but fail to internalize this general equilibrium effect into their intertemporal choices.

3.2 The Social Planner's Problem

In contrast to private households, a Social Planner internalizes the market clearing condition and does not take prices as given. In particular, the Planner will make borrowing and consumption decisions by solving the following problem:

$$V^{SP}(B, \mathbf{a}, \mathbf{y}) = \underset{C^T,\, B'}{max} U\left(C(C^T, Y^N)\right) + \beta \mathbb{E}\left[V\left(B', \mathbf{a}', \mathbf{y}'\right)\right] \tag{28}$$

subject to

$$B' = (1+r)B + Y^T - C^T$$
$$B' \geq -\kappa \left(Y^T + \left(\frac{1-\omega}{\omega} \left(\frac{Y^N}{C^T} \right)^{-\frac{1}{\epsilon}} \right) Y^N \right)$$

where, as before, $\mathbf{a}$ is a vector that contains the Planner's beliefs about the transitory and permanent components of the endowments, and $\mathbf{y} = \left\{Y^T, Y^N\right\}$. Let Λ_t^{SP} and μ_t^{SP}, the Lagrange multipliers of the social Planner corresponding to the budget and the borrowing constraint in the sequential version of the optimization problem described by (28). The problem above makes explicit that the Planner chooses borrowing directly and that the consumption for the non-tradable good satisfies market clearing in this market ($C^N = Y^N$).

As before, we need to transform the model to make it stationary. The transformed first-order conditions for the Planner's problem are:

$$\lambda_t^{SP}\left[1 - \mu_t^{SP}\hat{\Phi}_t\right] = \omega \hat{c}_t^{-\sigma+\frac{1}{\epsilon}} (\hat{c}_t^T)^{-\frac{1}{\epsilon}} \tag{29}$$

$$\lambda_t^{SP}\left[1 - \mu_t^{SP}\right] = \beta(1+r)e^{-\sigma\Delta_t^T}\mathbb{E}_t\lambda_{t+1}^{SP} \tag{30}$$

$$e^{\Delta_t^T}\hat{b}_{t+1} = \hat{b}_t(1+r) + e^{\Delta_t^T} - \hat{c}_t^T \tag{31}$$

$$\hat{b}_{t+1} \geq -\kappa \left(1 + \frac{1-\omega}{\omega} \left(\frac{\hat{c}_t^T}{e^{\Delta_t^N}} \right)^{-\left(\frac{1}{\epsilon}\right)} \frac{e^{\Delta_t^N}}{e^{\Delta_t^T}} \right) \tag{32}$$

$$\mu_t^{SP} \geq 0; \quad \mu_t^{SP} \left(\hat{b}_{t+1} + \kappa \left(1 + \frac{1-\omega}{\omega} \left(\frac{\hat{c}_t^T}{e^{\Delta_t^N}} \right)^{-\frac{1}{\epsilon}} \frac{e^{\Delta_t^N}}{e^{\Delta_t^T}} \right) \right) = 0 \tag{33}$$

Note that the first order condition (29) changes relative to that from the decentralized equilibrium described by (21). In particular, the constrained Planner would like to equate the marginal utility of tradable consumption (RHS of equation (29)), to the marginal utility of wealth, adjusted for the marginal change in the value of the collateral when consumption of tradable goods changes $\left(\Phi_t = \frac{\partial \tilde{BC}_t}{\partial C_t^T} = \kappa \frac{1-\omega}{\omega} \frac{1}{\epsilon} \left(\frac{\hat{c}_t^T}{e^{\Delta_t^N}}\right)^{\frac{1}{\epsilon}-1}\right)$, where BC stands for borrowing constraint.

The differences between the Planner's and the household's marginal utility of consumption are due to the pecuniary externality and explain why the competitive equilibrium undervalues wealth and chooses different allocations than the Planner. When the Planner's consumption increases by one unit, the marginal utility of consumption is affected by the marginal utility of transferring one unit of wealth to the future increases. Under the standard parameterization of these models, the combined effect means the constrained Planner will increase his precautionary savings and reduce external borrowing.[7]

More importantly, equation (29) shows that contrary to private households, when imperfect information is added into the mix, the constrained Planner adjusts its marginal utility of wealth to reflect that the increased uncertainty affects its valuation of how the value of collateral changes with consumption.

4 Quantitative Analysis

In this section, we describe the calibration of the model and present the quantitative results. We solve the model using global solution methods. Further details on the calibration and the solution method are available in appendix A and B.

4.1 Calibration

To calibrate our model, we divide our empirical strategy into two parts. First, we use the Kalman filter and its statistical properties to estimate the hidden states of the shocks

[7] See Schmitt-Grohé and Uribe (2020) for a thorough discussion on how different parameterizations can yield overborrowing/underborrowing relative to the Planner. See Arce et al. (2023) for a discussion on why macroprudential policy is still desirable regardless of whether the decentralized equilibrium faces more or less borrowing than the constrained Planner.

and the parameters governing the processes for the unobservable components of income. Second, we follow Bianchi (2011) to set the parameters of the model that do not affect the income processes.

Since the innovations, $\left\{\varepsilon_t^T, \varepsilon_t^N, \varepsilon_t^g\right\}$ affecting the transitory and permanent components of income are Gaussian, the Kalman filter's distribution of forecasts errors is also Gaussian (Hamilton, 1994). Therefore, we can write a log-likelihood function $\mathcal{L}(\Theta, s_t)$ that depends on the observable signals (s_t) and a vector (θ) containing the structural parameters conforming the state transition matrix $\mathbf{A}$ and the noise covariance matrix $\mathbf{Q}$. Our strategy is to get maximum likelihood estimates for the parameters in θ.[8]

We use annual data from Argentina from 1903 to 2018 from Ferreres (2020). We compute *tradable output* (Y_t^T) as the sum of the GDP in agriculture, forestry, fishing, mining, and manufacturing. *Non-tradable output* (Y_t^N) includes the residual between total and tradable GDP.[9] Following equations (10) and (11), we define the observable signals Δ_t^T and Δ_t^N as $\ln \frac{Y_t^T}{Y_{t-1}^T}$ and $\ln \frac{Y_t^N}{Y_{t-1}^T}$, respectively. The observable signals have a standard deviation equal to $\sigma_\Delta^T = 0.065$ and $\sigma_\Delta^N = 0.118$, and the correlation between the two series is 0.336. Thus, both signals are positively correlated, and the signal coming from the non-tradable sector is approximately twice as volatile as that from the tradable sector.

Table 1 presents the maximum likelihood estimates for the parameters of $\mathbf{A}$ and $\mathbf{Q}$. Our findings show that the relationship between transitory and trend shocks to income is contingent upon the sector. Specifically, transitory shocks exhibit greater persistence than trend shocks for tradable income, whereas trend shocks are less persistent than transitory shocks for the non-tradable sector. In terms of volatility, our analysis reveals that transitory shocks to tradable income are 1.5 times more volatile than trend shocks. However, the relationship is reversed for non-tradable income, where transitory shocks are about half as volatile as trend shocks. Unconditionally, the z_t^T, z_t^T, and g_t are highly

[8] See appendix A for more details.

[9] The GDP of the tradable sector includes the following categories: Farming, livestock, hunting, and forestry; Fisheries; Mine exploitation and quarries; and manufacturing. The GDP of the non-tradable sector is the sum of the sectoral GDP of Construction, Electricity, gas, and water; Transport, storage, and communications; financial intermediation; real estate activities; and other services.

volatile, with standard deviations of 10.0 percent, 4.1 percent, and 6.6 percent per year. Finally, following Garcia-Cicco et al. (2010), we set μ_g equal to 1.31 percent to match Argentina's average GDP per capita growth rate between 1900 and 2018.

Table 1: Estimated Parameters for Stochastic Income Processes.

Parameter	Estimate	Std. Deviation
ρ_{z^T, z^T}	0.7347	0.0867
ρ_{z^T, z^N}	-0.2553	0.0535
ρ_{z^N, z^T}	0.0337	0.1464
ρ_{z^N, z^N}	0.4170	0.0383
ρ_g	0.4968	0.1368
$\sigma_{z^T z^T}$	0.0680	0.1220
$\sigma_{z^N z^T}$	0.0004	0.1086
$\sigma_{z^N z^N}$	0.0370	0.0955
σ_g	0.0572	0.0517

Note: The table reports the estimated values for the parameters that dictate the behavior of the exogenous processes in the model. The second column shows the standard errors of the estimated parameters. Please refer to the main body of the paper for the notation of the parameters.

Appendix F discusses our results when varying the persistence and volatility of the income processes. This sensitivity analysis shows that the main results presented in the paper hold for plausible deviations from the estimated parameters used to model the stochastic income processes.

We follow Bianchi (2011) for the remaining structural parameters of the model. We set the international risk-free annual interest rate, r, to 4 percent. The inverse of the intertemporal elasticity of substitution, σ, is set to 2. The elasticity of substitution between tradable and non-tradable goods, ϵ, is set to 0.83. The share of tradable goods in the consumption aggregator, ω, is set to 0.31. The discount factor, β, and the parameter controlling the borrowing constraint's tightness, κ, are free parameters that we choose. We set them such that the competitive equilibrium with imperfect information matches Argentina's net foreign assets to GDP ratio equal to -29 percent of GDP and a frequency of financial crises equal to 5.5%. Table 2 summarizes the chosen parameters.

Table 2: Parameter values

Parameter	Meaning	Value	Source/Target
r	Interest Rate	4.00%	Bianchi (2011)
σ	Inverse of intertemporal elasticity of substitution	2.00	Bianchi (2011)
ϵ	Elasticity of substitution between Tradable and non-tradable goods	0.83	Bianchi (2011)
ω	Weight of C_t^T in C_t	0.31	Bianchi (2011)
β	Discount factor β	0.83	Average NFA-GDP: -29%
κ	Borrowing constraint	0.335	Frequency of crises: 5.5%
μ_g	Avg growth rate of g_t	1.31%	Argentina's average per capita GDP growth rate

Note: The parameters β and κ are calibrated to match data moments from Argentina. Appendix F discusses the results when assuming different calibrations of β and κ.

We discretize the estimated income processes using the simulation approach proposed by Schmitt-Grohé and Uribe (2009). Under perfect information, we assume that the agent directly observes the underlying states. We use three equally spaced grids of 19 points for each of the underlying components of income: z_t^T, z_t^N, and g_t. The resulting transition matrix summarizes the probability of transitioning from one of the known 6,859 (19^3) possible realizations to another.

Under imperfect information, the agent understands the stochastic structure of income shocks but cannot directly observe the underlying components. Instead, the agent can only observe the realizations of the two signals. To create the transition matrix, we first simulate a time series of 1,000,000 periods for the unobservable states. Next, we compute the value of the signals using the system of equations (12). Then, we apply the Kalman filter to the time series of Δ_t^T and Δ_t^N to compute forecasts for the underlying values of z_t^T, z_t^N, and g_t. Using distance minimization, we approximate each forecast and the realization of the observable signals to the values of five equally spaced grids of 19 points. Finally, to compute the transition matrix, we use the resulting discrete-valued time series to estimate the probability of transitioning from one realization of z_t^T, z_t^N, g_t, Δ_t^T and Δ_t^N to another. Notice that under imperfect information, the dimensionality of our exogenous state-space increased from 19^3 to 19^5 possible realizations.

Due to the nonlinearity introduced by the occasionally binding borrowing constraint,

we solve the model using global solution methods. We use value function iteration to find the solution for the Social Planner's problem. In the case of competitive equilibrium, we use time iteration. In both cases, the grid for bond holdings includes 501 equally spaced points.[10]

4.2 The Interaction Between the Information Friction and the Collateral Constraint.

We divide the analysis of our results into two parts. First, we study quantitatively how information frictions affect the business cycle. Second, we study the interaction between the information friction and the pecuniary externality in the collateral constraint. The first part can be interpreted as an extension of Boz, Daude, and Durdu (2011) to a setup involving a small open economy featuring occasionally binding constraints.

4.2.1 How Does the Information Friction Affect the Business Cycle?

Introducing imperfect information adds a significant source of uncertainty to the standard model of endogenous collateral constraints. Since we assume agents use the Kalman filter to solve the signal extraction problem, they will find it optimal to formulate beliefs that involve a non-zero probability that a specific shock of income is explained by changes in the transitory and the permanent components. After a shifter to the unobservable permanent component of income, the economy will respond as if there was a shifter to both the permanent and transitory components of income. The converse is also true, after a shock to a transitory component of income, the economy will respond as if the economy received changes in both components.

Similar to Boz et al. (2011), the uninformed economy will experience a business cycle with more persistence and amplification than an informed economy. To understand this result, refer back to equations (10) and (11). In our model, agents are aware that each period's tradable and non-tradable endowments convey information about the current transitory and permanent underlying components (Z_t^T, Z_t^N, g_t), as well as the previous

[10] For more details on the numerical method, see appendix B.

realization of the transitory component of tradable income (Z^T_{t-1}). This is a critical feature of our model because it means that the household adjusts its beliefs every period based on current realizations of observable variables and on whether these realizations are consistent with beliefs about past unobservables.

For instance, when a negative shock to the permanent component income occurs, the agent observes negative growth rates Δ^T_t and Δ^N_t. According to the measurement equation given by (10), a negative value of Δ^T_t could be explained by each of the following scenarios:

1. A negative transitory shock $\left(Z^T_t \downarrow\right)$.

2. A positive transitory shock in $t-1$ that went unnoticed $(Z^T_{t-1} \uparrow)$.

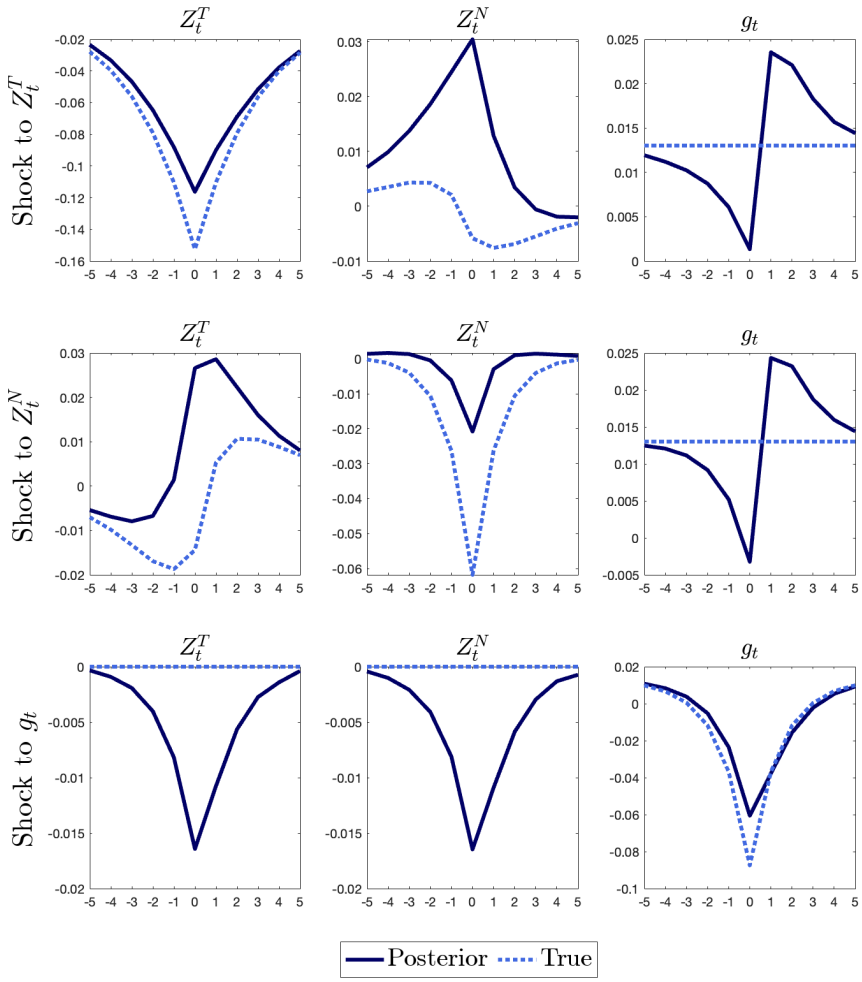
3. A negative shock to the permanent component $(g_t \downarrow)$.

The optimal forecast produced by the Kalman filter implies that agents will form beliefs $\tilde{z}^T_t$, $\tilde{z}^T_{t-1}$, and $\tilde{g}_t$ consistent with each of the three scenarios having a positive probability to have occurred. In other words, the agent's beliefs will satisfy $\tilde{z}^T_t - \tilde{z}^T_{t-1} < 0$. Suppose the economy starts at equilibrium (i.e., $z^s_t = z^s_{t-1} = 0$, $\forall\, s \in \{T,\, N\}$), then the actual growth rate observed today is determined only by the movement in the permanent component g_t. According to (10), $g_t = \Delta^T_t < \Delta^T_t - (\tilde{z}^T_t - \tilde{z}^T_{t-1}) = \tilde{g}_t < 0$. Therefore, agents believe that the shock to the permanent component is less negative than it is. Moreover, consistent with scenarios 1 and 2 being likely, the household will believe z^T_t, z^T_{t-1}, and z^N_t are changing.[11] Consistent with this set of beliefs, the uninformed economy's response to permanent shocks is more muted than in an informed economy.

Figure 1 compares the agents' posterior beliefs to the actual realization of the shocks. Each row shows a pure shock to an underlying component of income. For each case, it is possible to build a similar rationale to the one we presented above. As with the shock to g_t, agents assume that shocks to the transitory components of income are less

[11] According to equation (11), a negative shock to z^T_{t-1} that went unnoticed translates into a positive Δ^N_t. From the agent's perspective, this also can be explained by a positive shock to the transitory component of non-tradable income z^N_t, which explains why, in the first row of Figure 1, the household believes that $\tilde{z}^N_t$ increases at impact.

Figure 1: Response of Beliefs Under Different Observable Scenarios



Note: In this figure, each row compares the agent's posterior beliefs when the unobserved exogenous states are subject to a negative one-standard deviation. The variable being shocked is indicated in the left axis of each row. The horizontal axis spans five years before and after the shock occurrence.

severe than they are. Interestingly, starting in $t+1$, any shock to z_t^T or z_t^N will fade out as $z_{t+1}^j = \rho_{z^T,z^T} z_t^j$ where $j \in \{T, N\}$. The initial period of negative income growth is followed by several periods of positive but decreasing growth as $\Delta_{t+1}^j = (\rho_{z^j} - 1) z_t^j > 0$. This explains why in the first two rows of Figure 1, g_{t+1} turns positive after impact.

How does this fit into our analysis? First, the permanent-like responses to purely transitory shocks imply that the uninformed economy is more likely to observe additional consumption volatility. Second, frequently adjusting consumption due to uncertainty means the uninformed economy will face a higher likelihood of financial crises. Finally, since the Social Planner can internalize that increased uncertainty affects its valuation

of how the value of collateral changes with consumption (see equation (29)), the added volatility of consumption will amplify the welfare effects of the pecuniary externality embedded in the collateral constraint.

4.2.2 Borrowing and Consumption Under Imperfect Information

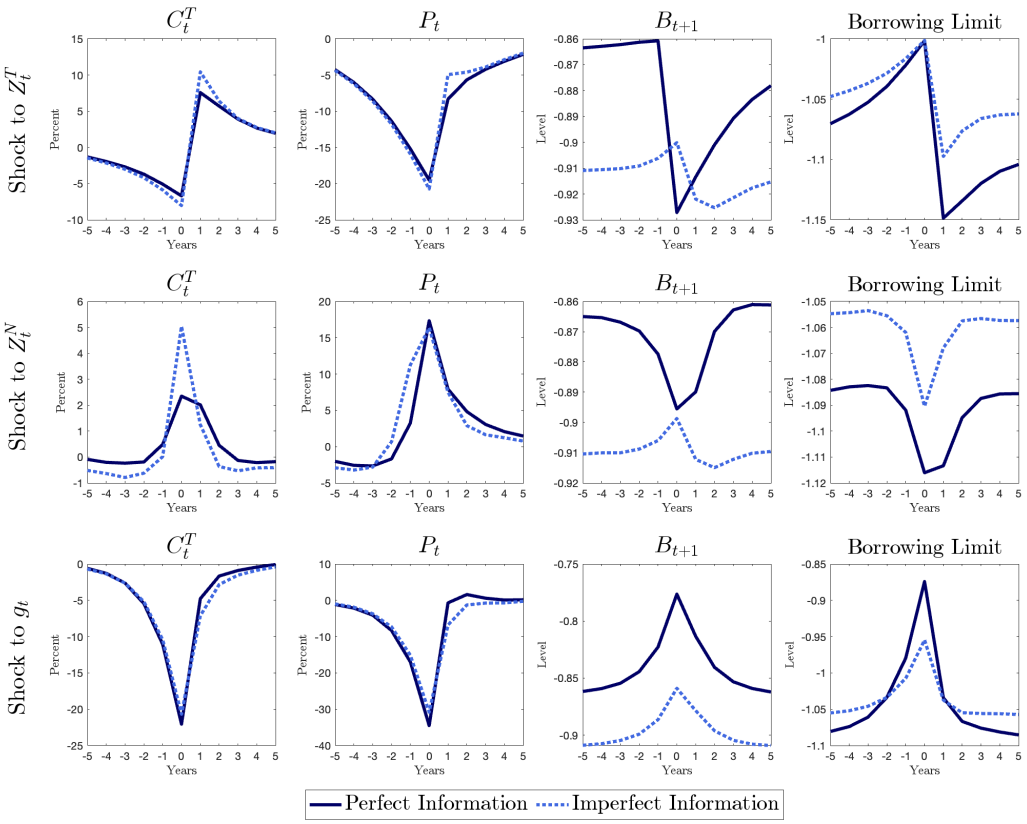
As we noted, a household with imperfect information will form incorrect beliefs about the unobserved components of income. For instance, the household will interpret a purely transitory shock as partially permanent and a strictly permanent shock as partially transitory.

Figure 2 shows the response of consumption, the relative price, bond holdings, and the borrowing limit to pure shocks to Z_t^T, Z_t^N, and g_t. The first row shows a pure one-standard-deviation negative shock to the transitory component of tradable income (Z_t^T). Under perfect and imperfect information, tradable consumption and prices fall, and the borrowing limit tightens in response to lower income. However, external borrowing responds differently across models. Consistent with the permanent consumption hypothesis, a transitory shock implies an increase in external borrowing to smooth consumption.

In contrast, the uninformed household reduces borrowing as it assumes the shock is partially permanent. The second row shows a shock to the transitory component of non-tradable income (Z_t^N). Under perfect information, as consumption of non-tradable goods falls, according to equation (27), the relative price p_t increases. This relaxes the collateral constraint and allows for an increase in tradable consumption financed with higher borrowing. Once again, as the imperfectly informed economy assumes it is partially permanent, the response of C_t^T and P_t^T is more muted. More importantly, as the shock is assumed to be partially permanent, the household reduces external borrowing.

Finally, the third row shows the effect of a negative shock on the permanent component of income. As in the previous scenarios, the response of C_t^T and p_t is in the expected direction. Both economies decrease borrowing, but the reduction is much lower under imperfect information.

Figure 2: Endogenous Responses to Negative Shocks to the Underlying Components of Income



Note: In this figure, each row compares the dynamics of the main aggregate variables under perfect and imperfect information when the economy is hit by a one-standard-deviation negative shock to the *selected* unobserved exogenous state (indicated in the left-axis of each row). The horizontal axis covers five years before and after the shock occurrence. Responses to a positive shock are shown in appendix C.

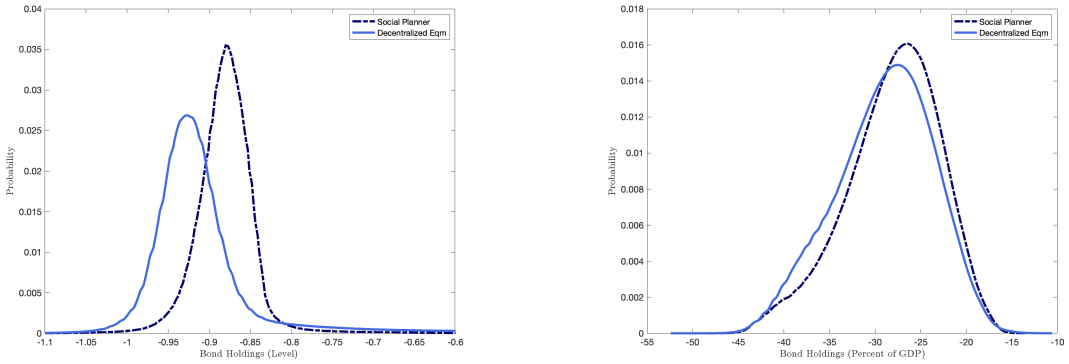
4.2.3 The Interaction Between the Information Friction and the Collateral Constraint

This section analyzes how the information friction interacts with the pecuniary externality. We study the degree of overborrowing, the frequency and severity of financial crises, the welfare costs created by market inefficiency, and the characteristics of the optimal macroprudential policy that restores constrained efficiency. Table 4 summarizes the key insights of this section.

Figure 3 shows the ergodic distribution of external borrowing under perfect and imperfect information. The first thing to note is that, as expected, the information friction does not change the qualitative observation that the pecuniary externality induces over-

Figure 3: Ergodic Distribution of Assets Under Imperfect Information

(a) Bond Holdings (b) Debt-to-GDP Ratio



Note: This figure shows the ergodic distribution of asset holdings for the constrained Planner and the competitive equilibrium under imperfect information. Debt increases to the left. The distribution is computed by repeatedly drawing from the policy functions of each model.

borrowing.[12] Both in absolute terms and as a percentage of GDP, the Social Planner chooses less debt than the decentralized economy.

Table 3: Debt-to-Output Ratios

	Perfect Information	Imperfect Information	*Information Effect*
Constrained Planner	26.16%	28.06 %	1.90 p.p
Competitive Equilibrium	27.15%	29.02 %	1.87 p.p
Externality Effect	0.99 p.p	0.96 p.p	-

Note: This table presents the average debt-to-output ratios for the four benchmark allocations we have considered. The information effect is computed as the difference between the second and first columns. The Externality effect is the difference between the second and first rows.

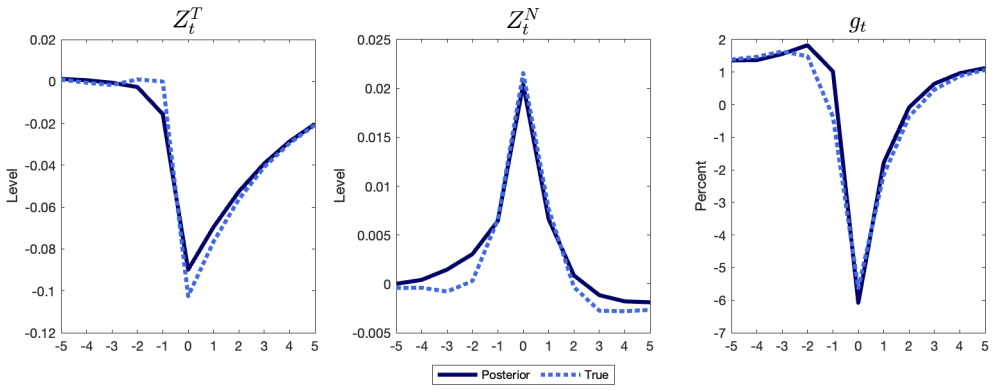
Table 3 presents average debt-to-output ratios for each equilibrium analyzed. The third row shows the difference between the Planner and competitive allocations holding the information set constant, i.e., the effect of the pecuniary externality. In our benchmark calibration, the total amount of overborrowing changes very little between informed and uninformed economies. Also, as shown in the third column of table 3, adding im-

[12] Schmitt-Grohé and Uribe (2020) showed that models with endogenous collateral constraints are prone to exhibit multiple equilibria. Models like Bianchi (2011) can display underborrowing for plausible calibrations. However, since our benchmark calibration is identical to Bianchi (2011), we implicitly discard the parameter scenarios that could yield underborrowing under imperfect information. This could be an interesting avenue for future research.

perfect information increases the amount of debt-to-GDP by about 1.9 percent for both equilibria.

In the decentralized economy, the interaction between the information friction and the financial constraint also amplifies consumption volatility and reduces the currency account variability. In contrast, the Social Planner maintains consumption volatility relatively constant under both information sets, while the volatility of the current account shifts from 3.1 percent of GDP to 1.46 percent. This illustrates how the interaction between the collateral constraint and the information friction reinforces the Planner's precautionary motive.

Figure 4: Shocks to the Underlying Component of Income Driving Financial Crises

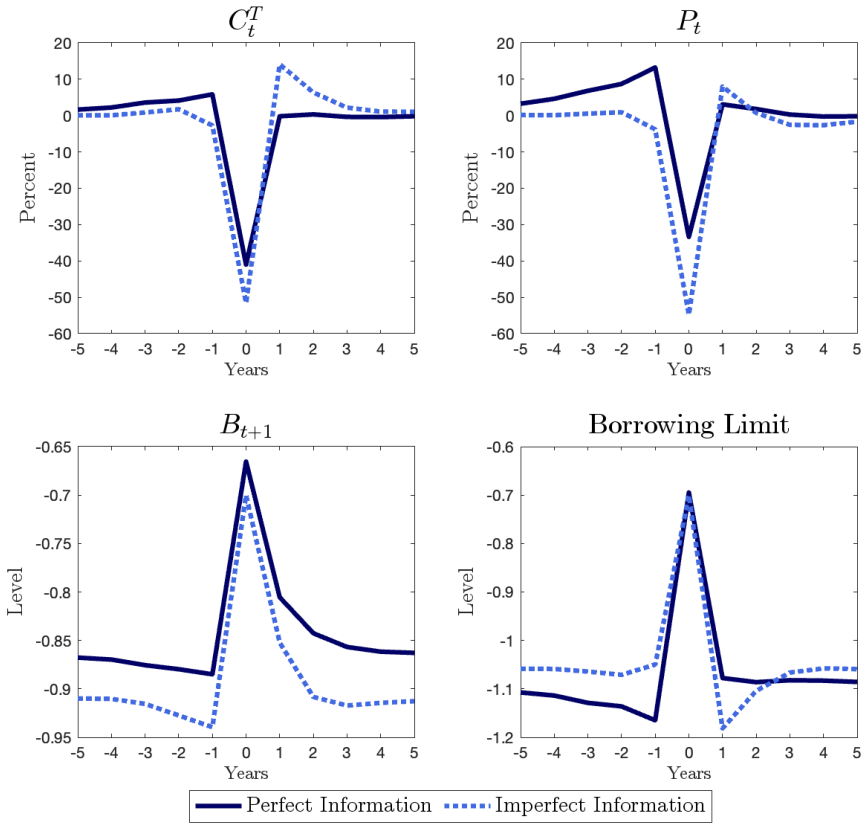


Note: Financial crises in our model occur when the collateral constraint binds and the economy experiences a sudden reversal in capital flows. In this figure, each plot illustrates the discrepancy between the agent's beliefs about the unobservable components of income and their true realizations. The horizontal axis covers five years before and after the crisis.

Regarding the driving forces behind Sudden Stops in the uninformed economy, Figure 4 shows that in the years preceding the crisis, the uninformed economy experiences a series of negative permanent income shocks, which agents perceive as transitory and as being partially offset by positive shocks to the nontradable endowment (Z_t^N). As seen in Figure 5, households react by increasing their debt in order to keep consumption relatively stable. This weakens their balance sheets just before the crisis emerges when simultaneous shocks to Z_t^T and g_T impact the economy at $t = 0$.

The higher exposure to debt has a more noticeable impact on the conditional moments rather than on unconditional averages. This finding makes intuitive sense, as experienc-

Figure 5: Endogenous Response to Financial Crises



Note: In this figure, each plot compares the dynamics of the main aggregate variables under perfect and imperfect information during a financial crisis. The horizontal axis covers five years before and after the crisis.

ing a binding constraint is rare; unconditional averages might obscure the full effect of these uncommon yet painful episodes. Table 4 shows that for the decentralized economy, financial crises become more frequent while debt does not increase dramatically under imperfect information. In contrast, the uninformed-constrained Planner experiences less financial crises than its perfectly informed counterpart. This result gives quantitative support to our initial intuition that the Social Planner can internalize that the increased uncertainty due to imperfect information affects how the value of collateral changes with consumption.

Table 4: Key Moments from Different Models Under Perfect and Imperfect Information

	Baseline Model				Recalibrated Model	
	Perfect Information		*Imperfect Information*		*Perfect Information*	
	D.E	*S.P*	*D.E*	*S.P*	*D.E*	*S.P*
Avg. Debt-to-GDP ratio (%)	-27.15	-26.16	-29.02	-28.06	-28.95	-28.60
Frequency of financial crises (%)	4.15	1.98	5.53	1.73	5.50	4.16
Consumption drop during financial crises (%)	-25.06	-24.55	-24.71	-21.08	-30.53	-29.14
Tradable consumption drop during financial crises (%)	-41.01	-37.91	-51.60	-46.34	-46.45	-41.83
$\sigma(C_t/Y_t)$ (%)	3.72	3.42	3.97	3.42	4.21	3.91
$\rho(CA_t, Y_t)$	-0.60	-0.53	-0.40	-0.01	-0.73	-0.67
$\sigma(CA_t/Y_t)$ (%)	4.64	3.07	4.24	1.46	7.67	5.77
Welfare cost (%)	0.11	-	0.24	-	0.15	-
Avg. tax on foreign debt (τ, %)	-	9.75	-	11.40	-	37.27

Note: In the baseline model, the parameters β and κ were adjusted to calibrate the decentralized economy with imperfect information to match an average Debt-to-GDP ratio of 29% and a frequency of crises equal to 5.5%. The recalibrated model's parameters were set so that the perfectly informed decentralized equilibrium matches the aforementioned targets. The welfare costs presented in the table were calculated relative to a constrained Planner sharing the same information set.

4.3 Welfare Costs and Optimal Macroprudential Policy

To compute the welfare loss caused by the pecuniary externality under perfect and imperfect information, we write the Planner's value function as:

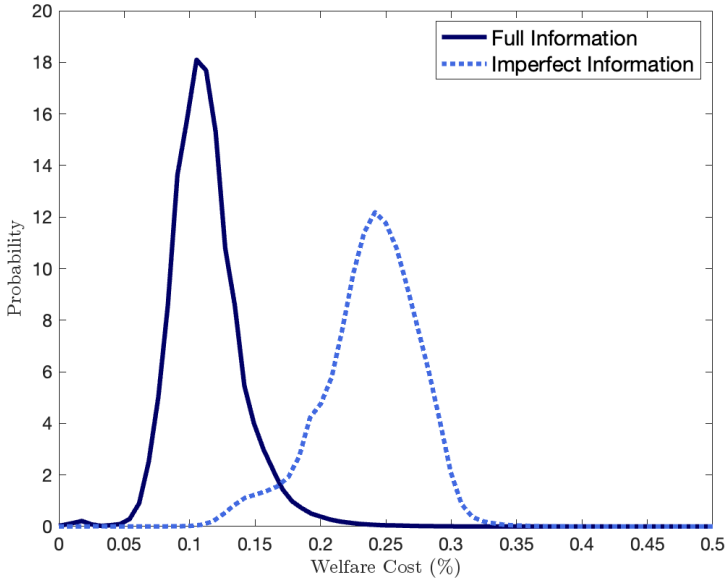
$$v^{SP}(x_t, b_t) = \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \frac{c_{t+s}^{CE}\left(1 + \frac{\Lambda(x_t, b_t)}{100}\right)}{1-\sigma} \tag{34}$$

where c_{t+s}^{CE} is the consumption level in the competitive equilibrium, x_t is a vector containing the exogenous states, and $\Lambda(x_t, b_t)$ represents how much equivalent consumption the household in a competitive economy is losing with respect to the constrained Planner due to the pecuniary externality. Solving Λ from (34), the welfare loss is given by:

$$\Lambda(x_t, b_t) = 100\left(\left[\frac{v^{SP}(x_t, b_t)}{v^{CE}(x_t, b_t)}\right]^{\left(\frac{1}{1-\sigma}\right)} - 1\right) \tag{35}$$

For the economy under imperfect information, the average welfare loss attributed to the pecuniary externality is approximately 0.24 percent of lifetime consumption, roughly twice the average loss observed under full information. Figure 6 depicts the ergodic distribution of welfare costs under both perfect and imperfect information.

Figure 6: Welfare Costs of the Pecunary Externality Under Different Information Sets



Note: This figure illustrates the ergodic distribution of welfare costs generated by the pecuniary externality under perfect and imperfect information. The distribution is computed by simulating the model for one million periods. The standard deviation for the welfare cost under perfect information is 0.027 percent and 0.037 percent under imperfect information.

Next, we quantify the welfare costs associated with the information friction. Table 5 indicates that when a private household transitions from perfect to imperfect information, it incurs in a loss of 1.06 percent in lifetime consumption. Likewise, a Planner operating in an economy with imperfect information faces a cost of 0.94 percent of her lifetime consumption to shift to an economy with perfect information. These findings underscore that the welfare costs related to information friction are notably higher than those from the pecuniary externality.

4.3.1 Optimal Macroprudential Policy

The existence of the pecuniary externality justifies the introduction of policies to restore credit market efficiency. In this section, we analyze the tax on foreign debt that a Social Planner would like to implement over the decentralized equilibrium.

As explained in section 3.2, private agents have a different valuation of wealth than the Social Planner due to the pecuniary externality. The optimal policy is defined as the

Table 5: Welfare Costs (Gains) From Moving Across Regimes

	Perfect Information		Imperfect Information	
	Constrained Planner	Decentralized Economy	Constrained Planner	Decentralized Economy
Informed Constrained Planner	-	0.11	0.94	1.18
Informed Decentralized Economy			-2.08	1.06
Uninformed Constrained Planner				0.24

Note: This table presents the welfare costs (gains) of moving across different regimes. The table should be read as the welfare cost implied by moving from a regime in the rows to a regime in the columns. A negative value implies a welfare gain. All values are in percent units of lifetime consumption. For instance, the welfare cost of moving from the informed constrained Planner to the informed decentralized economy equals 0.11 percent of lifetime consumption.

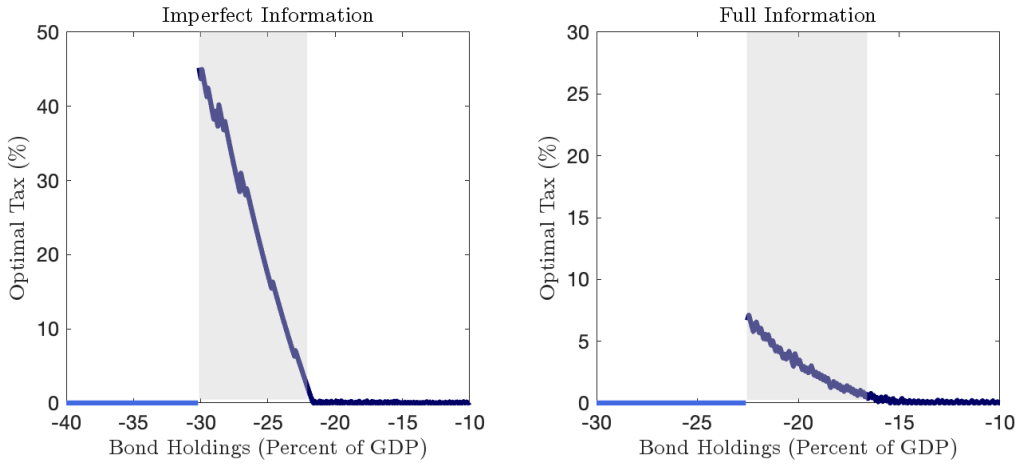
tax on foreign debt a Planner would impose on the decentralized equilibrium to equalize their marginal utilities of wealth (Bianchi, 2011). When the constraint binds ($\mu_t > 0$), there is generally a multiplicity of taxes that can implement the constrained-efficient allocation. We follow the standard convention and set the optimal tax τ_t to zero as both the Planner and the household in the competitive equilibrium have the same marginal utility of consumption; therefore, the same allocations for borrowing and consumption. If the constraint is not binding, but it is expected to bind in the future (i.e., $\mu_t = 0$ and $\mathbb{E}_t[\mu_{t+1}] > 0$), the optimal tax on foreign borrowing is given by:

$$\tau_t^* = \frac{\mathbb{E}\left[\mu_{t+1}^{SP}\Phi_{t+1}\right]}{\mathbb{E}\left[U_T\left(t+1\right)\right]}$$

where Φ_{t+1} is the marginal change in the value of the collateral due to changes in consumption of tradable goods (as defined in section 3.2), and U_T is the marginal utility of tradable consumption. In particular, the Planner implements a tax equal to the expected value of the uninternalized marginal cost of borrowing discounted by the expected value of the marginal utility of tradable consumption.

Figure 7 illustrates the optimal tax policy functions for the informed and uninformed equilibria when a one-standard-deviation negative shock hits the permanent income component. In both cases, the optimal function displays three identifiable areas. The first is

Figure 7: Optimal Tax Functions



Note: Debt increases to the left. The policy functions correspond to the case where a one-standard-deviation shock hits the permanent income growth component.

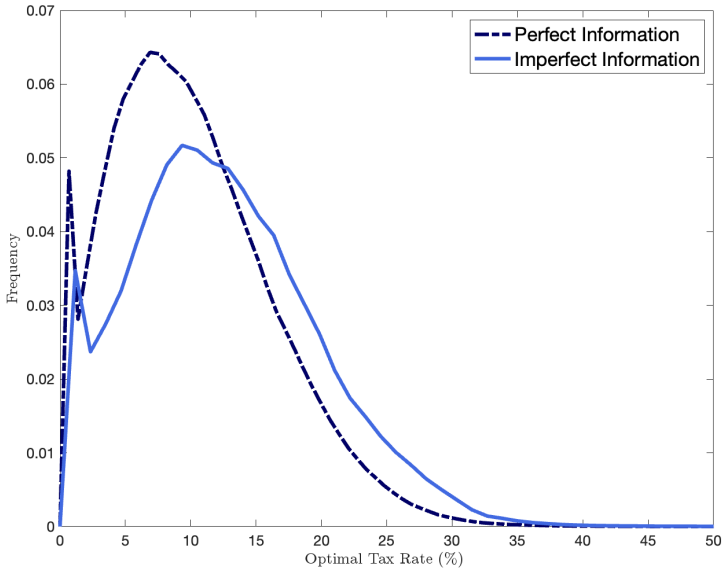
a section where the constraint is binding; therefore, as explained above, the tax is defined as zero. Second, a region in which the likelihood of observing a binding constraint is high, and the optimal tax increases rapidly with bond holdings. Third, a region where the decentralized allocations are close to the Planner's solution and the likelihood of facing a financial crisis is low. Figure 7 also shows that similar debt allocations entail higher taxes in the uninformed economy for this specific realization of the exogenous driving forces. We can generalize this result using simulated data.

Figure 8 shows the ergodic distribution of the optimal tax for both equilibria. Due to the increased welfare costs of the pecuniary externality resulting from the information friction, the Social Planner implements an average tax on foreign borrowing equal to 11.4 percent, about 1.7 percentage points higher than the average optimal tax under perfect information. The standard deviation of the tax distribution under imperfect information is 7.7 percent, about 1.4 percentage points higher than in a perfectly informed economy.

As before, conditional moments reveal the more noticeable differences between the tax policies of informed and uninformed economies. Figure 9 illustrates the dynamics of the optimal tax in the years preceding a Sudden Stop.[13] Specifically, it depicts a relatively constant gap between the tax rates during tranquil times. However, a wider gap emerges

[13] Appendix D shows the dynamics of the optimal tax in the years preceding and following a Sudden Stop.

Figure 8: Optimal Tax: Ergodic Distribution

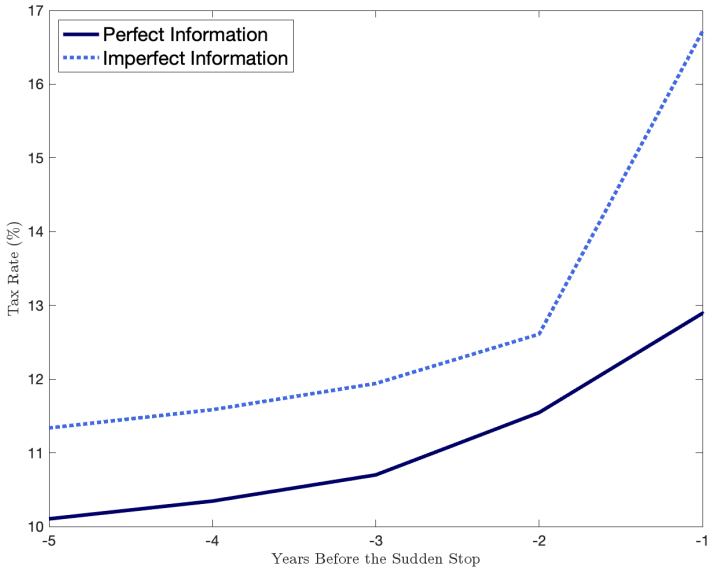


Note: This figure shows the ergodic distribution of the optimal tax under both imperfect and perfect information. The average tax under perfect information is 9.75% with a standard deviation equal to 6.3%. The average tax under imperfect information is 11.40% with a standard deviation of 7.7%.

in the year preceding the crisis. Negative shocks to both permanent and transitory components prompt households to increase their debt for consumption smoothing (refer to Figure 4). Uninformed agents inaccurately predict the shocks to be more transitory than they are, leading to a greater surge in debt holdings (as shown in Figure 5). Consequently, the uninformed Planner increases its tax rate by 4.1 percentage points (from 12.6 percent to 16.7 percent), while the informed Planner does so by 1.3 percentage points (from 11.6 to 12.9 percent).

The Planner's optimal tax policy under information and financial frictions has important implications for the role of macroprudential policies in preventing and mitigating the risk of financial crises. Implementing the optimal capital control policy decreases the frequency of financial crises -from 5.5 crises to 1.7 every 100 years- and mitigates their severity in the uninformed economy. In particular, the average drop in consumption during a Sudden Stop decreases from 25 to 21 percent due to the optimal tax policy. In contrast, the informed Planner implements a tax policy that reduces the drop in total consumption from 25 to 24.5 percent.

Figure 9: Optimal Tax Policy in the Years Preceding a Sudden Stop.



Note: In this figure, we compare the dynamics of the optimal tax policy under perfect and imperfect information in the years leading up to a Sudden Stop. The horizontal axis covers the five years before the crisis. The Sudden Stop occurs in period 0, at which point the optimal tax rate, by definition, moves to zero.

4.3.1.1 Cyclicality of Taxes

Under both perfect and imperfect information scenarios, the constrained Planner increases taxes during times of low GDP and reduces them during periods of high GDP. This behavior is consistent with the findings of Schmitt-Grohé and Uribe (2017), who observed that the Planner addresses the trade-off arising from impatient households and the need to prevent financial crises by raising taxes on foreign debt when income is low and crises are more likely. However, as Figure 10 illustrates, the cyclicality of the optimal tax changes depending on the nature of the shock to the underlying component of income and whether the economy is under perfect or imperfect information. Table 6, shows that this result is robust to several sensitivity variations with respect to the benchmark model.

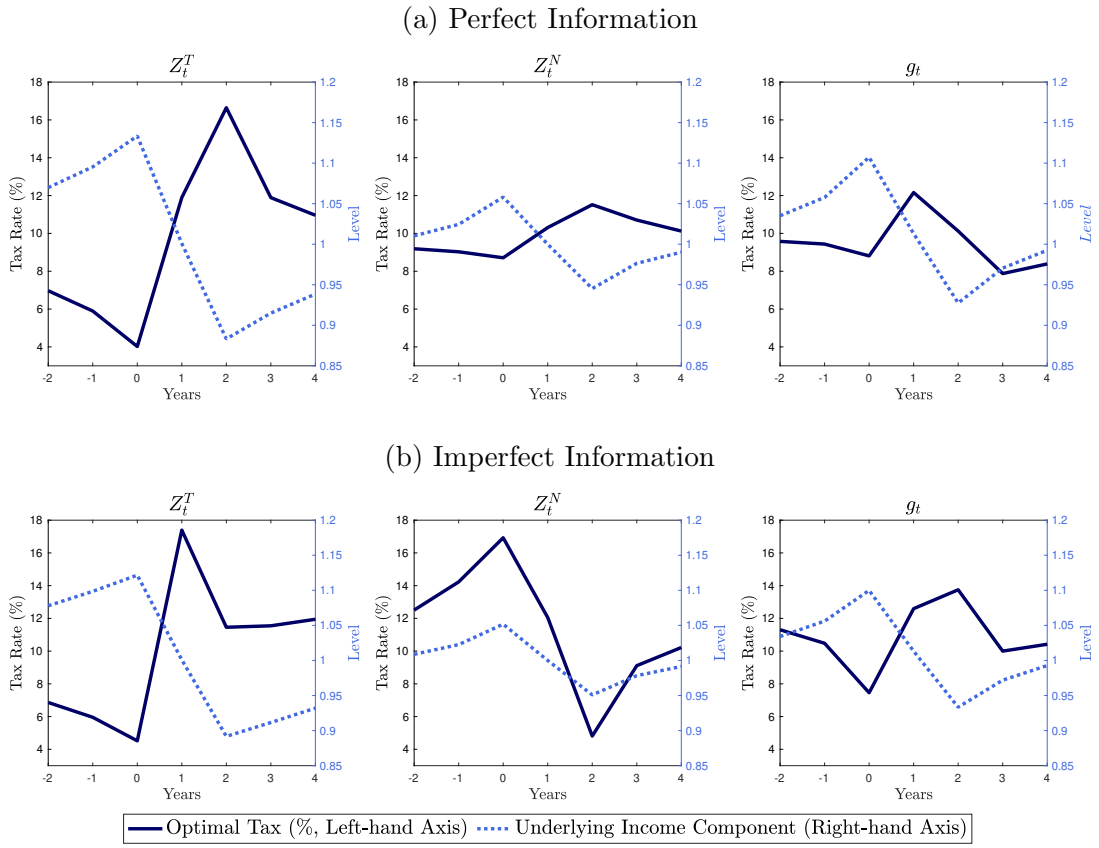
For instance, the cyclicality of the optimal tax with respect to transitory shocks to nontradable income Z_t^N shifts from negative to positive when considering the information friction. Under perfect information, the correlation between Z_t^N and the optimal tax policy is -0.18, while under imperfect information, the correlation is positive and equal

Table 6: Cyclicality of the Optimal Tax

	Total Output $\rho(\tau_t, Y_t)$		Permanent Shock $\rho(\tau_t, g_t)$		Transitory Shock Y_t^T $\rho(\tau_t, Z_t^T)$		Transitory Shock Y_t^N $\rho(\tau_t, Z_t^N)$	
	Perf. Info	*Imp. Info*	*Perf. Info*	*Imp. Info*	*Perf. Info*	*Imp. Info*	*Perf. Info*	*Imp. Info*
Baseline Model	-0.38	-0.52	-0.03	-0.16	-0.65	-0.55	-0.18	0.19
Sensitivity Analysis								
Autocorrelation ρ_g (15 % less)	-0.44	-0.57	-0.12	-0.24	-0.65	-0.53	-0.19	0.16
Autocorrelation ρ_g (15 % more)	-0.29	-0.42	0.09	-0.04	-0.65	-0.53	-0.18	0.22
Volatility σ_g (15 % less)	-0.39	-0.53	-0.03	-0.16	-0.65	-0.53	-0.19	0.18
Volatility σ_g (15 % more)	-0.37	-0.50	-0.04	-0.15	-0.66	-0.54	-0.19	0.20

Note: This table presents the correlations between the optimal tax rate and the different components of income for both perfect and imperfect information. Each rows displays sensitivity variations from the baseline model. As in Schmitt-Grohé and Uribe (2017), we define a countercyclical optimal tax as a capital control policy that increases during booms and decreases during economic recessions (positive correlation).

Figure 10: Optimal Tax Policy Under Different Boom-Bust Scenarios



Note: This figure illustrates the boom-bust dynamics of the optimal tax rate. A boom-bust cycle is defined as a scenario where the respective income component exceeds one standard deviation above the mean at period 0 and then drops below one standard deviation below the mean two years later. Each figure includes two years before the boom and two years after the bust. Panel (a) depicts the dynamics for the informed economy, while Panel (b) displays the results for the economy under imperfect information.

to 0.19.

Under perfect information, a negative shock to Z_t^N causes tradable goods to become relatively cheaper than nontradable goods, leading households to shift their consumption toward tradable goods ($C_t^T \uparrow$). Equations (3) and (27) show that this response reinforces real appreciation and relaxes the borrowing limit, incentivizing households to overborrow and increasing the likelihood of a Sudden Stop. To counteract this effect, the Planner follows a procyclical policy, raising the tax during periods of low income and lowering it during good times.

In contrast, the uninformed Planner finds it optimal to reduce taxes when negative transitory shocks to nontradable income hit the economy. As shown in section 4.2.1, when the household observes a negative growth rate in nontradable income, her beliefs about the fundamentals will be consistent with a negative shock to Z_t^N, a positive shock to Z_{t-1}^T that went unnoticed, or a negative shock to the permanent component g_t, and each scenario will be optimally weighted.

As a result, when a negative shock to Z_t^N hits the uninformed economy, households substitute away from the nontradable sector as nontradable goods become relatively more expensive. Higher C_t^T reinforces the increase in the relative price and relaxes the borrowing limit. However, despite facing a loosened collateral constraint, households choose to decrease borrowing since they believe the economy might be facing a permanent negative shock. The combination of lower debt and a more relaxed financial constraint leads the Planner to adopt a countercyclical macroprudential tax policy.

In response to shocks to the transitory component of tradable income (Z_t^T), we find that the optimal tax is procyclical under both information sets. However, when we consider imperfect information, the correlation between the tax and Z_t^T shifts from -0.65 to -0.55. Although this numerical difference is small, it highlights a less procyclical tax regime.

Under imperfect information, households react to shocks to Z_t^T by adjusting their consumption more significantly than households in a fully informed economy. When the shock is positive, the uninformed Planner will reduce taxes, but not as much as in the

perfectly informed economy. This is because if the shock turns out to be fully permanent, encouraging borrowing during good times could excessively increase the economy's vulnerability to large negative shocks. In contrast, if the shock is negative, the uninformed Planner increases taxes by less than in a perfectly informed economy because if the shock is permanent, inducing deleverage might lead to a binding borrowing constraint and trigger a Sudden Stop.

Finally, we study the optimal tax dynamics alongside shocks to the permanent component of income (g_t). In our baseline calibration, the perfectly informed economy displays a negative, albeit relatively acyclical, correlation between g_t and the optimal tax policy ($\rho(\tau_t, g_t) = -0.03$). Under imperfect information, however, as shown in Figure 10, the optimal policy becomes more procyclical as the correlation is negative and equal to -0.16.

Under perfect information, our findings are consistent with the results of Flemming et al. (2019), who found that in an economy affected by trend shocks, the optimal policy is less responsive to non-stationary shocks to income.[14] In a perfectly informed economy, permanent shocks convey information about the economy's future performance. Following a positive (or negative) shock, agents predict a continued improvement (or deterioration) in economic conditions, leading them to reallocate resources from (or towards) the future. Consequently, during good times, the Planner levies taxes to counteract the increase in borrowing, driven by households perceiving themselves as permanently wealthier. This policy helps mitigate the risk of facing a binding collateral constraint when the positive shock eventually reverts.

Since uninformed agents perceive permanent shocks as partially transitory, considering the information friction reverts back the cyclicality of the optimal tax. The uninformed Planner reduces the optimal tax during booms in g_t and increases it during bad times. This procyclical dynamics occur because, in response to a positive shock to g_t, consumption and borrowing increase by less than in the perfectly informed economy.

[14] As shown by Flemming et al. (2019), the persistence of the permanent shock ρ_g is key to this result. The more persistent the shock, the more countercyclical the policy response will be. Table 6 displays the cyclicality of the optimal tax under our baseline calibration and compares it with several sensitivity scenarios. In particular, under perfect information, increasing ρ_g by 15% increases the correlation of the optimal policy with the permanent component of income to 0.09 (from -0.03). Conversely, reducing ρ_g by 15% causes the correlation to decrease to -0.12.

Since uninformed agents know there is a risk the shock might be mean-reverting, they will save part of the windfall income. The uninformed Planner can reduce taxes during good times, because, even if borrowing goes up, the increase will be moderate and consistent with an economy that is permanently wealthier. In fact, in our simulation, the Planner sets the tax close to zero in approximately 3.6 percent of the booms in permanent income as the decentralized economy becomes sufficiently insured against financial crises.

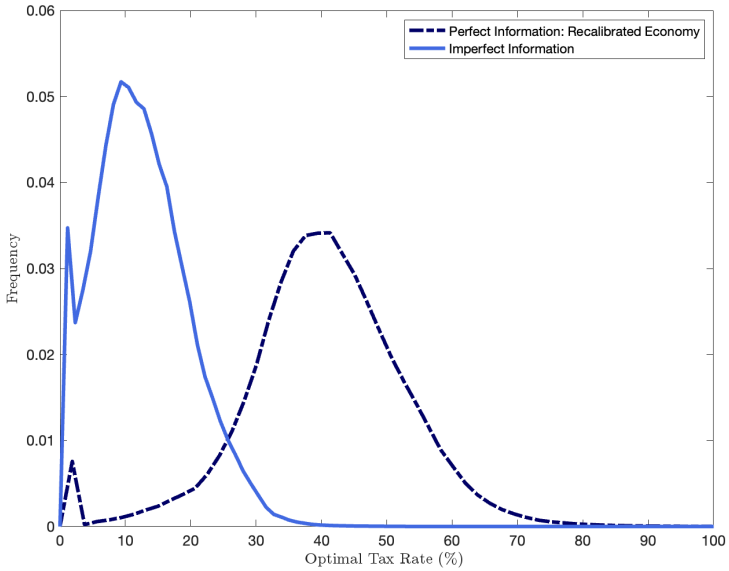
4.3.1.2 Policy Implementation

Due to the information friction, the constrained Planner chooses a highly nonlinear tax policy that adjusts taxes on external debt more frequently than an informed Planner. However, data indicates that policymakers generally prefer "stickier" policy rules (Acosta et al., 2020). Moreover, the nonlinearity of the optimal rule makes it challenging to implement. In this section, we analyze the welfare benefits of implementing simpler policies.

In particular, we consider a Planner who, at time 0, chooses the fixed tax rate that brings him closer to the second-best solution. Following Bianchi (2011), we find that a fixed tax rate equal to 10 percent (about 88% of the ergodic mean from the optimal tax distribution) yields a welfare cost of 0.06 percent of lifetime consumption, about one-fourth of the welfare costs of the decentralized solution. Under the optimal fixed tax rate regime, the likelihood of crises drops to 2.4 percent, and the decentralized economy borrows about 0.4 percentage points of GDP less than the constrained Planner. Consistent with Hernandez and Mendoza (2017), we also find that fixed tax rates equal to or above the average state-contingent tax rate are welfare-decreasing, as they effectively eliminate the occurrence of financial crises at the cost of reducing borrowing and consumption smoothing.

Another relevant issue for a policymaker is whether assuming a model under perfect information significantly departs from the optimal tax policy. To address this concern, we study the optimal policy enacted by a Planner in a perfectly informed economy calibrated to match the long-term debt-to-GDP ratio and frequency of crises in the data. Columns

Figure 11: Optimal Tax Distribution: Recalibrated Economy



Note: This figure depicts the ergodic distribution of the optimal tax under imperfect information using the benchmark calibration. It also shows the distribution for the optimal tax in the recalibrated, fully-informed decentralized economy.

5 and 6 of Table 4 summarize our findings.

In the recalibrated economy, the informed Planner opts for a mean tax about three times larger (37.27 %) than the average macroprudential tax implemented by the uninformed Planner (11.40 %). As illustrated by Figure 11, Planner in the recalibrated economy mostly chooses taxes between 20 and 60 percent of external debt.

The differences observed stem from a crucial aspect of the recalibration process. Based on our estimated stochastic processes, achieving the targeted moments under perfect information requires a higher degree of impatience. Specifically, the recalibrated economy with full information requires an annual discount factor (β) equal to 0.53. This value is significantly lower than the standard values used in the literature.[15] With highly impatient households in the recalibrated economy, households borrow more and face more frequent Sudden Stops, prompting the Planner to impose higher taxes than in the benchmark models. [16]

[15]For comparison, in a model with transitory shocks and perfect information, Bianchi (2011) sets β equal to 0.91. In our benchmark model with imperfect information and transitory and permanent shocks, we set $\beta = 0.83$ to match an average NFA-to-GDP ratio of 29 percent. Flemming et al. (2019), and Seoane and Yurdagul (2019) set β equal to Bianchi (2011).

[16]See Appendix E for more details on the optimal policy functions.

The difference in the level of impatience between the recalibration and our benchmark underscores the importance of relaxing the assumption of imperfect information to match the levels of debt observed in the data under reasonable parameterization in the presence of transitory and permanent shocks to income. [17]

5 Concluding Remarks

This paper studies the role of imperfect information in generating Sudden Stops in a model where agents are subject to a borrowing constraint that depends on the tradable value of domestic income. Our findings underscore the significant implications of accounting for the interaction between information and financial frictions for the efficacy of macroprudential policies in averting and mitigating the risks of financial crises. Furthermore, considering this interaction changes the model's prediction about the cyclicality of the optimal policy.

[17] See Appendix F for an array of exercises replicating our results using plausible deviations from our primary calibration. Overall, our findings indicate that, although there are quantitative variations, our qualitative results remain consistent across each case.

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A Calibration Details

As mentioned in the paper, we use the Kalman filter and its statistical properties to estimate the structural parameters governing the income processes included in our model.

In particular, since we assume the innovations, $\left\{\varepsilon_t^T,\, \varepsilon_t^N,\, \varepsilon_t^g\right\}$ are Gaussian, we can derive a likelihood function $\mathcal{L}(\Theta,\, s_t)$, where s_t is a two-column matrix that contains the observable signals Δ_t^T and Δ_t^N; and (θ) is a vector containing the structural parameters of the model (Hamilton, 1994). The log-likelihood function is given by

$$l(\Theta,\, s_t) = -\frac{Tn}{2}\ln(2\pi) - \frac{T}{2}\ln\Big(\det(\mathbf{ZPZ}')\Big) + \frac{1}{2}\sum_{t=1}^{T}\Big((\mathbf{s_t^{\bullet}} - \mathbf{Za}_{t|t-1})'(\mathbf{ZPZ}')^{-1}(\mathbf{s_t^{\bullet}} - \mathbf{Za}_{t|t-1})\Big) \quad (36)$$

which can be maximized with respect to Θ to find the maximum likelihood estimates of the parameters that form the state transition matrix $\mathbf{A}$ and the noise covariance matrix $\mathbf{Q}$. As shown by equations 12 and 13, the output of this process is a vector $\Theta^* = \left(\rho_{z^T,z^T},\, \rho_{z^T,z^N},\, \rho_{z^N z^T},\, \rho_{z^N,z^N},\, \rho_g,\, \sigma_{z^T z^T},\, \sigma_{z^N z^T},\, \sigma_{z^N,z^N}, \sigma_g\right)$ plus the corresponding forecasts for the unobservable components of income Z_t^T, Z_t^N and g_t.

Following Garcia-Cicco et al. (2010), estimating trend shocks in the data requires long samples. We use annual data from Argentina from 1903 to 2018 from Ferreres (2020). We compute *tradable output* (Y_t^T) as the sum of the GDP of the following categories: Farming, livestock, hunting, and forestry; Fisheries; Mine exploitation and quarries; and manufacturing. *Non-tradable* GDP is the sum of the sectoral output of construction, electricity, gas, and water; Transport, storage, and communications; financial intermediation; real estate activities; and other services. Non-tradable output equals total GDP minus tradable output.

Following equations (10) and (11), we define the observable signals Δ_t^T and Δ_t^N as $\ln\frac{Y_t^T}{Y_{t-1}^T}$ and $\ln\frac{Y_t^N}{Y_{t-1}^T}$, respectively. We detrend these series using a quadratic trend. We find the maximum likelihood estimates using the following computational algorithm:

1. Set an initial value Θ_0.

2. Set matrices $\mathbf{A}$ and $\mathbf{Q}$ to form the state-space described in (13).

3. Using the Kalman Filter, compute $\mathbf{a}_{t|t-1}$ and P following (15),(16), and (17).

4. Compute the log-likelihood function value using 36.

5. Iterate over values for Θ until a local maximum, denoted as $\hat{\Theta}$, is found.[18]

6. Use $\hat{\Theta}$ as the initial value to start a global maximization search process. [19]

7. Iterate over values for Θ until you find a global maximum Θ^*.

8. Define the information matrix as the negative hessian of $l(\Theta^*, s_t)$ divided by the length of Δ_t^T and Δ_t^N.

9. Compute the standard errors of Θ^* as the squared root of the diagonal elements of the inverted information matrix.

The Matlab code required to implement this routine is available at https://bit.ly/458eSSm.

A.1 Robustness Check

A substantial body of literature in economics has been dedicated to studying the role of permanent and transitory income components and how to decompose macroeconomic aggregates.[20] Moreover, it has been well-established that identification is a delicate issue. For instance, Quah (1992) showed that infinite decompositions can separate the same time series into permanent and transitory components.

To address this concern, we conduct a robustness check to ensure that the estimated parameters effectively maximize the log-likelihood function. Specifically, we simulate the function, varying the values of the two crucial parameters that determine the relevance of shocks to the permanent income component—the persistence of those shocks (ρ_g) and the volatility of trend shocks (σ_g). Meanwhile, we keep the values of the remaining parameters

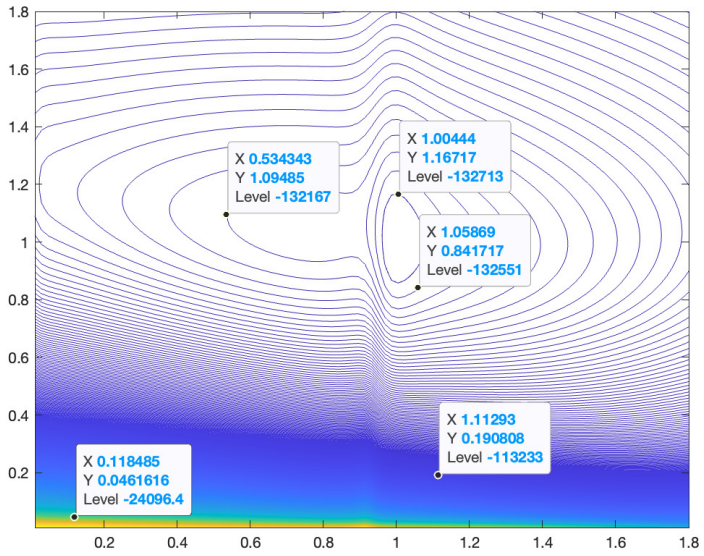
[18] For this step, we use Matlab's *fmincon* minimization routine. The bounds are set to prevent negative numbers from appearing in the diagonal elements of matrix $\mathbf{Q}$.

[19] For this step, we use Matlab's *patternsearch* command.

[20] See, for example, Cuddington and Winters (1987); Quah (1992); Harvey and Koopman (2000); Garratt et al. (2006); Aguiar and Gopinath (2007); Oh et al. (2008) among others.

at their estimated targets. This exercise aims to determine whether the log-likelihood function exhibits additional local or global minima across a wide range of parameter values. We varied the two parameters of interest from 1% to 180% of their calibrated values. The upper restriction on the values is imposed to maintain the assumption that shocks to the trend mean revert.

Figure 12: Maximum Likelihood Function: Contour Plot



Note: Monte Carlo simulation of the Log-likelihood function implied by our calibration. The values of (ρ_g) and (σ_g) vary within 1% and 180% of their point estimates. The other parameters in the model remain at their estimated targets.

Figure 12 illustrates the main takeaways from this exercise. First, the negative of the log-likelihood function is minimized precisely at the point (1, 1)—our calibrated values. This outcome is not surprising, as the log-likelihood function was the criterion used to select these parameters. Second, the log-likelihood function is well-behaved and exhibits no other local minima. Third, the value of the log-likelihood function rapidly decreases as we move towards combinations of parameter values where trend shocks are relatively less important. In other words, the maximization algorithm favors our estimated parameters over a limit scenario where ρ_g and σ_g are arbitrarily small.

Similar exercises conducted for the other parameters in our model yielded comparable results. The log-likelihood function attained a maximum value smaller than in our benchmark calibration. In those perturbed simulations, the algorithm still preferred to

choose points away from the aforementioned limit scenario.

B Solution Method

In this appendix, we explain in detail the methods used to solve for the equilibria under perfect and imperfect information. Regarding perfect information, we follow the algorithm proposed by Bianchi (2011) to find the solutions for both the decentralized equilibrium and the Social Planner's problem. However, we extend the solution method to include a different state space for shocks to account for growth shocks.

Under imperfect information, the state space changes as the agent only observes the signals and not the fundamental components of income. In this sense, the state space under imperfect information is larger as it includes not only the exogenous processes for Z_t^T, Z_t^N, and g_t but also the processes for the signals Δ_t^T, and Δ_t^N. Moreover, the resulting transition matrix incorporates the information friction.

We use the following algorithm to discretize the state-space under imperfect information:

1. Simulate a time series of 1,000,000 periods for the unobservable states Z_t^T, Z_t^N, and g_t.

2. Compute the value of the signals Δ_t^T and Δ_t^N using the system of equations (12).

3. Apply the Kalman filter to Δ_t^T and Δ_t^N to compute forecasts for the underlying values of $\tilde{z}_t^T$, $\tilde{z}_t^N$, and $\tilde{z}_t$.

4. Using distance minimization, approximate each forecast and the realization of the observable signals to the values of five equally spaced grids of 19 points.

5. With the resulting discrete-valued time series, estimate the probability of transitioning from a given quintet $\{z_t^T, z_t^N, g_t, \Delta_t^T, \Delta_t^N\}$ to another.

6. Reduce the resulting transition matrix by eliminating those rows and columns representing cases with zero probability of occurrence.

With the calculated transition matrix and corresponding grids, we can proceed to solve for the equilibrium in each of the proposed models. Under perfect and imperfect information, we use standard value function iteration to solve the Social Planner's problem. For the competitive equilibrium, we use time iteration. The process includes an equally spaced grid for the endogenous state B_{t+1} with 501 points. The algorithm is as follows:

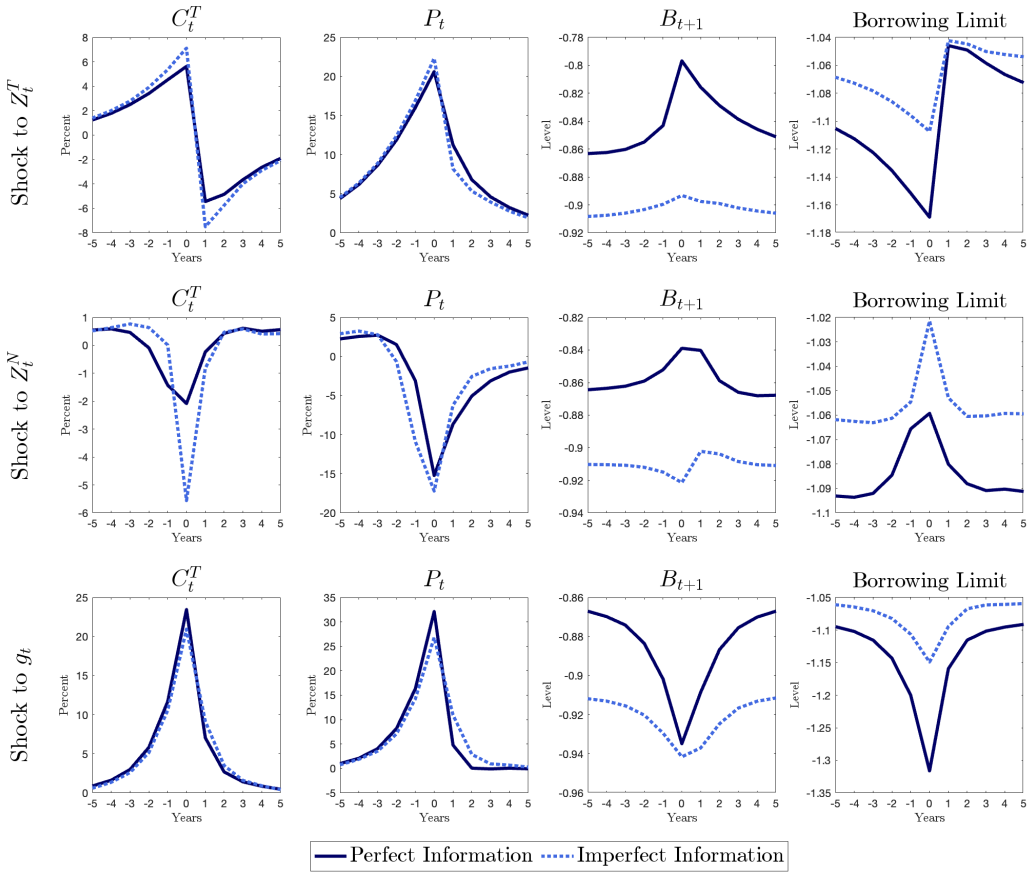
1. For a conjecture of B_{t+1}, and given the endowment, solve for the price of relative price p, and tradable consumption c_t^T.
2. Compute the marginal utility of consumption: this will give you a mapping $z^T \times z^N \times z \times g^T \times g^N \times B$ into $\mathbb{R}$.
3. Compute the Euler equation for each point of the mapping.
4. Get the optimal value of the Lagrange multiplier associated to the occasionally binding borrowing constraint $\mu^*(b_{t+1})$ as the $\underset{b_{t+1} \in B}{arg\,min} |\mu\,(b_{t+1})\,|$
5. Update your initial conjecture of the marginal utility of consumption.
6. Iterate until you reach a fixed point.

All the Matlab code is available at https://bit.ly/458eSSm.

C Responses to Positive Shocks to the Underlying Components of Income

Each row of Figure 13 compares the dynamics of the main aggregate variables under perfect and imperfect information when the economy is hit by a one-standard-deviation positive shock to the unobserved exogenous state (as indicated in the left-axis of each row). The horizontal axis covers five years before and after the shock occurrence.

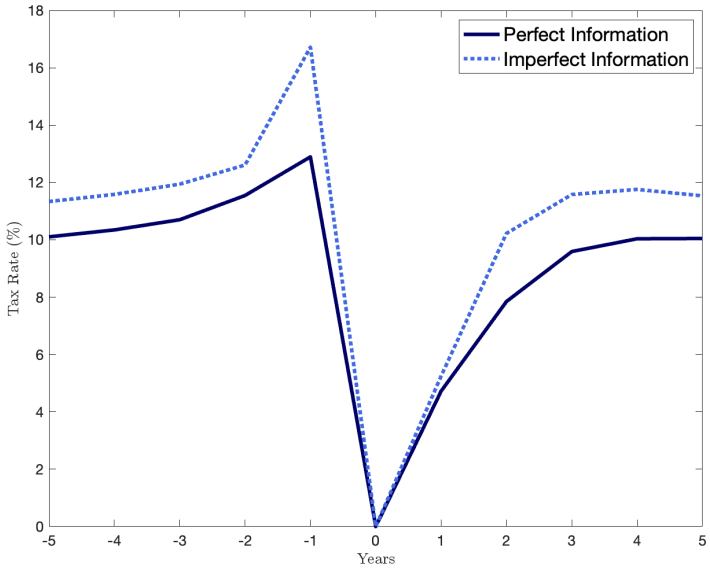
Figure 13: Endogenous Responses to Shocks to the Underlying Components of Income



D Optimal Tax Policy During a Sudden Stop

Conditional moments reveal the more noticeable differences between the tax policies of informed and uninformed economies. Figure 14 illustrates the dynamics of the optimal tax in the years before and after a Sudden Stop. Specifically, it depicts a relatively consistent gap between the tax rates during tranquil times. However, a wider gap emerges in the year preceding the crisis. Negative shocks to both permanent and transitory components prompt households to increase their debt for consumption smoothing. Uninformed agents inaccurately predict the shocks to be more transitory than they are, leading to a greater surge in debt holdings. Consequently, the uninformed Planner increases its tax rate by 4.1 percentage points (from 12.6 percent to 16.7 percent), while the informed Planner does so by 1.3 percentage points (from 11.6 to 12.9 percent).

Figure 14: Optimal Tax Policy in a Sudden Stop.



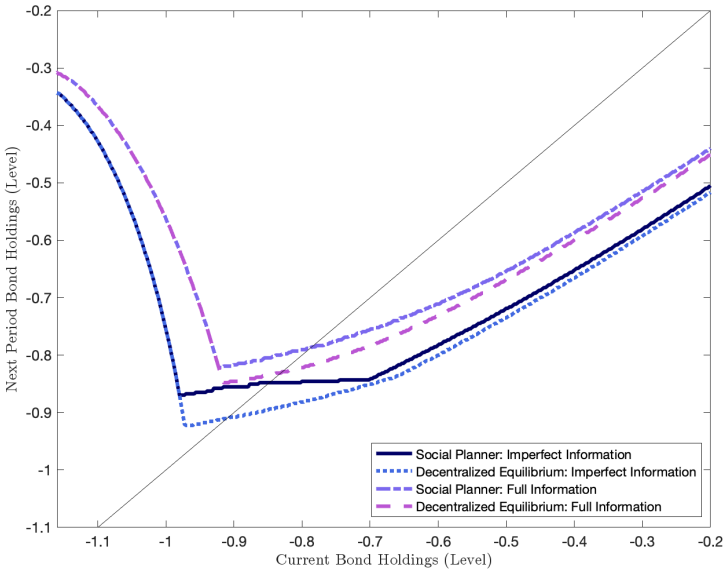
Note: In this figure, we compare the dynamics of the optimal tax policy under perfect and imperfect information during a Sudden Stop. The horizontal axis covers the five years before and after the crisis. The Sudden Stop occurs in period 0, and the optimal tax rate, by definition, moves to zero.

E Policy Functions

This section describes the bond decision rules for the decentralized and constrained-efficient equilibrium based on current bond holdings. Figure 15 compares the policy functions for the informed and uninformed cases when the economy experiences a one-standard-deviation negative shock to the permanent income component. Like the perfectly informed case in Bianchi (2011), the policy functions exhibit a non-monotonic behavior characterized by a kink due to the borrowing constraint under imperfect information. The kink is located precisely where the financial constraint is satisfied with equality but is not binding. It becomes binding for any debt level to the left of this point, while for any point to the right, the constraint is slack.

Given our calibration for the exogenous processes of the transitory and permanent income components, both the Social Planner and the decentralized equilibrium in the uninformed economy maintain higher debt levels than their counterparts in the informed economy. Furthermore, under both information sets, the Social Planner consistently opts

Figure 15: Policy Functions for a Negative One Standard-Deviation Shock to the Permanent Component of Income



Note: This figure highlights the distinct decision rules followed by the Social Planner and the decentralized equilibrium in the informed and uninformed economies, especially as current debt levels approach the critical region where the collateral constraint becomes binding. Debt increases to the left.

for lower levels of the next period's debt than private households. However, as current debt levels approach the region where the collateral constraint becomes binding, the uninformed Planner deviates further from the decentralized equilibrium calibration than the informed Planner. As detailed in Section 3.1, this precautionary behavior from the uninformed Planner relates to how it adjusts its marginal utility of wealth to reflect that the increased uncertainty due to the information friction affects its valuation of how the collateral value changes with consumption.

E.1 Policy Rules in the Recalibrated Economy

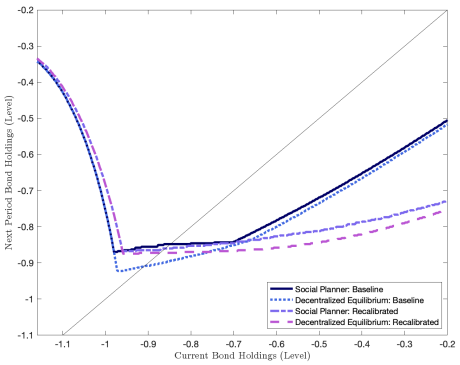
In section 4.3.1.2, we studied the optimal tax policy of a perfectly informed economy calibrated to match the moments in the data. We showed that the informed Planner in the recalibrated economy chooses a tax policy that implies an average tax similar to the mean tax implemented by the uninformed Planner.

Figure 16a compares policy functions between the baseline calibration under imperfect

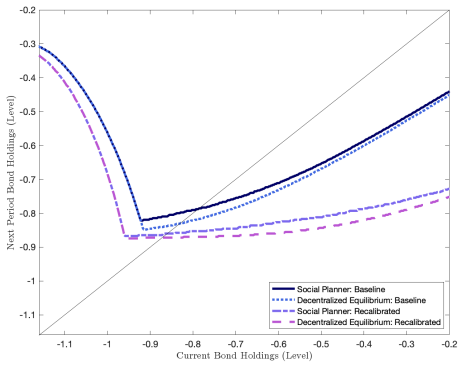
information and the recalibrated perfectly informed economy. Due to the lower degree of impatience implied by the recalibration, the Planner and private households in this scenario hold more debt than in the baseline calibration. However, in the region where the collateral constraint is more likely to bind, the policy rules for both Planners become very similar. This similarity explains why, in both calibrations, the tax tends to activate at similar debt levels. Nevertheless, the degree of overborrowing implied by both models differs significantly, accounting for the distinct distributions shown in Figure 11. Additionally, Figure 16b illustrates differences in policy functions between the baseline and the recalibration under perfect information.

Figure 16: Policy Functions: Recalibrated Economy

(a) Imperfect Information



(b) Perfect Information



Note: Figure 16a compares the policy functions between the baseline calibration under imperfect information and the recalibrated perfectly informed economy. Figure 16b illustrates the differences between the policy functions for the baseline and the recalibration under perfect information. Debt increases to the left.

F Sensitivity Analysis

We conducted a series of exercises to evaluate alternative parameter values, exploring their impact on the outcomes. This comprehensive analysis allowed us to assess the sensitivity of the results and gain deeper insights into the model's behavior. We divided our sensitivity analysis into three sets. Table 7 summarizes the results for the calibrations we tested.

First, we tested the parameters affecting the stochastic processes for the underlying

income components. In particular, we considered alternative values for the persistence and volatility affecting the permanent and transitory components. We studied deviations above and below 15 percent from the estimated parameters for each case.

We conclude that while quantitatively different, our qualitative results hold. In particular, the welfare costs of overborrowing under imperfect information are roughly twice, and the mean tax is roughly six times larger than the respective values in the perfectly informed economy. The level of overborrowing is roughly one percentage point, and the difference between the frequency of financial crises is similar.

Second, we solved the model for different values of β to show that the differences between these economies are not due to the impatience of the household. Although our baseline model requires a relatively impatient household to match the data on debt-to-GDP and the frequency of crises. Our results hold qualitatively for a model solved using a higher β.

Finally, we switch our benchmark to a perfectly informed decentralized economy calibrated to match the same moments as in our baseline model. The primary outcome of this exercise is that in the recalibrated economy, the informed Planner opts for a mean tax comparable to the average macroprudential tax implemented by the uninformed Planner. However, as illustrated by Figure 11, the increase in the mean tax is attributed to the recalibrated Planner choosing taxes between 20 and 60 percent of external debt for a larger fraction of the time.

These differences stem from one crucial caveat in the recalibration. Given our estimated stochastic processes, the degree of impatience required to match the average debt-to-GDP ratio and the frequency of financial crises observed in the data is very high. In particular, the recalibrated economy requires an annual discount factor (β) of 0.53, which is quite low for the standard values used in the literature. Due to the higher degree of impatience implied by the recalibration, the Planner and private households in this economy hold more debt than in the baseline calibration.

Table 7: Sensitivity Analysis

	Welfare Costs		*Tax on Debt*		*Debt-to-Output Ratio*				*Probability of Crises*				*Severity of Financial Crises*											
													Consumption				*RER*				*Current Account-to-Output*			
	Perf. Info	*Imp. Info*	*Perf. Info*	*Imp. Info*	*Perf. Info*		*Imp. Info*		*Perf. Info*		*Imp. Info*		*Perf. Info*		*Imp. Info*		*Perf. Info*		*Imp. Info*		*Perf. Info*		*Imp. Info*	
					D.E	*S.P*	*D.E*	*S.P*	*D.E*	*S.P*	*D.E*	*S.P*	*D.E*	*S.P*	*D.E*	*S.P*	*D.E*	*S.P*	*D.E*	*S.P*	*D.E*	*S.P*	*D.E*	*S.P*
Baseline ($\beta = 0.83,\ \kappa = 0.335$)	0.11	0.24	9.75	11.40	-27.15	-26.16	-29.02	-28.06	4.15	1.98	5.53	1.73	-25.06	-24.55	-24.71	-21.08	66.57	62.20	70.90	59.15	17.41	14.20	15.48	8.28
$\beta = 0.90,\ \kappa = 0.335$	0.06	0.11	4.33	4.83	-25.92	-24.85	-28.12	-27.17	2.42	1.02	2.95	0.78	-22.94	-22.64	-22.15	-18.86	65.17	62.90	68.75	61.52	15.14	12.52	12.59	7.26
Recalibrated F.I Economy ($\beta = 0.53,\ \kappa = 0.3525$)	0.15	0.24	37.27	11.40	-28.95	-28.60	-29.02	-28.06	5.50	4.16	5.53	1.73	-30.53	-29.15	-24.71	-21.08	86.25	77.00	70.90	59.15	25.89	21.91	15.48	8.28
Autocorrelation ρ_g *(15 % less)*	0.12	0.25	9.97	11.59	-27.17	-26.15	-29.05	-28.06	4.25	2.01	5.54	1.75	-24.98	-24.34	-24.70	-21.10	65.93	61.03	71.35	58.77	17.32	13.92	15.59	8.08
Autocorrelation ρ_g *(15 % more)*	0.11	0.22	9.55	11.17	-27.11	-26.15	-28.99	-28.04	4.03	1.95	5.40	1.76	-25.08	-24.68	-24.51	-21.18	67.44	63.68	70.94	59.29	17.55	14.55	15.52	8.46
Volatility σ_g *(15 % less)*	0.12	0.25	10.19	11.69	-27.49	-26.49	-29.15	-28.19	4.40	2.03	5.80	1.81	-24.12	-23.41	-23.85	-20.15	65.80	61.23	69.85	58.18	17.45	14.08	15.37	8.11
Volatility σ_g *(15 % more)*	0.10	0.23	9.32	11.07	-26.82	-25.85	-28.90	-27.93	3.93	1.92	5.23	1.68	-25.98	-25.66	-25.51	-21.98	67.42	63.58	72.42	-24.53	17.38	14.38	15.68	8.40

Note: This table summarizes the key descriptive statistics for each alternative calibration tested. We measure the welfare costs as the percentage of lifetime consumption lost relative to a Social Planner sharing the same information set. The probability of a financial crisis is defined as the frequency of crises occurring every 100 years. The consumption and RER changes during a financial crisis are the percentage changes relative to their respective ergodic means when the collateral constraint binds and the economy experiences a one-standard deviation current account reversal.

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