Optimal Exchange-Rate Policy Under Collateral Constraints and Wage Rigidity

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Abstract

This paper conducts a quantitative study of the optimal exchange-rate policy in a small open economy that faces the “credit-access–unemployment” trade-off: In the presence of nominal wage rigidity, exchange-rate depreciation reduces unemployment; in the presence of collateral constraints linking debt to the value of income, exchange-rate depreciation reduces the borrowing capacity. This paper shows that the optimal policy during financial-crisis episodes is characterized by a large currency depreciation and current-account adjustment, as typically observed in emerging-market economies during sudden stops. The welfare costs of a full-employment policy are, on average, one order of magnitude lower than those of a fixed exchange-rate regime. Optimal departures from the full-employment policy can provide a rationale for managed-floating exchange-rate policies, and depend on the nature of the shocks and the level of external borrowing.

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1 Introduction

During external crises, exchange-rate policy in emerging-market economies (EMs) seem to leave policymakers between a rock and a hard place: Preventing currency depreciation could bring more unemployment, but if liabilities are denominated in foreign currency, currency depreciation could increase debt in terms of domestic income, leading to financial destabilization, and compromising credit access. The potential conflict for exchange-rate policy between these two welfare concerns, credit access and unemployment, is often a central element of the policy debate, as was observed during the East Asian and Latin American crises in the late 1990s (Fischer, 1998; Calvo, 2001; Stiglitz, 2002) and during the peripheral European crises that started in 2008 (see, for example, Krugman, 2010; Feldstein, 2011).

This paper conducts a quantitative analysis of the optimal exchange-rate policy when facing this “credit-access–unemployment” trade-off. It constructs an environment that provides a theoretical justification for this trade-off, combining two key ingredients: a downward nominal wage rigidity (as in Schmitt-Grohé and Uribe, 2014), and a collateral constraint linking debt, denominated in the international unit of account, to tradable and nontradable income (as in Mendoza, 2002). In this framework, credit access and unemployment are two conflicting factors affecting welfare: Devaluations are associated with a welfare gain – by decreasing the real value of wages they reduce involuntary unemployment – but are also associated with a welfare cost – by increasing the value of external debt in terms of domestic income, they tighten the collateral constraint and can trigger an endogenous “sudden stop.”

The main finding in calibrated versions of the model is that the optimal policy during financial-crisis episodes (or periods of binding credit constraints) generally implies a large real exchange-rate depreciation (a 14 percent fall on average in the relative price of nontradables), which is achieved by allowing for nominal currency depreciation (22 percent on average at the crisis trough), and large current-account adjustment (2 percent of output on average), as typically observed in EM data during sudden-stop episodes. The first reason for this result is that the welfare costs related to intertemporal misallocation of consumption are typically smaller than the welfare costs related to higher unemployment. For instance, during financial crises, the welfare costs of a full-employment exchange-rate policy, are 20 percent of those of a fixed exchange-rate regime (an average welfare cost during periods of binding collateral constraints of 0.13 percent and 0.75 percent of consumption per period, respectively).\(^2\) The second reason for this result is that, even when borrowing is required to finance imported inputs or investment in

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1 Calvo (1998) labeled sudden stops episodes of large and abrupt reversals in external credit flows that characterize EMs. For a review of the Fisherian debt-deflation approach to sudden stops, including the form of collateral constraint used in this paper, see Korinek and Mendoza (2013).

2 Fixed exchange-rate regimes are also costly because they induce an inefficient adjustment to negative shocks with involuntary unemployment in periods of nonbinding collateral constraints.
physical capital, and credit access also affects production, preventing currency depreciation is an inefficient way of relaxing credit constraints, considering the unemployment costs associated with the increased collateral values.

During the average episode of binding collateral constraint, although the full-employment policy has relatively small welfare costs, the optimal currency depreciation is half of that of the full-employment policy. Thus, the framework of this paper also provides a rationale for a managed-floating exchange-rate policy, frequently observed in EMs during financial crises (see, for example, Calvo and Reinhart, 2002). The paper shows that the nature of the shocks, the state of the economy, and the structural characteristics of the economy are key determinants for the optimal degree of “fear of floating” during financial crises: Higher external interest rates, a larger intratemporal elasticity of substitution, or a large mobility of labor across sectors calls for a smaller unemployment; a more elastic labor supply, a higher share of income that can be pledged as collateral, or a higher external debt level calls for more contained currency depreciation. As an example of the latter, the paper studies the case of Latvia and the recent Euro crisis, in which a high external debt level would lead to an optimal policy characterized by contained currency depreciation and higher unemployment levels than those observed in the data.

Relationship with the Literature. This paper is related to several branches of the literature. First, it is related to the literature that has studied sudden stops as the endogenous response of an economy with currency mismatch to real currency exchange-rate depreciation. Mendoza (2002) formalized this argument by considering an environment in which debt is linked to the value of tradable and nontrade income, which can lead to endogenous sudden stops through Fisher’s (1933) debt-deflation mechanism: Binding constraints lead to deleveraging, which leads to a fall in the price of nontradables, which further tightens the collateral constraint. This form of financial friction has then been widely studied in the literature to capture the main stylized facts about sudden stops in EMs (see, for example, Mendoza, 2005; Durdu, Mendoza, and Terrones, 2009; Korinek, 2011; Bianchi, 2011; Benigno et al., 2011, 2012a,b,c). The present paper is the first in studying nominal exchange-rate policy in an environment featuring this form of financial friction. Previous studies have typically considered real models, in which the policy instrument during periods of binding collateral constraints is a tax (subsidy) on nontradable or tradable goods (see, for example, Benigno et al., 2012a). The present paper expands this literature by considering a nominal model and a monetary instrument, which present the policymaker a different trade-off: While subsidizing nontradable goods leads simultaneously to increased employment and higher prices of nontradable goods (relaxing the credit constraint), currency depreciation leads to an increase in employment and a decrease in the price of non-
tradable goods (tightening the credit constraint).\footnote{Appendix D.5 shows that in the model economy studied in the present paper, using taxes on nontradable or tradable consumption together with the capital-control tax, a Ramsey planner can achieve an allocation characterized by full employment and nonbinding collateral constraint in all states (as Benigno et al., 2012b, show in an economy without wage rigidity), eliminating the trade-off that exchange-rate policy faces between credit access and unemployment.}

The paper is also related to the large body of literature studying nominal exchange-rate policy during financial crises. A key difference with respect to this literature is the form of financial friction studied in the present paper, which in turn leads to different policy implications. For instance, in a large subset of this literature, borrowing access is linked to asset prices: Cespedes, Chang, and Velasco (2004), Devereux, Lane, and Xu (2006), Cúrdia (2009), and Gertler, Gilchrist, and Natalucci (2007) study economies featuring the financial accelerator mechanism (Bernanke, Gertler, and Gilchrist, 1999). In a recent related paper, Fornaro (2015) studies an economy with a collateral constraint that limits external debt to a fraction of the market value of asset holdings (as in Bianchi and Mendoza, 2011). In these frameworks, currency depreciation leads to higher asset prices and improved credit access. In the present setup, borrowing capacity is linked to the value of income. In this environment, the combination of a nontradable sector and liability dollarization creates a currency mismatch that makes currency depreciation financially destabilizing (in line with the traditional “original sin” argument; see Eichengreen, Hausmann, and Panizza, 2005; Calvo, 1999).\footnote{The concern that currency depreciation can be financially destabilizing goes back at least to Keynes, who, when the Great Depression started, recommended against devaluation, claiming that the costs in terms of debt revaluation and financial destabilization would outweigh the benefits (Irwin, 2011). In the same line, Diaz-Alejandro (1965), analyzing Argentina’s exchange-rate policy in the 1950s, highlighted the possibility that devaluations would lead to negative wealth effects and adjustment in consumption from income distribution and balance-sheet effects.}

The hypothesis of currency depreciations being financially destabilizing has been previously formalized, for instance, in Aghion, Bacchetta, and Banerjee (2001), and Braggion, Christiano, and Roldos (2009) using credit constraints on firms. In these papers, however, currency depreciations are financially destabilizing because they cause output contraction. Empirical evidence on contractionary devaluations has been mixed (see Bahmani-Oskooee and Miteza, 2003 for a survey). The present paper shows that even if currency depreciations are not contractionary, but the associated currency mismatch reduces the value of income, this can still lead to a large consumption adjustment under binding credit constraints and entailing a welfare cost. For these reasons, the form of financial friction considered in this paper gives rise to a trade-off between credit access and unemployment that has not been formally studied in the literature of exchange-rate policy.

Finally, it is worth noting that, while most of the above-mentioned literature on nominal exchange-rate policy during financial crises compares different (possibly nonoptimal) exchange-
rate regimes, the present paper derives the fully optimal exchange-rate policy. The paper shows that the optimal allocation is a nonmonotonic function of the states; therefore, considering the optimal policy, instead of comparing exchange-rate regimes, is relevant.

**Layout.** The rest of the paper is organized as follows. Section 2 presents the model economy. Section 3 defines three possible exchange-rate regimes in this setup (optimal, full-employment, and fixed exchange-rate policies), provides analytical results describing the exchange-rate-policy trade-off that emerges in this economy, and empirical evidence supporting the key mechanisms of the policy trade-off. Section 4 presents the quantitative analysis comparing the aggregate dynamics and welfare under the three exchange-rate regimes. Section 5 studies additional considerations from exchange-rate policy that have been provided in the literature: imported inputs that require external borrowing, physical capital, and high external debt (with a special focus on Latvia and the recent Euro crisis). Section 6 concludes.

### 2 The Model Economy

This section describes the model economy used to conduct exchange-rate policy analysis. It extends the two-sector (tradable and nontradable), dynamic, stochastic, small open economy model with a downward nominal wage rigidity from Schmitt-Grohé and Uribe (2014), to include a collateral constraint linking debt to the value of tradable and nontradable income. The economy only has access to a one-period, non-state-contingent debt instrument, which is denominated in units of tradable goods and captures liability dollarization. The model then features a nominal rigidity and financial frictions that will interact to determine the exchange-rate-policy trade-off.

Tradables are endowed to the economy, and their price is determined by the law of one price. Nontradables are produced by the economy, and their price is determined by domestic demand and supply. Fluctuations in the small open economy are driven by exogenous shocks to the value of the tradable endowment (which can be interpreted as shocks to terms of trade or to productivity in the tradable sector), to total factor productivity (TFP) in the nontradable sector, and to the interest rate on external debt, three sources of business-cycle fluctuations that have been widely studied in EMs (Mendoza, 1995; Neumeyer and Perri, 2005; Uribe and Yue, 2006).

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5Optimal monetary policy has been largely studied in open economies with complete asset markets, and in open economies in which the financial friction is that financial markets are incomplete (see, for example, Clarida, Gali, and Gertler, 2001; Schmitt-Grohé and Uribe, 2001; Devereux and Engel, 2003; Corsetti and Pesenti, 2005; Gali and Monacelli, 2005; De Paoli, 2009a,b; Corsetti, Dedola, and Leduc, 2010; Schmitt-Grohé and Uribe, 2014). The present paper constitutes a contribution in this direction for a small open economy in which financial frictions include an imperfect access to credit markets, with the presence of occasionally binding collateral constraints.
2.1 Households

Households’ preferences over consumption are described by the expected utility function:

\[ E_0 \sum_{t=0}^{\infty} \beta^t U(c_t), \tag{1} \]

where \( c_t \) denotes consumption in period \( t \); \( U : \mathbb{R}_+ \rightarrow \mathbb{R} \) is a twice continuously differentiable, strictly increasing, strictly concave function; the subjective discount factor, \( \beta \in (0, 1) \), and \( E_t \) denotes expectation conditional on the information set available at time \( t \).

The consumption good is assumed to be a composite of tradable and nontradable goods, with a constant elasticity of substitution (CES) aggregation technology:

\[ c_t = A(c^T_t, c^N_t) = \left[ a\left(\frac{c^T_t}{c^N_t}\right)^{1-\frac{1}{\xi}} + (1 - a)\left(\frac{c^N_t}{c^T_t}\right)^{1-\frac{1}{\xi}}\right]^{\frac{\xi}{\xi-1}}, \tag{2} \]

where \( c^T_t \) denotes tradable consumption and \( c^N_t \) denotes nontradable consumption.

Each period, households receive a stochastic endowment \((y^T_t)\) and profit from the ownership of firms producing nontradable goods \((\Pi_t)\). They inelastically supply \( h \) hours of work to the labor market. (Appendix D.3 relaxes these assumptions, studying production in the tradable sector and an elastic labor supply.) Due to the presence of the wage rigidity (discussed in detail in the next sections), households will only be able to sell \( h_t \leq \bar{h} \) hours in the labor market. The actual hours worked \((h_t)\) is determined by firms and taken as given by the households.

Households have access to a one-period, non-state-contingent bond denominated in units of tradable goods that can be traded internationally paying an exogenous and stochastic gross interest rate \( R_t \). The model therefore assumes full liability dollarization. Debt acquired in period \( t \) is taxed at rate \( \tau^d_t \). (Section 3 discusses the role of the tax on external debt; Appendix D.4 considers an economy without this instrument.) Households’ sequential budget constraint is therefore given by

\[ \frac{d_{t+1}}{R_t} \left(1 - \tau^d_t\right) = d_t + c^T_t + p_t c^N_t - (y^T_t + w_t h_t + \Pi_t) - T_t, \tag{3} \]

where \( d_{t+1} \) denotes the level of debt assumed in period \( t \) and due in period \( t+1 \), \( p_t \equiv \frac{p^N_t}{p^T_t} \) denotes the relative price of nontradables in terms of tradables, \( w_t \) denotes the wage rate in terms of tradable goods, and \( T_t \) denotes a lump sum transfer in period \( t \).

It is assumed that households face a collateral constraint by which debt cannot exceed a fraction \( \kappa > 0 \) of income:

\[ d_{t+1} \leq \kappa \left(y^T_t + w_t h_t + \Pi_t\right). \tag{4} \]

This form of collateral constraint, introduced in Mendoza (2002), has been used extensively in the literature on small open economies to capture the effect of currency mismatch on external...
credit-market access: While collateral includes income from both tradable and nontradable sectors, external debt is fully denominated in units of tradables.\textsuperscript{6} Section 3.2.2 reviews empirical evidence providing support for this form of credit constraint.

In addition, households are assumed to face a no-Ponzi-game constraint of the form

$$d_{t+1} \leq d^N,$$

where $d^N$ denotes the \textit{natural debt limit}.\textsuperscript{7} As in Aiyagari (1994), this is defined as the maximum value of external debt that the household can repay almost surely starting from that period, assuming that its tradable consumption is zero forever. Formally, denoting $y^T_t$ as the minimum possible level of tradable endowment and $R$ as the maximum possible level of external interest rate, the natural debt limit is defined as $d^N \equiv \frac{R}{R-1}y^T_t$.

The household problem is to choose state-contingent plans for $c_t$, $c^T_t$, $c^N_t$, and $d_{t+1}$ that maximize the expected utility (1) subject to the consumption aggregation technology (2), the sequential budget constraint (3), the collateral constraint (4), and the no-Ponzi game constraint (5), for a given initial debt level, $d_0$; for the given sequence of prices, $w_t$ and $p_t$; for the given sequence of hours worked, $h_t$, profits, $\Pi_t$, stochastic tradable endowment, $y^T_t$, and interest rate, $R_t$; and for the given sequence of policies, $\tau^d_t$ and $T_t$. Denoting by $\lambda_t$ the Lagrange multiplier associated with the budget constraint (3) and by $\mu_t$ the Lagrange multiplier associated with the collateral constraint (4), the optimality conditions (provided $d_{t+1} < d^N$) are (2), (3), and (4), with the first-order conditions

$$\lambda_t R_t^{-1} \left(1 - \tau^d_t\right) = \beta E_t \lambda_{t+1} + \mu_t,$$

$$U_{cT} (c^T_t, c^N_t) = \lambda_t,$$

$$\left(1 - \frac{a}{\kappa}\right) \left(\frac{c^T_t}{c^N_t}\right)^{\frac{1}{\xi}} \equiv P (c^T_t, c^N_t) = p_t,$$

and the complementary slackness conditions

$$\mu_t \geq 0, \mu_t \left(\kappa \left(y^T_t + w_t h_t + \Pi_t\right) - d_{t+1}\right) = 0.$$\textsuperscript{8}

\textsuperscript{6} Korinek (2011) shows that this form of the collateral constraint can be rationalized as a renegotiation-proof form of debt contract in an imperfect credit market in which households can renegotiate external debt and lenders can extract at most a fraction of borrowers’ current income if debt is renegotiated. Bianchi and Mendoza, 2013 derive a similar constraint linking debt to the market value of assets as an incentive compatibility constraint from a limited enforcement problem.

\textsuperscript{7}Since the collateral value in the credit limit (4) depends on relative prices which can be affected by policy variables, constraint (5) is imposed in addition to (4) to prevent Ponzi schemes induced by the policymaker (Mendoza, 2005; Benigno et al., 2012b).
2.2 Firms

Each period, operating in competitive labor and product markets, firms hire labor to produce the nontradable good, \( y_t^N \). Profits each period are given by

\[
\Pi_t = p_tZ_tF(h_t) - w_t h_t,
\]

where \( Z_t \) denotes an exogenous and stochastic productivity shock, and \( F : \mathbb{R}_+ \to \mathbb{R} \) is a twice continuously differentiable, strictly increasing, strictly concave function.

The firms’ problem is to choose \( h_t \) to maximize profits given prices \( p_t \) and \( w_t \). The first-order condition of this problem is

\[
p_t Z_tF'(h_t) = w_t.
\]

This condition implicitly defines the firms’ demand for labor.

2.3 The Labor Market

Nominal wages \( (W_t) \) are assumed to be downwardly rigid as in Schmitt-Grohé and Uribe (2014):

\[
W_t \geq \gamma W_{t-1},
\]

for \( \gamma > 0 \). Section 3.2.2 reviews empirical evidence supporting this form of wage rigidity.

It is assumed that the law of one price holds for tradable goods, implying that \( P_t^T = E_t P_t^{T*} \), where \( E_t \) is the nominal exchange rate and \( P_t^{T*} \) is the foreign-currency price of tradable goods. Assuming that \( P_t^{T*} \) is constant and normalized to one, wages in terms of tradable goods \( (w_t) \) can be expressed as

\[
w_t = \frac{W_t}{E_t}.
\]

From this, the wage rigidity can be expressed as

\[
w_t \geq \gamma \frac{w_{t-1}}{\epsilon_t},
\]

where \( \epsilon_t \) is the gross depreciation rate of the nominal exchange rate: \( \epsilon_t \equiv \frac{E_t}{E_{t-1}} \).

Actual hours worked cannot exceed the inelastically supplied level of hours:

\[
h_t \leq \overline{h}.
\]

When the nominal wage rigidity binds, the labor market can exhibit involuntary unemployment, given by \( \overline{h} - h_t \). This implies a slackness condition must hold at all dates and states:

\[
\left( w_t - \gamma \frac{w_{t-1}}{\epsilon_t} \right) \left( \overline{h} - h_t \right) = 0.
\]

This condition means that when the nominal wage rigidity is not binding, the labor market must exhibit full employment, and if it exhibits unemployment, it must be the case that the nominal wage rigidity is binding.
2.4 The Government

The government determines the exchange-rate depreciation, $\epsilon_t$, and imposes a proportional tax (subsidy) on debt $\tau^d_t$, which is rebated lump sum to households ($T_t$), to balance its budget each period:

$$\frac{d_{t+1} \tau^d_t}{R_t} = T_t. \quad (14)$$

Section 3 defines different exchange-rate regimes and how the capital-control tax is determined.

2.5 General Equilibrium Dynamics

The market for nontradable goods clears at all times:

$$c^N_t = Z_t F(h_t). \quad (15)$$

Combining the equilibrium price equation, (8), with condition (15), the firms’ optimality condition, (10), can be expressed as

$$w_t = \left(1 - \frac{a}{a} \right) \left(c^T_t \right)^{\frac{1}{\bar{\xi}}} Z^{1 - \frac{1}{\bar{\xi}}} F \left( h_t \right)^{-\frac{1}{\bar{\xi}}} F' \left( h_t \right). \quad (16)$$

Combining condition (15) with the households’ budget constraint, (3), the definition of the firms’ profits, and the government’s budget constraint, (14), the resource constraint of the economy becomes

$$\frac{d_{t+1}}{R_t} = d_t + c^T_t - y^T_t. \quad (17)$$

Using the definition of firms’ profits, the equilibrium price equation, (8), and the market-clearing condition for nontradables, (15), the collateral constraint, (4), can be reexpressed as

$$d_{t+1} \leq \kappa \left( y^T_t + \left(1 - \frac{a}{a} \right) \left(c^T_t \right)^{\frac{1}{\bar{\xi}}} Z^{1 - \frac{1}{\bar{\xi}}} F \left( h_t \right)^{1 - \frac{1}{\bar{\xi}}} \right) \equiv \tilde{d} \left( h_t, c^T_t, s^X_t \right). \quad (18)$$

where $s^X_t \equiv \left[ y^T_t \quad R_t \quad Z_t \right]'$ denote the vector of exogenous states, which is assumed to follow a first-order Markov process.

The general equilibrium dynamics are then given by stochastic processes $\{c^N_t, c^T_t, h_t, p_t, w_t, d_{t+1}, \lambda_t, \mu_t, T_t\}_{t=0}^\infty$ satisfying the set of equations (GE): $\{(5), (6), (7), (8), (9), (11), (12), (13), (14), (15), (16), (17), (18), (51), (52), (53), (54)\}$, given an exchange-rate policy $\{\epsilon_t\}_{t=0}^\infty$, a capital-control tax policy $\{d^d_t\}_{t=0}^\infty$, initial conditions $w_{-1}$ and $d_0$, and exogenous stochastic processes $\{s^X_t\}_{t=0}^\infty$.

3 Exchange-Rate Regimes: Definitions, Analytical Results, and Empirical Evidence

This section formally defines the optimal exchange-rate policy and discusses the trade-off between credit access and unemployment the exchange-rate policy can face in the model economy.
presented in the previous section. Empirical evidence supporting this trade-off is discussed. Analytical results relating credit access and unemployment are established, providing a framework for understanding the quantitative characterization of the optimal exchange-rate policy to be presented in the next section. Two additional exchange-rate regimes are also defined in this section – full-employment and fixed – to provide standard benchmarks for the study of the optimal exchange-rate policy.

3.1 Definition of Exchange-Rate Regimes

This section defines three possible exchange-rate regimes: optimal, full-employment, and fixed. Exchange-rate regimes are defined conditional on an optimal capital-control tax policy ($\tau_d^t$). The reason for using this capital-control tax is twofold. First, previous literature has shown that both the credit constraint and the downward wage rigidity considered in this paper embody a pecuniary externality that may induce inefficient external borrowing (Bianchi, 2011; Benigno et al., 2012a; Schmitt-Grohé and Uribe, 2014).\(^8\) The optimal capital-control tax eliminates any borrowing inefficiency, and allows for a comparison across exchange-rate regimes isolating the effect of exchange-rate policy from this distortion.

Second, without the optimal capital-control tax, the set of restrictions for the optimal policy includes a forward-looking constraint (namely, the household’s intertemporal borrowing decision (6)). As shown in Kydland and Prescott (1977), Bellman’s (1957) principle of optimality fails in this context, and standard dynamic programming techniques cannot be applied. Using an optimal capital-control tax technically simplifies the problem, allowing for the use of standard dynamic programming techniques. Nevertheless, Appendix D.4 studies the sensitivity of the optimal exchange-rate policy to the assumption of optimal capital-control taxes by restricting the Ramsey planner’s set of available instruments to the nominal exchange rate. In this context, time-invariant optimal policies under commitment are obtained using the recursive saddlepoint method developed in Marcet and Marimon (2011).\(^9\)

**Optimal Exchange-Rate Policy.** The optimal exchange-rate policy with optimal capital-control taxes is defined as follows:

\(^8\)Inefficient borrowing arises when the social costs of borrowing differ from the private costs of borrowing. Bianchi (2011) shows that in an endowment economy, the collateral constraint in the form of tradable and nontradable income induces overborrowing, in the sense that the social costs of borrowing exceed the private costs of borrowing; in this setup, the constrained social planner borrows less than the competitive equilibrium. Benigno et al. (2011, 2012a) define overborrowing (underborrowing) as a situation in which a constrained social planner would take on less (more) debt than decentralized agents; in this sense, the authors find that whether an economy with this form of collateral constraint features overborrowing or underborrowing depends on the structure of the economy (e.g., endowment or production), and on the calibration. Schmitt-Grohé and Uribe (2014) show that the downward wage rigidity, combined with a fixed exchange-rate policy, induces overborrowing.
Definition 1. The optimal exchange-rate policy with optimal capital-control taxes is the set of processes \( \{ \epsilon_t, \tau^d_t \} \) that maximize households’ expected lifetime utility (1) subject to the set of equations describing the general equilibrium dynamics (GE).

Appendix A shows that any \( \{ d_{t+1}, c^T_t, h_t \} \) that satisfy (5), (12), (17), and (18) also satisfy (GE). The Ramsey problem is then to maximize (1) with respect to \( \{ d_{t+1}, c^T_t, h_t \} \), subject to (5), (12), (17), and (18). The dynamics under the optimal exchange-rate policy with optimal capital-control taxes can be thus expressed with the Bellman equation,

\[
V^{OP} (s^X, d) = \max_{d', c^T, h} \left[ U \left( A \left( c^T, ZF \left( h \right) \right) \right) + \beta \mathbb{E}_{s^X'} V^{OP} (s'^X, d') \right]
\]

subject to
\[
\frac{d'}{R} = d + c^T - y^T,
\]
\[
d' \leq \tilde{d} \left( h, c^T, s^X \right),
\]
\[
d' \leq d^N,
\]
\[
h \leq \tilde{h},
\]

where time subscripts for variables dated in period \( t \) have been dropped, and a prime is used to indicate variables dated in period \( t + 1 \); \( V^{OP} (s^X, d) \) denotes the value function for households under optimal exchange-rate and capital-control–tax policies. This formulation will be used in the quantitative analysis.

Full-Employment Exchange-Rate Policy. For this regime, consider an exchange-rate policy aimed at maintaining full employment at all states and dates: Under the full-employment policy,

\[
h_t = \tilde{h}, \ \forall t.
\]

Definition 2. The full-employment exchange-rate policy with optimal capital-control taxes is the set of processes \( \{ \epsilon_t, \tau^d_t \} \) that maximize households’ expected lifetime utility (1) subject to the set of equations describing the general equilibrium dynamics (GE), and the full-employment constraint (20).

Appendix A shows that any \( \{ d_{t+1}, c^T_t, h_t \} \) that satisfy (5), (17), (18), and (20) also satisfy (GE) and (20). Therefore, the dynamics under the full-employment exchange-rate policy with optimal capital-control taxes can be expressed with the Bellman equation,

\[
V^{FE} (s^X, d) = \max_{d', c^T} \left[ U \left( A \left( c^T, ZF \left( \tilde{h} \right) \right) \right) + \beta \mathbb{E}_{s^X'} V^{FE} (s'^X, d') \right]
\]

subject to
\[
\frac{d'}{R} = d + c^T - y^T,
\]
\[
d' \leq \tilde{d} \left( h, c^T, s^X \right),
\]
\[
d' \leq d^N,
\]

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where \( V^{\text{FE}}(s^X, d) \) denotes the value function for households under the full-employment exchange-rate policy with optimal capital-control taxes.

**Fixed Exchange-Rate Policy.** Finally, consider a policy aimed at keeping the exchange rate fixed at all states and dates:

\[ \epsilon_t = 1, \quad \forall t. \] (22)

**Definition 3.** The fixed exchange-rate policy with optimal capital-control taxes is the set of processes \( \{ \epsilon_t, \tau_t^d \} \) that maximize households’ expected lifetime utility (1) subject to the set of equations describing the general equilibrium dynamics (GE), and currency peg constraint (22).

Appendix A shows that any \( \{ d_{t+1}, c_T^T, h_t, w_t, \epsilon_t \} \) that satisfy (5), (11)–(13), (16)–(18), and (22) also satisfy (GE) and (22). Thus, the dynamics under the currency peg with an optimal capital-control-tax policy can be expressed with the Bellman equation,

\[
V^{\text{PEG}}(s^X, d, w_{-1}) = \max_{d', c_T^T, h, w} \left[ U(A(c_T^T, ZF(h))) + \beta \mathbb{E}_{s^X} V^{\text{PEG}}(s^{X'}, d', w) \right]
\] (23)

where \( V^{\text{PEG}}(s^X, d, w_{-1}) \) denotes the value function for households under the currency peg and optimal capital-control taxes and the subscript \( -1 \) is used to indicate variables dated in period \( t - 1 \).

### 3.2 Optimal Exchange-Rate Policy, Unemployment and Credit Limit: Analytical Results and Empirical Evidence

This section studies the relationship between unemployment and the credit limit under the optimal exchange-rate policy. Although, given the complexity of the model, a numerical solution is required for a full characterization, some analytical results can be obtained to show the trade-off involved in exchange-rate policy. These results will be relevant to understanding the next section’s numerical solution for the dynamics of the economy under the optimal exchange-rate policy. Proposition 1 characterizes the allocation under the optimal exchange-rate policy defined in the previous section.
Proposition 1. Under the optimal exchange-rate policy with optimal capital-control taxes (Definition 1), the following conditions hold at all dates and states.

- If $\xi < 1$, 
  \[
  (\bar{h} - h_t) \left( \bar{d} (h_t, c_T, s_X) - d_{t+1} \right) = 0.
  \]

- If $\xi \geq 1$, 
  \[ h_t = \bar{h}. \]

Proof. See Appendix B.

Two conclusions follow from this result. First, the allocation under the optimal exchange-rate policy and the capital-control tax features no unemployment under no binding collateral constraints. Given that the capital-control tax eliminates any inefficient borrowing, eliminating unemployment when the credit constraint does not bind leads to a welfare gain (a higher consumption of nontradables), without any welfare cost.9

Second, unemployment under the optimal exchange-rate policy depends on the intratemporal elasticity of substitution. If the intratemporal elasticity of substitution is greater than or equal to one, the full-employment policy regime is the optimal policy regime. If the intratemporal elasticity of substitution is less than one, a slackness condition is established between unemployment and the collateral constraint: If the collateral constraint is not binding, the labor market must exhibit full employment, and if there is unemployment, the collateral constraint must be binding. As discussed in Section 3.2.2, empirical evidence from EMs provides wide support for the intratemporal elasticity of substitution being less than one. To understand the role of the intratemporal elasticity of substitution and the interaction between unemployment and the collateral constraint under the optimal exchange-rate policy, a discussion is in order regarding the trade-off facing exchange-rate policy in this economy.

3.2.1 The Credit-Access–Unemployment Trade-Off

Parallel to the traditional inflation–unemployment trade-off in the New Keynesian literature, the exchange-rate policy in this economy may face a “credit-access–unemployment” trade-off. Under binding nominal downward wage rigidity, a depreciation of the nominal exchange rate decreases real wages and, thus, helps reduce unemployment. But it is also associated with a real exchange-rate depreciation, which decreases the value of nontradable output in tradable units. Recall that the collateral in this economy is given by the value, in tradable units, of tradable and nontradable output. Accordingly, if the price effect (real exchange-rate depreciation) dominates the quantity

---

9 Note that, given that the small open economy has access only to external bonds denominated in units of tradables, while the presence of incomplete financial markets leads to inefficient consumption fluctuations relative to an economy with complete asset markets, eliminating unemployment does not lead to more inefficient consumption fluctuations. For related literature studying the risk-sharing channel of monetary policy with incomplete markets, see De Paoli (2009b) and Corsetti, Dedola, and Leduc (2010).
effect (employment increase), an exchange-rate depreciation can decrease the collateral value and tighten the credit limit. The price effect dominates the quantity effect if the intratemporal elasticity of substitution between tradables and nontradables is less than one ($\xi < 1$). As discussed in the next section, this assumption is widely supported by empirical evidence from EMs. Under this assumption, the following proposition can be established.

**Proposition 2.** If $\xi < 1$, given an initial state $(s_t^X, d_t)$, for any debt level $d_{t+1}^*$ with associated tradable consumption $c_{t}^{T*} = (d_t^* R_t^{-1} - d_t + y_t^T) > 0$ for which $d_{t+1}^* > \overline{d}(\overline{h}, c_{t}^{T*}, s_t^X)$, there exists a level of employment, $h_t^* \in (0, \overline{h})$, for which $d_{t+1}^* = \overline{d}(h_t^*, c_{t}^{T*}, s_t^X)$.

**Proof.** See Appendix B.

This result shows that for any debt level that does not satisfy the credit limit under full employment, there exists a level of employment below full employment for which the real exchange rate is sufficiently appreciated to ensure the credit limit is satisfied for that debt level. This result stems from the fact that if the intratemporal elasticity of substitution is less than one, the collateral constraint is decreasing in the level of employment.$^{10}$ This provides a theoretical justification for the existence of the exchange-rate policy debate, typically observed during financial crises in EMs, that weighs the two policy objectives. The optimal choice under this trade-off can be characterized using the first-order conditions of the optimal policy problem (19).

**Remark 1.** If $\xi < 1$, in an allocation under the optimal exchange-rate policy with optimal capital-control taxes (Definition 1) in which, at time $t$, $h_t < \overline{h}$, then two conditions hold:

\[
U_c A_N (c_t^T, ZF (h_t)) = \phi_t^\mu \left( \frac{1 - \xi}{\xi} \right) \kappa P (c_t^T, ZF (h_t)),
\]

\[
\phi_t^\mu = \left( \frac{\phi_t^F}{R_t} - \beta E_t \phi_{t+1}^F \right),
\]

where $\phi_t^\mu$ and $\phi_t^F$ denote the nonnegative multipliers associated with the collateral constraint (18) and the resource constraint (17), respectively, in the Ramsey problem of optimal exchange-rate policy with optimal capital-control taxes.

**Proof.** See Appendix B.

Equation (24) shows that in any optimal allocation in which there is unemployment, the Ramsey planner equates the marginal benefit of increasing employment, given by the marginal utility of nontradable consumption, to its marginal cost in terms of tightening the collateral

---

$^{10}$If the intratemporal elasticity of substitution is greater than or equal to one ($\xi \geq 1$), the credit access–unemployment trade-off vanishes, as implied by Proposition 1. In particular, if the intratemporal elasticity of substitution is equal to one ($\xi = 1$), employment does not influence the collateral constraint. If the intratemporal elasticity of substitution is greater than one ($\xi > 1$), the credit-access–unemployment trade-off overturns, and a decrease in unemployment also helps relax the collateral constraint.
constraint. Equation (25) shows that the shadow price of relaxing the credit constraint for the Ramsey planner, $\phi^R_t$, is the wedge between the current shadow value of wealth for the Ramsey planner and the expected value of reallocating wealth to the next period.

### 3.2.2 Empirical Evidence for the Trade-Off Mechanisms

The credit-access–unemployment trade-off hinges on three key mechanisms: the value of income affecting borrowing capacity, currency depreciation having a negative effect on the value of income, and currency depreciation reducing the value of real wages. This section provides empirical support for each of these mechanisms.

**Credit-Access and Income.** The collateral constraint considered in this paper links debt to the value of income. Two branches of the empirical literature provide evidence supporting this link between credit-access and income. First, several studies using household-level data have documented that current income is a significant determinant of the probability that a household is credit constrained. This is the case, for instance, in Jappelli (1990), Crook (2001), and Gropp, Scholz, and White (1997) for the US economy, and Guiso, Jappelli, and Terlizzese (1996) and Crook and Hochguertel (2007) for other OECD economies (see Crook, 2006, and Jappelli and Pistaferri, 2010, for related surveys).

Second, a number of macroeconomic studies of EMs have documented that debt-to-GDP ratio is an important determinant for the capacity of these economies to borrow from international markets. For instance, Reinhart, Rogoff, and Savastano (2003) document that EMs seem to exhibit difficulty in supporting debt-to-GDP levels above certain thresholds observed in developed-market economies. Edwards (2004) shows that the external debt-to-GDP level is a significant determinant of the probability that EMs experience a sudden stop. Schirmmelpfennig, Roubini, and Manasse (2003) show that the external debt-to-GDP level is a significant determinant of the probability of an EM experiencing a debt crisis.

**Income and Currency Depreciation.** As shown in Propositions 1 and 2, a tension exists between credit access and unemployment only if the elasticity of substitution between tradable and nontradable goods is less than one ($\xi < 1$). If this is the case, tradable and nontradable goods are gross complements, and the price effect (real exchange-rate depreciation) associated with increasing employment dominates the quantity effect (employment increase). As a result, exchange-rate depreciation can decrease the value of income, decreasing the value of the collateral in the model.

There is wide support from the empirical literature for the intratemporal elasticity of substitution being less than one. In a sample of developed and emerging-market economies, Stockman
and Tesar (1995) estimate a value of the elasticity of substitution at 0.44. Separating the samples into developed and emerging economies, Mendoza (1995) finds values of the elasticity of 0.74 and 0.43, respectively. Studying EMs, González-Rozada et al. (2004) found estimates in the range between 0.4 and 0.48 for Argentina, and Lorenzo, Aboal, and Osimani (2005) found estimates in a range between 0.46 and 0.75 for Uruguay. Moreover, following this empirical literature, the studies referenced in the present paper that calibrate a two-sector, small open economy model generally use a value for the elasticity of substitution in the range between 0.44 and 0.83.

**Real Wages and Currency Depreciation.** In the environment considered in this paper, nominal wages are downwardly rigid. Therefore, real wages can be affected by inflation following currency depreciation. The assumption of a downward nominal wage rigidity is supported by several empirical studies using microeconomic data as Gottschalk (2005), Barattieri, Basu, and Gottschalk (2010), and Daly, Hobijn, and Lucking (2012), for the US economy. It is also consistent with macroeconomic studies focused on wage adjustment during recession episodes. For instance Schmitt-Grohé and Uribe (2014) document that the adjustment of wages following the 2001 Argentinean crisis and the recent crisis in the Euro Area is consistent with downward nominal wage rigidity. Calvo, Coricelli, and Ottonello (2014), using a sample of financial crises in developed, and emerging-market economies, show that, unlike episodes with low inflation, episodes with high inflation display a significant a persistent adjustment of real wages, which is consistent with the presence of nominal wage rigidity.

**4 Quantitative Analysis**

The objective of this section is to quantitatively characterize the aggregate dynamics of the model economy under the optimal exchange-rate policy and to compare its performance, in terms of welfare, to that under the full-employment and the fixed exchange-rate policies, both during periods of financial crises and under regular business-cycle fluctuations.

**4.1 Calibration and Computation**

To characterize the aggregate dynamics under the different exchange-rate regimes, calibrated versions of the functional equations (19), (21) and (23) are solved numerically. Due to the presence of occasionally binding constraints, I resort to the value-function-iteration method over a discretized state space to compute the numerical solutions.

---

11 Ostry and Reinhart (1992) found evidence inconclusive in this respect with estimates between 0.66 and 1.44, depending on the EM region and the instrumental variable considered. For a survey on the methodologies used to estimate the elasticity of substitution between tradable and nontradable goods, see Akinci (2011).
As mentioned in Section 2, the consumption aggregator is assumed to be a CES aggregator. I also assume a constant relative risk aversion utility function and an isoelastic form for the production function:

\[ U(c) = \frac{c^{1-\sigma} - 1}{1-\sigma}, \]

\[ F(h) = h^\alpha. \] (26)

The model is calibrated at the annual frequency, to match Argentinean data. Argentina is used as a benchmark to conduct this exercise as an EM country whose exchange-rate regimes and financial crises have been widely studied. All parameter values used in the baseline calibration are shown in Table 1. The inverse of the intertemporal elasticity of substitution is set to \( \sigma = 2 \), a standard value in the business-cycle literature for small open economies (see, for example, Mendoza 1991). The intratemporal elasticity of substitution is set to \( \xi = 0.44 \), using the estimates of González-Rozada et al. (2004) for Argentina. (See Section 3.2 for a review of the literature on this parameter.) I set \( \alpha = 0.75 \), following the evidence in Uribe (1997) on the labor share in the nontradable sector in Argentina, and \( \gamma = 0.96 \), following the evidence in Schmitt-Grohé and Uribe (2014) on downward nominal wage rigidity. The mean level of tradable output and the labor endowment \( (\bar{h}) \) are normalized to one. The parameters \( \{\beta, a, \kappa\} \) are used to match three key moments in the ergodic distributions of the model under the optimal exchange-rate policy to the ones observed in historical Argentinean data (for the period 1975–2011). The three data moments considered are typically targeted in the related literature (following Bianchi, 2011): an average level of external debt-to-GDP ratio of 21 percent, a share of tradable output in GDP of 32.9 percent, and a frequency of sudden stops of 5.5 percent. A sudden stop in the model is defined as a period in which the economy exhibits a change in the current account larger than one standard deviation, following Eichengreen, Gupta and Mody (2006), from which the frequency of sudden stops is obtained for a sample of EMs.\(^{12}\) (See the Data Appendix C for further details on data sources, and on the construction of the series.) The parameter values obtained from minimizing the squared difference between the model and empirical moments are \( \beta = 0.705, a = 0.3 \) and \( \kappa = 0.23 \). Appendix D studies the sensitivity of the optimal policy to this calibration.

It is assumed that the three exogenous driving forces, tradable endowment, interest rates, and TFP, follow a first-order VAR of the form

\[ \tilde{s}_t^X = \Phi \tilde{s}_{t-1}^X + \varepsilon_t, \] (27)

where \( \tilde{s}_t^X = \left[ \ln(y_t^T) \quad \ln(Z_t) \quad \ln(R_t/\bar{R}) \right] \), \( \varepsilon_t = \left[ \varepsilon_t^y \quad \varepsilon_t^R \quad \varepsilon_t^Z \right] \sim \text{i.i.d. } N(\emptyset, \Omega) \), and \( \bar{R} \) denotes the mean interest rate level. The parameters of this stochastic process are estimated using

\(^{12}\)The frequency for EMs is similar to the frequency in Argentina during this period, and to other empirical estimates, such as Calvo, Izquierdo, and Mejia (2008).
Table 1. Baseline Parameter Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$</td>
<td>2</td>
<td>Inverse of intertemporal elasticity of substitution</td>
</tr>
<tr>
<td>$\xi$</td>
<td>0.44</td>
<td>Intratemporal elasticity of substitution</td>
</tr>
<tr>
<td>$a$</td>
<td>0.23</td>
<td>Share of tradables</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.705</td>
<td>Annual subjective discount factor</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>0.23</td>
<td>Share of income used as collateral</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.75</td>
<td>Labor share in nontradable sector</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.96</td>
<td>Degree of downward nominal rigidity</td>
</tr>
</tbody>
</table>

Argentinean data since 1983.\(^\text{13}\) Tradable endowment is measured with the cyclical component of value added in agriculture and manufacturing. TFP is measured with the cyclical component of TFP estimates constructed in Aravena and Fuentes (2013) and Penn World Tables. Interest rates on external debt are measured as the sum of EMBI spreads and the Treasury Bill rate. (Appendix D.2 studies an economy with interest-rate shocks calibrated to those of the risk-free rate.) Since the data on EMBI spreads for Argentina is available since 1994, the series were extended back to 1983, using the Neumeyer and Perri (2005) dataset, which uses a measure similar to the one considered here. The interest rate series is then deflated with a measure of expected dollar inflation. Data Appendix C provides further details on data sources and estimation results.

The estimated process is approximated with a Markov chain, setting a grid of five equally spaced points for $\ln(y_t^T)$, $\ln(Z_t^T)$, and $\ln(R_t/R)$, yielding 125 exogenous states. To estimate the transition-probability matrix, I use the method proposed by Terry and Knoteck (2011) extending Tauchen (1986).\(^\text{14}\) Finally, to approximate the aggregate dynamics of the economy under the optimal and full-employment policies, I discretize the endogenous state space ($d_t$) using 401 equally spaced points. To approximate the dynamics under a currency peg, I use 151 equally spaced points for debt ($d_t$) and 150 equally spaced points for the log of the previous-period wage ($w_{t-1}$). The next sections present the results of the quantitative analysis.

4.2 Policy Functions

Figure 1 shows the policy functions for the calibrated model under the optimal exchange-rate policy and compares them to those under the two benchmark exchange-rate regimes: full em-

\(^{13}\)The years 2002–2005, in which Argentina defaulted and was excluded from international markets (Crucés and Trebesch, 2013), are not included in the estimation.

\(^{14}\)I am grateful to Stephen J. Terry and Edward S. Knoteck II for sharing the code for the Markov-chain approximations of vector autoregressions, which were used in this paper to estimate the transition-probability matrix of the stochastic process.
ployment and fixed exchange rate. In particular, it depicts the decision rules for the nominal devaluation rate, the real exchange rate, unemployment, and next-period debt as a function of the state variables. In each panel, only one state variable varies (on the horizontal axis), and the remaining state variables are fixed at their unconditional means (under the optimal policy, if the state is endogenous). In each panel, a shaded region depicts the state space in which the collateral constraint binds under the optimal policy. The panels on the two right columns do not have a shaded region since varying TFP or the interest rate – while keeping the rest of the states fixed at their respective means – is not sufficient to make the collateral constraint bind.

In the region of nonbinding collateral constraint, the decision rules of optimal and full-employment policies coincide, as implied by Proposition 1. In this region, currency depreciation is increasing in the initial debt level, the level of TFP, and the interest rate, and decreasing in the level of tradable endowment. In the region of binding collateral constraint, while currency depreciation in the full-employment policy continues to be decreasing in the level of tradable endowment, currency depreciation under the optimal exchange-rate policy becomes increasing in the level of tradable endowment. Positive unemployment emerges under the optimal exchange-rate policy in the region of binding collateral constraint, decreasing in the level of tradable endowment. In this region, the optimal policy is willing to choose unemployment to allow for a higher next-period debt. The decision rules for the currency peg show that this regime, in contrast to the optimal and full-employment policies, implies positive unemployment in the state-space regions in which the collateral constraint does not bind. In these regions, the fixed exchange-rate regime makes the downward rate rigidity binding. Consistent with this, the real-exchange-rate decision rule under the currency peg displays less sensitive than that of the other two exchange-rate regimes.

4.3 Optimal Exchange-Rate Policy during Financial Crises

This section characterizes the optimal exchange-rate policy under periods of binding collateral constraints, or financial crises, and compares the dynamics of the economy under the different exchange-rate regimes. To do this, the calibrated version of the model is simulated for 1 million quarters, identifying periods in which the collateral constraint is binding under the optimal exchange-rate policy. The beginning of a financial crisis episode \((t = 0)\) is defined as the first period in which the collateral constraint binds. The responses of the variables, during all episodes of financial crisis, are then averaged.

Figure 2 depicts the average external shock during a financial-crisis episode. In the two years that precede such an episode, tradable endowment and TFP contract and interest rates

\[15\text{Under no binding collateral constraints, the optimal exchange-rate policy always consists of depreciating the nominal exchange rate in response to negative shocks to achieve full employment, as implied by Proposition 1.}\]
Note: The real exchange rate is expressed in log deviations from its sample mean. The devaluation rate, unemployment rate and next-period debt are expressed in levels. In each panel, only one state variable varies (on the horizontal axis), and the remaining state variables are fixed at their unconditional means (under the optimal policy, if the state is endogenous). Shaded regions denote regions of the state space in which the collateral constraint binds under the optimal policy.

increase. At the crisis trough ($t = 0$), tradable output is 7 percent below its mean, TFP is 3 percent below its mean, and the annual interest rate is 14 percent, 3 percentage points above its mean. In the three years following the trough, both tradable output and TFP recover their precrisis levels, and the external interest rate falls below its precrisis level.

The average responses of the nominal exchange rate and endogenous variables under the different exchange-rate regimes are shown in Figure 3. The optimal policy in periods of binding collateral constraints is characterized by large nominal and real currency depreciation: At the crisis trough ($t = 0$), the nominal exchange rate depreciates 22 percent and the relative price of nontradable goods is 14 percent below its mean (which represents one standard deviation, as shown in Section 4.6). Currency depreciation is less than half of that under the full-employment
policy (49 percent nominal depreciation on average at the crisis trough, $t = 0$). As a result, some involuntary unemployment emerges under binding collateral constraints (2 percent on average at the crisis trough).

The real-exchange-rate depreciation under the optimal policy implies that the contraction of tradable consumption under the optimal policy is larger than the contraction in nontradable consumption: At the crisis trough, tradable consumption is 12 percent below its mean, while nontradable consumption is 5 percent below its mean. This contraction in tradable consumption implies a reversal of the current account, and an adjustment of external borrowing. In this
sense, sudden stops (understood as large current-account adjustments), are in fact part of the endogenous response to large negative external shocks under the optimal exchange-rate policy to prevent greater unemployment. In fact, under the currency peg, the combination of nominal wage rigidity and a fixed nominal exchange rate leads to greater unemployment (4 percent on average at the crisis trough), which implies a significantly lower real currency depreciation than under the optimal policy (the relative price of nontradable goods is 3 percent below its mean at the crisis trough), that relaxes the borrowing limit. As a consequence, under a currency peg, external debt continues to increase and the current-account deficit expands.

The large, but still contained, optimal currency depreciation during periods of financial crisis is consistent, for instance, with the typical behavior observed in EMs during the global financial turbulence of 2008 (see Figure 4). During this episode, EMs considerably depreciated the exchange rate (24 percent on average), but also contained the depreciation, as can be observed in the fall in international reserves.

Figure 4: Exchange-Rate Policy in Emerging-Market Economies – Lehman Episode.

Note: Nominal exchange rate and international reserves figures were computed as the simple average for the countries included in the EMBI, except countries with no separate legal tender. Data sources and detail of countries included in the sample: See Data Appendix C.

4.4 Means and Volatilities by Exchange-Rate Regime

Table 2 shows that the differences between the optimal and full-employment policies during periods of binding collateral constraint (analyzed in Sections 4.2 and 4.3) translate, on the one hand, into a lower volatility of tradable consumption and total consumption, and, on the other hand, into a higher average unemployment rate. This reflects the fact that, under binding collateral constraints, the optimal policy allows for lowering the nontradable consumption to improve the
Table 2. Means and Volatilities by Exchange-Rate Regime

<table>
<thead>
<tr>
<th></th>
<th>OP</th>
<th>FE</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Means</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu(c)$</td>
<td>0.98</td>
<td>0.98</td>
<td>0.98</td>
</tr>
<tr>
<td>$\mu(c^T)$</td>
<td>0.94</td>
<td>0.94</td>
<td>0.95</td>
</tr>
<tr>
<td>$\mu(c^N)$</td>
<td>1.00</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>$\mu(p)$</td>
<td>2.05</td>
<td>2.05</td>
<td>2.09</td>
</tr>
<tr>
<td>$\mu(u)$</td>
<td>0.14</td>
<td>0.00</td>
<td>0.9</td>
</tr>
<tr>
<td>$\mu(d)$</td>
<td>0.61</td>
<td>0.60</td>
<td>0.57</td>
</tr>
<tr>
<td><strong>Volatilities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma(c)$</td>
<td>7.80</td>
<td>8.00</td>
<td>8.00</td>
</tr>
<tr>
<td>$\sigma(c^T)$</td>
<td>10.9</td>
<td>11.6</td>
<td>8.6</td>
</tr>
<tr>
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<td>6.90</td>
<td>7.90</td>
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<tr>
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<td>17.5</td>
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<tr>
<td>$\sigma(u)$</td>
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<td>0.00</td>
<td>3.0</td>
</tr>
<tr>
<td>$\sigma(d)$</td>
<td>0.10</td>
<td>0.10</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Note: OP, FE, and CP denote optimal exchange-rate policy, full-employment exchange-rate policy, and currency peg, respectively, as defined in Section 3. The variables $c$, $c^T$, $c^N$, $p$, $u$, and $d$, denote, respectively, consumption, tradable consumption, nontradable consumption, relative price of nontradables, unemployment rate, and external debt. Volatilities and mean unemployment expressed in percent. Moments computed using parameters from Table 1 by simulating the calibrated model for 1 million periods.

intertemporal allocation of consumption. The differences in first and second moments between the optimal and full-employment policies are slight since the unconditional probability of binding collateral constraints is relatively low (5.1 percent).

The currency peg displays a larger difference in terms of the average unemployment rate with respect to the optimal exchange-rate regime. The reason is that, as previously analyzed, currency pegs also display unemployment when the collateral constraint does not bind but the wage rigidity does. This response of currency pegs to negative shocks also results in a higher volatility of nontradable and total consumption with respect to the other two regimes.

### 4.5 Welfare and Exchange-Rate Regimes

This section compares welfare under the different exchange-rate regimes. The welfare costs of an exchange-rate regime $i$ with respect to an exchange-rate regime $j$ are computed as the percentage increase in the consumption stream under exchange-rate regime $i$ that will make the representative household indifferent between that consumption stream and the one under the exchange-rate regime $j$. Formally, the compensation rate under the regime $i$ with respect to
regime \( j \), \( \lambda^{i,j} \), in a state, \( s_t \), is implicitly defined by

\[
E \left\{ \sum_{k=0}^{\infty} \beta^k U \left( c^j_{t+k} \left( 1 + \lambda^{i,j} (s_t) \right) \right) \mid s_t \right\} = E \left\{ \sum_{k=0}^{\infty} \beta^k U \left( c^i_{t+k} \right) \mid s_t \right\},
\]

where \( i, j \in \{ \text{OP, FE, PEG} \} \). Under the assumed form of period utility function, it follows that

\[
\lambda^{i,j} (s_t) = \left[ \frac{V^j (s_t) (1 - \sigma) + (1 - \beta)^{-1}}{V^i (s_t) (1 - \sigma) + (1 - \beta)^{-1}} \right]^{\frac{1}{1 - \sigma}} - 1.
\]

Since welfare costs are state dependent, Figure 5 begins by showing the welfare costs of the full-employment and fixed exchange-rate policies, with respect to the optimal exchange-rate policy, as functions of the state, and the welfare cost of the fixed exchange-rate policy, with respect to the full-employment exchange-rate policy, as a function of the state. As in Figure 1, each panel varies only one state variable (on the horizontal axis), leaving the others fixed at their unconditional means (under the optimal policy, if the state is endogenous). In each panel, a shaded region shows where in the state space the collateral constraint binds under the optimal policy. Welfare costs are particularly high in regions of the state space in which the collateral constraint binds. It is relevant to note, however, that plotting welfare costs by state does not take into account the correlation of the shocks; to take this into account, the welfare costs during financial crises and the distribution of welfare costs are studied next.

Figure 6 shows the welfare costs during financial-crisis episodes (as defined in Section 4.3). Financial crises are periods in which the welfare costs of both the full-employment policy and the currency peg increase. The size of the increase in the welfare costs of the full-employment policy are, again, much smaller than the increase in the welfare costs of currency pegs: At the crisis trough, the welfare costs of the full-employment and currency-peg policies, with respect to the optimal exchange-rate policy, are 0.13 percent and 0.74 percent, respectively. As a consequence, the welfare costs of the currency peg with respect to the full-employment exchange-rate regime also rise during financial crises, reaching 0.66 percent at the crisis trough, meaning that currency pegs are particularly costly in terms of welfare during periods of binding collateral constraints.

Finally, Table 3 shows the first and second moments of the distribution of welfare costs and indicates that the average welfare cost of the full-employment policy with respect to the optimal policy (0.02 percent) is more than one order of magnitude smaller than the welfare cost of the currency peg with respect to the optimal policy (0.57 percent).\(^{16}\) A key reason why the welfare costs of the full-employment policy are relatively small is that, as shown in Section

\(^{16}\)Formally, the mean of the welfare costs of an exchange-rate regime \( i \) with respect to an exchange-rate regime \( j \), denoted \( \overline{\lambda}^{i,j} \) is given by

\[
\overline{\lambda}^{i,j} = \sum_{s_t} \pi^i(s_t) \lambda^{i,j}(s_t),
\]

where \( \pi^i(s_t) \) denotes the unconditional probability of state \( s_t \) under exchange-rate regime \( i \).
Figure 5: Welfare Costs by State.

Note: welfare costs, expressed in percent. The welfare costs of exchange-rate regime $i$ with respect to exchange-rate regime $j$ are defined as the percentage increase in the consumption stream under exchange-rate regime $i$ that will make the representative household indifferent between that consumption stream and that under the exchange-rate regime $j$ in a given state. Each panel varies just one state variable (on the horizontal axis); the rest remaining fixed at their unconditional means (under the optimal policy, if the state is endogenous). Shaded regions denote regions of the state space in which the collateral constraint binds under the optimal policy.

3, the allocation under the optimal exchange-rate policy features no unemployment under no binding collateral constraints, and that the unconditional probability of binding collateral constraints is relatively low (5.1 percent).

Figure 6: Welfare Costs During Financial Crises.

Note: Welfare costs expressed in percent. The welfare costs of an exchange-rate regime $i$ with respect to an exchange-rate regime $j$ are defined as the percentage increase in the consumption stream under exchange-rate regime $i$ that will make the representative household indifferent between that consumption stream and the one under the exchange-rate regime $j$ in a given state. See Section 4.3 for the definition of a financial-crisis episode.
Table 3. Welfare Costs by Exchange-Rate Regime

<table>
<thead>
<tr>
<th>Welfare Costs of:</th>
<th>Full-Employment Policy</th>
<th>Currency Peg</th>
<th>Currency Peg</th>
</tr>
</thead>
<tbody>
<tr>
<td>with respect to:</td>
<td>Optimal Policy</td>
<td>Optimal Policy</td>
<td>Full-Employment Policy</td>
</tr>
<tr>
<td>Mean</td>
<td>0.02</td>
<td>0.57</td>
<td>0.54</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.08</td>
<td>0.42</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Note: Welfare costs expressed in percent. The welfare costs of an exchange-rate regime $i$ with respect to an exchange-rate regime $j$ are defined as the percentage increase in the consumption stream under exchange-rate regime $i$ that will make the representative household indifferent between that consumption stream and the one under the exchange-rate regime $j$ in a given state.

4.6 Data and Model Predictions

This section compares the predictions of the model with the data, during both financial crises and regular business cycles. Although the structure of the model is relatively simple, several predictions of the model are in line with those observed in the data. The predictions of the model are compared with data from Argentina, the economy for which the model economy was calibrated. Figure 7 illustrates the fact that Argentina, as did most EMs, alternated between different exchange-rate regimes during the period of study (Ilzetzki, Reinhart, and Rogoff, 2010). For this reason, the predictions of the three exchange-rate regimes are relevant to a comparison of the data.

For financial-crisis episodes, Figure 8 shows that the predictions of the model are close to the dynamics of the average sudden-stop episode observed in the data. The average episode in the data is constructed using three sudden-stop episodes observed in Argentina in 1982, 1989, and 2001 (Eichengreen, Gupta, and Mody, 2006; Calvo, Izquierdo, and Talvi, 2006). For the model’s prediction, I restrict attention to financial-crisis episodes (as defined in Section 4.3) in which tradable endowment and TFP were at or above their trend in $t = -2$ and below their trend in $t = 0$ (these features were observed in all sudden-stop episodes found in the data). Figure 8 indicates that the current-account reversal, the real-exchange-rate depreciation, and the contraction in real wages, economic activity and consumption predicted by the model in these financial-crisis episodes are similar in magnitude to those observed in the data. The increase of unemployment predicted by the model is also in line with the one observed in the data, which lies between the unemployment predicted by the currency peg and that predicted under the optimal policy. This can be related to the fact that, as Figure 7 indicates, sudden-stop episodes are periods of transition between exchange-rate regimes.

For regular business cycles, Table 4 shows that, in several dimensions, the second moments

---

17 Nominal exchange rates and external debt were excluded from the comparison due to hyperinflation episodes and default episodes that occurred in some of these periods (for hyperinflation episodes, see Sargent, Williams, and Zha, 2009; for default episodes, see Cruces and Trebesch, 2013).
Table 4. Second Moments – Data and Model

<table>
<thead>
<tr>
<th>Volatilities</th>
<th>Data</th>
<th>Model Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma(Y) )</td>
<td>8.4</td>
<td>6.3 6.2 6.9</td>
</tr>
<tr>
<td>( \sigma(C)/\sigma(Y) )</td>
<td>1.1</td>
<td>1.2 1.2 1.1</td>
</tr>
<tr>
<td>( \sigma(C)/\sigma(u) )</td>
<td>0.4</td>
<td>0.1 0.0 0.4</td>
</tr>
<tr>
<td>( \sigma(p) )</td>
<td>19.7</td>
<td>14.3 16.3 6.7</td>
</tr>
<tr>
<td>( \sigma(w) )</td>
<td>24.4</td>
<td>17.5 19.3 8.7</td>
</tr>
<tr>
<td>( \sigma(TB/Y) )</td>
<td>2.8</td>
<td>2.2 2.4 1.5</td>
</tr>
<tr>
<td>( \sigma(CA/Y) )</td>
<td>3.0</td>
<td>1.6 1.8 1.5</td>
</tr>
</tbody>
</table>

Correlations with output

<table>
<thead>
<tr>
<th>Correlations with output</th>
<th>Data</th>
<th>Model Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho(C,Y) )</td>
<td>97.6</td>
<td>95.4 94.2 97.9</td>
</tr>
<tr>
<td>( \rho(u,Y) )</td>
<td>−35.1</td>
<td>−21.4 — −49.2</td>
</tr>
<tr>
<td>( \rho(p,Y) )</td>
<td>59.8</td>
<td>31.7 33.6 −1.0</td>
</tr>
<tr>
<td>( \rho(w,Y) )</td>
<td>76.6</td>
<td>62.2 61.9 64.9</td>
</tr>
<tr>
<td>( \rho(TB/Y,Y) )</td>
<td>−90.5</td>
<td>−38.2 −39.4 −22.8</td>
</tr>
<tr>
<td>( \rho(CA/Y,Y) )</td>
<td>−87.6</td>
<td>2.1 −3.3 29.2</td>
</tr>
</tbody>
</table>

Autocorrelations

<table>
<thead>
<tr>
<th>Autocorrelations</th>
<th>Data</th>
<th>Model Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho(Y_t,Y_{t-1}) )</td>
<td>72.4</td>
<td>59.9 61.8 56.8</td>
</tr>
<tr>
<td>( \rho(C_t,C_{t-1}) )</td>
<td>74.8</td>
<td>53.0 50.8 59.9</td>
</tr>
<tr>
<td>( \rho(u_t,u_{t-1}) )</td>
<td>80.6</td>
<td>−0.1 — 12.8</td>
</tr>
<tr>
<td>( \rho(p_t,p_{t-1}) )</td>
<td>73.7</td>
<td>6.8 −1.1 56.6</td>
</tr>
<tr>
<td>( \rho(w_t,w_{t-1}) )</td>
<td>61.6</td>
<td>21.2 12.9 76.8</td>
</tr>
<tr>
<td>( \rho(TB_t/Y_t,TB_{t-1}/Y_{t-1}) )</td>
<td>70.0</td>
<td>15.3 6.5 32.4</td>
</tr>
<tr>
<td>( \rho(CA_t/Y_t,CA_{t-1}/Y_{t-1}) )</td>
<td>59.0</td>
<td>−7.6 −14.6 3.3</td>
</tr>
</tbody>
</table>

Note: Values expressed in percent. OP, FE, and CP denote optimal exchange-rate policy, full-employment exchange-rate policy, and currency peg, respectively, as defined in Section 3. The variables \( Y, C, TB, \) and \( CA \) denote, respectively, GDP, consumption, trade balance, and current account, expressed in real terms; the variables \( u, p, \) and \( w \) denote, respectively, unemployment rate, relative price of nontradables, wages in units of tradables. Moments in the data were computed for the period 1980–2011. Variables in the data were quadratically detrended. GDP and consumption, in the data are expressed in per capita terms. Moments predicted by the model were computed using parameters from Table 1, with 1000 simulations of the same length as the data sample. Real GDP, consumption, real exchange rate, real wage expressed in log deviations from their sample means. Data sources: see Data Appendix C.
Figure 7: Exchange-Rate Regimes in Argentina and Emerging-Market Economies.

Note: Data on exchange-rate regimes from Ilzetzki, Reinhart, and Rogoff (2010). Classification codes: 1. No separate legal tender, preannounced peg or currency board arrangement, preannounced horizontal band that is narrower than or equal to +/-2 percent, or de facto peg; 2. preannounced crawling peg, preannounced crawling band that is narrower than or equal to +/-2 percent, de facto crawling peg, or de facto crawling band that is narrower than or equal to +/-2 percent; 3. de facto crawling band that is narrower than or equal to +/-5 percent, moving band that is narrower than or equal to +/-2 percent, managed floating; 4. freely floating; 5. freely falling; 6. dual market in which parallel-market data is missing.

predicted by the model are in line with those observed in the Argentinean data. The model predicts around 80 percent of the volatility of output observed in the data. The model also captures that consumption volatility exceeds output volatility, which is a key feature of EM business cycles (Aguiar and Gopinath, 2007; Uribe and Schmitt-Grohé, 2014). The predictions of the model for the standard deviations of the unemployment rate, the real wage and the real exchange rate are in line with those observed in the data. All exchange-rate regimes seem to be contributing with important predictions observed in the data. For instance the prediction of the model for the unemployment rate under a currency peg is close to the one observed in the data, which is consistent with the fact that, as documented in Figure 7, in more than 60 percent of the periods since 1980, Argentina was under either a peg or a narrow crawling peg. However, in the other periods, Argentina experimented transitions between exchange-rate regimes or large currency depreciation, accounting for most of the large volatility of relative prices observed in
Another relevant dimension observed in the data for Argentina, and in general for EMs, which is qualitatively captured by the model is the countercyclical trade balance (Aguiar and Gopinath, 2007; Uribe and Schmitt-Grohé, 2014). However, the correlation of the trade balance with output predicted by the model is smaller in absolute value than the one observed in the data. Since the correlation with net factor income from abroad is strongly procyclical both in the data and in the model, the model predicts a procyclical current account. As discussed in Benigno et al. (2012a), an element that could make the model predict a more countercyclical trade balance and current account is the presence of investment (see, for example, Backus, Kehoe, and Kydland, 1993). For consumption, the correlations with output predicted by the model are close with that observed in the data. For relative prices, the models under the optimal policy and full employment capture the procyclical behavior observed in the data, although the correlations predicted by the model are smaller in absolute value than those observed in the data. Finally, the autocorrelations predicted by the model are generally consistent with those observed in the data. These are better captured by the predictions of the model under the optimal policy or the full-employment policy (as shown in Figure 8).

**Figure 8: Financial Crises – Model and Data.**

*Note:* Real exchange rate, real wage, real GDP, and consumption expressed in log deviations from their sample means in the model, and from a log quadratic trend in the data. Current-account-to-GDP ratio expressed in deviations from its sample mean in the model and from a quadratic trend in the data. Unemployment rate expressed in levels in the model, and in deviation from $t-2$ values in the data. See Section 4.3 for the definition of a financial-crisis episode. Data sources: see Data Appendix C.
data. For unemployment, trade balance and the current account, the autocorrelation coefficients predicted by the model are smaller than those observed in the data. The autocorrelation of output, consumption, and relative prices predicted by the model (particularly under the currency peg) are in line with those observed in the data.

5 Additional Considerations for Exchange-Rate Policy

This section studies three environments that could, in principle, limit the optimality of currency depreciation during financial crises. First, it considers an economy with imported inputs that require working-capital financing. Second, it studies an economy in which physical capital is used as an input of production. Third, focusing on the recent crisis in Latvia and the Euro Area, it studies an economy that enters a financial crisis with relatively high levels of external debt.

5.1 Imported Inputs

This section expands the model economy of Section 2 to consider an environment in which production uses an imported input for which working-capital financing is required. This case is of interest because it introduces a contractionary effect associated with currency depreciation and tightening of credit constraints, which is a frequent concern in academic and policy circles in the context of currency mismatch. The particular channel considered, imported intermediate inputs, has been closely studied in the related literature (see, for example, Braggion, Christiano, and Roldos, 2009; Mendoza and Yue, 2012; Bianchi and Mendoza, 2013).

Formally, it is now assumed that households have access to a technology to produce tradable goods with an imported intermediate good as input:

$$y^T_t = Z^T_t (m_t)^\eta_m,$$

where $y^T_t$ denotes the gross output of tradable goods in period, $Z^T_t$ denotes an exogenous and stochastic productivity shock, $m_t$ denotes the imported intermediate goods used in production and $\eta_m \in (0, 1)$.

The sequential budget constraint of households is now given by

$$\frac{d_{t+1}}{R_t} \left( 1 - \tau_i d_t \right) = d_t + c^T_t + p_t c^N_t + p^m m_t - (y^T_t + w_t h_t + \Pi_t) - T_t,$$

where $p^m$ is the (constant) price of imported inputs in terms of tradable goods, purchased by households in a competitive international market.

It is assumed that a share $\psi > 0$ of the cost of purchasing imported inputs, $p^m m_t$, must be paid in advance of production, using external working-capital loans. Working-capital loans
are assumed to be within-period debt, repaid at the end of each period. As in Section 2, households face a collateral constraint by which external debt (including both intertemporal debt and working-capital loans) cannot exceed a fraction $\kappa$ of income:

$$d_{t+1} + \psi p^m m_t \leq \kappa \left( y_t^T + w_t h_t + \Pi_t \right).$$

Households’ first-order condition with respect to the purchase of imported inputs is given by

$$m_t = \overline{m}_t \left( \frac{1 + \mu_t \psi}{1 + \mu_t \kappa} \right),$$

where $\overline{m}_t \equiv \left( \frac{\eta m Z_t^T}{p^m} \right)^{1/\eta m}$ is the unconstrained choice of imported inputs. This condition indicates that the collateral constraint introduces a wedge in the choice of imported inputs. If $\psi > \kappa$, this wedge is increasing in the shadow value for the household of relaxing the credit constraint, $\mu_t$. Currency depreciation, by tightening the collateral constraint, can therefore have a contractionary effect on production. However, the overall effect of currency depreciation on economic activity will also depend on the effect that currency depreciation has on unemployment. This is studied next, in a calibrated version of this model.

The rest of the equilibrium conditions are the same as in the baseline economy. To calibrate the model, the share of intermediate inputs in gross output is set to $\eta_m = 0.43$, following the evidence provided in Mendoza and Yue (2012) for Argentina. It is assumed that all costs of intermediate inputs must be paid in advance, and set $\psi = 1$. The parameters $\{\beta, a, \kappa\}$ are used to match the three targets from the baseline calibration (average external debt-to-GDP ratio, share of tradable output in GDP, and frequency of sudden stops observed in the data). The remaining parameters are set as in the baseline calibration (Table 1). Given the lack of historical sectoral data on measured TFP for Argentina, and to facilitate comparison with the baseline calibration, it is assumed that the stochastic process is the same as in (27), with $Z_t^T$ taking the place of $y_t^T$.

Figure 9 depicts the optimal nominal exchange rate and endogenous variables for the average financial-crisis episode (as defined in Section 4.3) in the economy with imported inputs. As in

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18 The assumption that working-capital loans are within-period debt follows related literature and is aimed at focusing on the effect of collateral on production (see Bianchi and Mendoza, 2013) instead of the effect that interest rate fluctuations have on factor costs (see Neumeyer and Perri, 2005; Uribe and Yue, 2006).

19 This assumption is similar to that used in Neumeyer and Perri (2005) and aim to provide an upper bound on the effects of intermediate inputs on credit needs. In an alternative calibration, the value of $\psi$ was set to match a working-capital-to-GDP ratio of 6.6 percent, proxied using the average M1-to-GDP ratio in Argentina of 9.8 percent and the estimate that two-thirds of M1 in the US economy is held by firms (Schmitt-Grohé and Uribe, 2007). The optimal policy under this alternative calibration is similar to the one presented in this section. However, given that imported inputs would have a small financial requirement in this case, the differences between the optimal policy and the unconstrained choice of intermediate inputs is significantly smaller than the case shown in Figure 9.
the baseline model economy, the optimal allocation is characterized by large nominal currency depreciation (25 percent on average at the crisis trough). Consequently, there is a relatively small increase in the unemployment rate (3 percent on average at the crisis trough), compared to the adjustment of imported inputs (16 percent on average at the crisis trough). Figure 9 also shows the path that exchange rate and unemployment would have taken to support the same level of borrowing as in the optimal policy and the unconstrained choice of imported inputs ($\pi_t$). This would have been required to contain currency depreciation, leading unemployment to increase to 10 percent at the crisis trough and to a larger contraction of economic activity (as measured by real GDP) compared to the optimal policy. It follows that for plausible values of parameters, currency depreciation is not overall contractionary in this economy. Therefore, even considering the effect that currency depreciation has on intermediate inputs, preventing currency depreciation is an inefficient way to maintain credit access.

![Figure 9: Financial Crises – Economy with Imported Inputs.](image)

**Figure 9: Financial Crises – Economy with Imported Inputs.**

*Note:* Real exchange rate, imported inputs, and real GDP expressed in percent deviations from their sample means. Current account expressed in deviations from its sample mean. Devaluation rate and unemployment rate expressed in levels.

### 5.2 Physical Capital

This section expands the model economy of Section 2 to consider an economy with physical capital. This case is relevant given that a frequent concern associated with currency depreciation is that tightening in borrowing constraints can affect aggregate investment and, through this channel, economic activity. This extension also allows us to study the effect of currency
depreciation on the price of capital, a key variable considered in the literature on exchange-rate policy for financial stability (see, for example, Cespedes, Chang, and Velasco, 2004; Gertler, Gilchrist, and Natalucci, 2007; Fornaro, 2015).

It is assumed that households have access to a technology to produce tradable goods with physical capital as input and to a capital-accumulation technology given, respectively, by

\[ y_T^t = Z_T^t(k_t)^{\eta_k}, \]
\[ k_{t+1} = (1 - \delta)k_t + i_t, \]

where \( y_T^t \) denotes output of tradable goods, \( Z_T^t \) denotes an exogenous and stochastic productivity shock, \( k_t \) denotes physical capital, \( i_t \) denotes gross investment, \( \eta_k \in (0,1) \) and \( \delta \in (0,1) \).

Households’ sequential budget constraint is now given by

\[ \frac{d_{t+1}}{R_t} \left(1 - \tau d_t^d\right) = d_t + c_t^T + p_t c_t^N + i_t + \Phi \left(\frac{i_t}{k_t}\right) k_t - (y_T^t + w_t h_t + \Pi_t) - T_t, \]

where \( \Phi : \mathbb{R} \to \mathbb{R} \) is a twice continuously differentiable, strictly convex function that introduces investment-adjustment costs.

Denoting the Lagrange multiplier associated with the capital-accumulation constraint as \( q_t \lambda_t \), households’ first-order conditions with respect to investment and the stock of capital are given by

\[ q_t = 1 + \Phi' \left(\frac{i_t}{k_t}\right), \]
\[ \lambda_t q_t = \beta E_t \lambda_{t+1} \left[ \eta_k \frac{y_{t+1}}{k_{t+1}} (1 + \mu_t) + (1 - \delta) q_{t+1} + \Phi' \left(\frac{i_{t+1}}{k_{t+1}}\right) \frac{i_{t+1}}{k_{t+1}} + \Phi \left(\frac{i_{t+1}}{k_{t+1}}\right) \right]. \]

The rest of the equilibrium conditions are the same as in the baseline economy.

To calibrate the model, I set \( \eta_k = 0.5 \), following the evidence in Uribe (1997) on the capital share in the tradable sector in Argentina. The capital-adjustment cost function is assumed to be quadratic: \( \Phi(x) = \frac{\phi}{2} (x - \delta)^2 \). The depreciation rate and the parameter governing the degree of investment-adjustment costs are set to \( \delta = 0.1255 \) and \( \phi = 4.6 \), following the estimation of García-Cicco, Pancrazi, and Uribe (2010) for Argentina. The parameters \( \{ \beta, a, \kappa \} \) are used to match the three targets from the baseline calibration (average external debt-to-GDP ratio, share of tradable output in GDP, and frequency of sudden stops observed in the data). The remaining parameters are set as in the baseline calibration (Table 1). As in the previous section, it is assumed that the stochastic process is the same as in (27), with \( Z_T^t \) taking the place of \( y_T^t \).

Figure 10 depicts the optimal nominal exchange rate and endogenous variables for the average financial-crisis episode (as defined in Section 4.3) in the economy with physical capital. The optimal allocation is characterized by large nominal currency depreciation (22 percent on average at the crisis trough) and current-account adjustment (3.7 percentage points of GDP), similar to
those of the baseline economy. There is a relatively small increase in the unemployment rate (0.8 percent on average at the crisis trough), compared to the adjustment of capital (8 percent below its mean at the crisis trough). Therefore, preventing currency depreciation is also an inefficient way to maintain credit-access in an economy with physical capital.

It is relevant to note that the price of capital has a similar contraction under the full-employment and optimal exchange-rate policies, although the former displays higher currency depreciation. This result is relevant given that, as mentioned in Section 1, several studies consider that a channel by which currency depreciation can lead to more financial stability is by increasing the price of capital. The present paper shows that in an environment in which the debt capacity is linked to the value of income, currency depreciation is limited in its ability to increase the price of capital.

5.3 High External Debt: Latvia and the Euro Crisis

This section applies the model economy developed in this paper to the recent crisis in the Euro Area, with a particular focus on the case of Latvia. This case is of interest since, unlike financial crises in Argentina and other EMs (studied in Section 4), Latvia is an example of a country that decided to maintain the currency peg during the crisis. Moreover, the trade-off studied in
this paper was an explicit part of the policy debate (see, for example, International Monetary Fund, 2013). This section shows that the high levels of external debt with which Latvia and most Euro economies started the financial-crisis episode can rationalize a policy of not allowing currency depreciation.

To calibrate the model economy of Section 2 to the Euro Area, the parameters \( \{\beta, a, \kappa\} \) are used to match three key moments in the ergodic distributions of the model under the optimal exchange-rate policy to the ones observed in historical data for a sample of Euro economies for the period 1970–2013.\(^{20}\) As in Section 4, the three data moments considered are an average level of external debt-to-GDP ratio of 34.6 percent, a share of tradable output in GDP of 21.4 percent, and a frequency of sudden stops of 5.5 percent. As in Section 4, I set \( \sigma = 2, \xi = 0.44, \) and \( \alpha = 0.75. \) The stochastic process (27) is estimated using data of the sample of Euro Area economies. (More details on the data, sample, and estimation results are provided in Data Appendix C.) To compute the dynamics predicted by the model for Latvia under a currency peg, I set the wage-rigidity parameter to \( \gamma = 0.96, \) following the evidence presented in Schmitt-Grohé and Uribe (2014) on downward nominal wage rigidity and using data on TFP growth (for details see Data Appendix C). For comparison, I also compute the dynamics under a currency peg with the average wage rigidity of Greece, Ireland, Portugal, and Spain (henceforth, the GIPS economies), which corresponds to \( \gamma = 0.99. \) To compare the financial crises predicted by the model with those observed in the recent crisis, I restrict attention to financial-crisis episodes (as defined in Section 4) in which tradable endowment and TFP were at or above their trend in \( t = -2 \) and below their trend in \( t = 0, \) and external debt was one standard deviation above its average level in \( t = -2 \) (all these features were observed in the sample countries of the Euro Area in the period 2008–2010). These episodes are labeled “high-external-debt” financial-crisis episodes. “Regular” financial crises, in which no restriction is imposed on the initial debt level (as in Section 4), are also computed for comparison.

Figure 11 shows that, unlike in “regular” financial crises, the optimal exchange-rate policy during “high-external-debt” financial crises does not allow for nominal currency depreciation in the years following a financial-crisis episode, and even implies inducing currency appreciation at the crisis trough. In the case of Latvia, the resulting unemployment under the optimal policy is even higher than the one predicted under a currency peg or than the one observed in the data. A key element for this conclusion is relative to other Euro economies, Latvia displays a relatively low wage rigidity, which leads to relatively more adjustment of nominal wages under a currency peg (the model under a currency peg predicts that nominal wages contract by 8 percent two years after the trough, in line with the adjustment observed in the data). For the GIPS

\(^{20}\)Included in the sample are Bulgaria, Cyprus, Estonia, Greece, Ireland, Italy, Latvia, Lithuania, Portugal, Spain, Slovenia, and Slovakia. Data of each country is included as it becomes available in the data sources. For details, see Data Appendix C.
Figure 11: Financial Crises in the Euro Area – Model and Data.

Note: Data on GIPS economies refers to the simple average of Greece, Ireland, Portugal, and Spain. See Section 4.3 for the definition of a financial-crisis episode. Period $t=-2$ in the model was associated to year 2008 in the data. Unemployment rate expressed in deviation from $t=-2$ values. A “regular” financial crisis episode in the model is one in which tradable endowment and TFP were at or above their trend in $t=-2$ and below their trend in $t=0$. A “high-external-debt” financial-crisis episode is a regular financial-crisis episode in which external debt was one standard deviation above its average level in $t=-2$. Data sources: see Data Appendix C.

In particular, Blanchard, Griffiths, and Gruss (2013) show that productivity increases during the crisis drove much of the reduction in unit labor costs in Latvia, which is captured in the model when computing the value of the degree of wage rigidity, $\gamma$, which is adjusted for long-run productivity growth.
increase in unemployment observed in the recent crisis in Latvia and in the GIPS economies is greater than what would have been optimal in a “regular” recession episode, in which optimal currency depreciation is to allow for an average 13 percent currency depreciation at the crisis trough and 40 percent a period before.

6 Conclusions

This paper conducts a quantitative study of the optimal exchange-rate policy facing a trade-off between credit access and unemployment, which captures a central discussion of the policy debate typically observed during financial crises in EMs. In the presence of downward nominal wage rigidity, allowing for nominal exchange-rate depreciations can help attenuate unemployment. In the presence of liability dollarization and collateral constraints linking debt to tradable and nontradable income, fighting real exchange-rate depreciation alleviates the adjustment of consumption or inputs that require external borrowing.

The main finding is that the optimal exchange-rate policy during financial crises is characterized by large currency depreciation, and current-account adjustment, as observed in the data of sudden-stop episodes in EMs. In this sense, sudden stops are generally part of the endogenous response to large negative shocks under the optimal exchange-rate policy: While exchange-rate policy could prevent sudden stops by resisting real exchange-rate depreciation, the associated unemployment costs make this policy suboptimal.

The welfare cost of a full-employment policy is an order of magnitude smaller than the welfare cost of a fixed exchange-rate regime. However, this paper’s findings suggest that the optimal degree of “fear of floating” during financial crises depends on the nature of the shocks, the level of external borrowing, and structural characteristics of the economy. This means simple policy recipes will, in general, not be optimal during EMs’ financial crises, and that what is optimal during a financial-crisis episode in a given economy might not be optimal in another economy or in an episode involving a different combination of shocks.

In future research, several extensions related to the present paper’s framework could be considered. First, the paper has studied an environment in which only income can be used as collateral. Including both income and capital as collateral, would be computationally demanding, but would enrich the study of the trade-off faced by the policymaker. Second, the paper studies the optimal exchange-rate policy when the policymaker has access to a commitment technology. An interesting area of future research is the optimal time-consistent exchange-rate policy in a framework in which the policymaker does not have commitment. Third, the paper assumes that all debt is denominated in a foreign currency. A relevant extension would be a study of the interaction between exchange-rate policy and optimal currency composition of external debt under the framework of this paper. These extensions are planned for future research.
References


Online Appendix
–Not for Publication –

A Omitted Constraints in Ramsey Problems

In 3.1, to characterize the allocation under the different exchange-rate regimes, I follow the strategy of setting up the Ramsey problem dropping constraints; this Appendix shows that the omitted constraints are satisfied.

A.1 Optimal Exchange-Rate Policy

This section shows that any \( \{d_{t+1}, c^T_t, h_t\} \) that satisfy (5), (12), (17), and (18) also satisfy (GE). Pick \( c^N_t = Z_t F (h_t) \) to satisfy (15). Pick \( p_t = \left(\frac{1-a}{a}\right) \left(\frac{c^T_t}{c^T_t}\right)^{\frac{1}{2}} \) to satisfy (8). Pick \( \mu_t = 0 \). This makes (9) hold. Pick \( \lambda_t = U_c (c^T_t, c^N_t) A_T (c^T_t, c^N_t) \) to satisfy (7). Choose \( \tau_t^d = 1 - R_t \beta E_t \lambda_{t+1} \lambda_t + \mu_{t+1} \) to satisfy (6). Choose \( T_t \) to satisfy (14) as: \( T_t = \tau_t^d d_{t+1} R_t^{-1} \). Pick \( w_t = \left(\frac{1-a}{a}\right) \left(\frac{c^T_t}{c^T_t}\right)^{\frac{1}{2}} Z_t^{1-\frac{\frac{1}{2}}{} F (h_t)^{1-\frac{1}{2}} F' (h_t)} \) to satisfy (16). Given \( w_{t-1} \), pick \( \epsilon_t \) to satisfy (11) with equality: \( \epsilon_t = \gamma \frac{w_{t-1}}{w_t} \). Finally, since (11) holds with equality, (13) always holds: \( (w_t - \gamma \frac{w_{t-1}}{\epsilon_t}) (\bar{h} - h_t) = 0 \).

A.2 Full-Employment Exchange-Rate Policy

This section shows that any \( \{d_{t+1}, c^T_t, h_t\} \) that satisfy (5), (17), (18), and (20), also satisfy (GE) and (20). Pick \( c^N_t = Z_t F (h_t) \) to satisfy (15). Pick \( p_t = \left(\frac{1-a}{a}\right) \left(\frac{c^T_t}{c^T_t}\right)^{\frac{1}{2}} \) to satisfy (8). Pick \( \mu_t = 0 \). This makes (9) hold. Pick \( \lambda_t = U_c (c^T_t, c^N_t) A_T (c^T_t, c^N_t) \) to satisfy (7). Choose \( \tau_t^d = 1 - R_t \beta E_t \lambda_{t+1} \lambda_t + \mu_{t+1} \) to satisfy (6). Choose \( T_t \) to satisfy (14) as: \( T_t = \tau_t^d d_{t+1} R_t^{-1} \). Pick \( w_t = \left(\frac{1-a}{a}\right) \left(\frac{c^T_t}{c^T_t}\right)^{\frac{1}{2}} Z_t^{1-\frac{\frac{1}{2}}{} F (h_t)^{1-\frac{1}{2}} F' (h_t)} \) to satisfy (16). Given \( w_{t-1} \), pick \( \epsilon_t \) to satisfy (11) with equality: \( \epsilon_t = \gamma \frac{w_{t-1}}{w_t} \). Finally, by (20) and (12), (13) always holds: \( (w_t - \gamma \frac{w_{t-1}}{\epsilon_t}) (\bar{h} - h_t) = 0 \).

A.3 Fixed Exchange-Rate Policy

This section shows that any \( \{d_{t+1}, c^T_t, h_t, w_t, \epsilon_t\} \) that satisfy (5), (11)–(13), (16)–(18), and (22), also satisfy (GE) and (22). Pick \( c^N_t = Z_t F (h_t) \) to satisfy (15). Pick \( p_t = \left(\frac{1-a}{a}\right) \left(\frac{c^T_t}{c^T_t}\right)^{\frac{1}{2}} \) to satisfy (8). Pick \( \mu_t = 0 \). This makes (9) hold. Pick \( \lambda_t = U_c (c^T_t, c^N_t) A_T (c^T_t, c^N_t) \) to satisfy (7). Choose \( \tau_t^d = 1 - R_t \beta E_t \lambda_{t+1} \lambda_t + \mu_{t+1} \) to satisfy (6). Choose \( T_t \) to satisfy (14) as: \( T_t = \tau_t^d d_{t+1} R_t^{-1} \).
B Proofs

B.1 Proof of Proposition 1

The Ramsey problem of optimal exchange-rate policy under an optimal capital-control tax is to maximize (1) with respect to \( \{d_{t+1}, c^T_t, h_t\} \), subject to (5), (12), (17) and (18). The Lagrangean of the Ramsey problem is then given by

\[
L = E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{U \left( A \left( c^T_t, Z_t F (h_t) \right) \right)}{R_t} + \phi^F_t \left[ \frac{d_{t+1}}{R_t} - d_t + \psi^F_t \right] + \phi^\mu_t \left[ \frac{d - d_{t+1}}{R_t} \right] + \phi^W_t \left[ \bar{h} - h_t \right] \right\},
\]

where \( \phi^F_t, \phi^\mu_t, \phi^W_t \), and \( \phi^W_t \) are Lagrange multipliers.

The optimality conditions associated with this problem (provided \( d_{t+1} < d^N \)) are (12), (17), (18), the first-order conditions

\[
\frac{\phi^F_t}{R_t} = \beta E_t \phi^F_{t+1} + \phi^\mu_t, \quad (28)
\]

\[
\phi^F_t = U_c A_T (c^T_t, Z_t F (h_t)) + \phi^\mu_t \kappa \left( \frac{1}{\xi} \right) \left( \frac{1-a}{a} \right) \left( \frac{c^T_t}{Z_t F (h_t)} \right)^{\frac{1}{\xi}-1}, \quad (29)
\]

\[
\phi^W_t = Z_t F' (h_t) \left[ U_c A_N \left( c^T_t, Z_t F (h_t) \right) + \phi^\mu_t \left( \frac{1-\xi}{\xi} \right) \kappa \left( \frac{1-a}{a} \right) \left( \frac{c^T_t}{Z_t F (h_t)} \right)^{\frac{1}{\xi}} \right], \quad (30)
\]

and the complementary slackness conditions

\[
\phi^\mu_t \geq 0; \quad \phi^\mu_t \left[ \kappa \left( y^T_t + \frac{1-a}{a} \right) \left( c^T_t \right)^{\frac{1}{\xi}} \left( Z_t \right)^{1-\frac{1}{\xi}} \left(F (h_t) \right)^{1-\frac{1}{\xi}} - d_{t+1} \right] = 0, \quad (31)
\]

\[
\phi^W_t \geq 0; \quad \phi^W_t \left[ \bar{h} - h_t \right] = 0. \quad (32)
\]

First, consider the case with \( \xi < 1 \). Assume, contrary to the statement of the proposition, that under the optimal exchange-rate policy, at some date \( t, h_t < \bar{h} \) and \( d_{t+1} < \bar{d} (h_t, c^T_t, s^X_t) \).

By (32) it follows that \( \phi^W_t = 0 \). By (30), and since \( c^T_t > 0, h_t > 0, Z_t > 0, F' (h_t) > 0, \quad U_c A_N \left( c^T_t, F (h_t) \right) > 0, \quad \left( \frac{1-\xi}{\xi} \right) < 0 \), this implies that \( \phi^\mu_t > 0 \), which contradicts (31), which requires \( \phi^\mu_t \left[ \bar{d} (h_t, c^T_t, s^X_t) - d_{t+1} \right] = 0 \).

Second, consider the case with \( \xi \geq 1 \). Assume, contrary to the statement of the proposition, that under the optimal exchange-rate policy, at some date \( t, h_t < \bar{h} \). By (30), and since \( c^T_t > 0, h_t > 0, Z_t > 0, F' (h_t) > 0, \quad U_c A_N \left( c^T_t, F (h_t) \right) > 0, \quad \left( \frac{1-\xi}{\xi} \right) \geq 0 \) and \( \phi^\mu_t \geq 0 \), this implies that \( \phi^W_t > 0 \), which contradicts (32), which requires \( \phi^W_t \left[ \bar{h} - h_t \right] = 0 \).
B.2 Proof of Proposition 2

Given the initial state \((s_t^X, d_t)\) and a debt level \(d_{t+1}^*\) with associated tradable consumption \(c_t^T = (d_{t+1}^* R_t^{-1} - d_t + y_t^T)\), pick \(h_t^*\) such that \(d_{t+1}^* = \overline{d}(h_t^*, c_t^T, s_t^X)\). This implies setting \(h_t^*\) as:

\[
h_t^* = F^{-1} \left( \left( \frac{1-a}{a} \right) (d_{t+1}^* R_t^{-1} - d_t + y_t^T) \right)^{\frac{1}{\xi}} Z_t^{\frac{1-\xi}{1}} \left( d_{t+1}^* \kappa^{-1} - y_t^T \right)^{-1} \right)^{\frac{1}{1-\xi}}.
\]

By assumption \(d_{t+1}^* > \overline{d}(h_t^*, c_t^T, s_t^X)\). Since \(\xi < 1\), it follows that

\[
\overline{h}_t > F^{-1} \left( \left( \frac{1-a}{a} \right) (d_{t+1}^* R_t^{-1} - d_t + y_t^T) \right)^{\frac{1}{\xi}} Z_t^{\frac{1-\xi}{1}} \left( d_{t+1}^* \kappa^{-1} - y_t^T \right)^{-1} \right)^{\frac{1}{1-\xi}},
\]

and thus \(h_t^* < \overline{h}_t\).

Finally, since \((d_{t+1}^* R_t^{-1} - d_t + y_t^T)^{\frac{1}{\xi}} > 0, Z_t^{\frac{1-\xi}{1}} > 0\) and \(F(\overline{h}_t) > 0\), by the assumption that \(d_{t+1}^* > \overline{d}(h_t^*, c_t^T, s_t^X)\), it also follows that \(d_{t+1}^* > \kappa y_t^T\), and thus \(h_t^* > 0\).

B.3 Proof of Remark 1

As shown in Section 3.1, the optimality conditions associated with the problem of optimal exchange-rate policy with capital-control taxes (Definition 1) are (12), (17), (18), (28), (29) (30), (31) and (32). In an allocation in which at time \(t\), \(h_t < \overline{h}_t\), by (32) it follows that \(\phi_t^W = 0\). Replacing in (30), (24) is obtained.

B.4 Proof of Proposition 3

The Lagrangian of the unconstrained first-best problem is given by:

\[
\mathcal{L} = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{U}{A} \left( c_t^T, Z_t F( h_t) \right) + \phi^F_t \left[ d_{t+1}^* R_t^{-1} - d_t + y_t^T - c_t^T \right] + \phi_t^N \left[ d^N - d_{t+1}^* \right] + \phi_t^W \left[ \overline{h}_t - h_t \right] \right\},
\]

where \(\phi^F_t, \phi^N_t,\) and \(\phi^W_t\) are Lagrange multipliers.

The optimality conditions associated with this problem are (5), (12), (17), the first order conditions:

\[
\phi^F_t = \beta \mathbb{E}_t \phi^F_{t+1} + \phi^N_t, \quad (33)
\]

\[
\phi^F_t = U_t A_T \left( c_t^T, Z_t F( h_t) \right), \quad (34)
\]

\[
\phi^W_t = Z_t F' ( h_t) U_t A_N \left( c_t^T, Z_t F( h_t) \right), \quad (35)
\]

and the complementary slackness conditions:

\[
\phi^N_t \geq 0; \quad \phi^N_t \left[ d^N - d_{t+1}^* \right] = 0, \quad (36)
\]

\[
\phi^W_t \geq 0; \quad \phi^W_t \left[ \overline{h}_t - h_t \right] = 0. \quad (37)
\]
I now show that there exists a tax policy \(\{\tau_t^{N*}, \tau_t^{d*}\}\) such that allocations \(\{d_{t+1}^*, c_t^T, h_t^*\}\) that satisfy the optimality conditions of the unconstrained first-best, also satisfy (GE') and (22). Pick \(\epsilon_t = 1\) for all \(t\) to satisfy (22). Note that the unconstrained first-best allocation always features full employment: by (35), and since \(Z_t F'(h_t) > 0\), and \(U_c, A_{N,t}(c_t^T, Z_t F(h_t)) > 0\), it follows that \(\phi^{LV}_t > 0\), and thus, by (37), \(h_t^* = \overline{h}\). This implies that (13) always holds. Choose \((1 + \tau_t^{N*}) = \min \left\{ \frac{\left(1 - \frac{a}{\alpha}\right)\left(\frac{c_t^T}{Z_t F(h_t)}\right)^{1/2} Z_t F(h_t)}{\gamma h^{y_{t-1}}}, \frac{\left(\frac{c_t^T}{Z_t F(h_t)}\right)^{1/2} Z_t F(h_t)}{(d_{t+1} - 1 - y_t^*\frac{c_t^T}{Z_t F(h_t)})} \right\}\), and \(w_t^*\) to satisfy (53). This implies that (54) and (11) always hold. Pick \(c_t^{N*} = Z_t F(\overline{h})\) to satisfy (15). Pick \(p_t^* = \frac{1}{1 + \tau_t^{N*}} \left(\frac{1 - a}{\alpha}\right)\left(\frac{c_t^T}{c_t^{N*}}\right)^{1/2}\), to satisfy (51). Pick \(\mu_t^* = \eta_t^* = 0\) for all \(t\). This makes (9) and (5) hold. Pick \(\lambda_t^* = U_c(c_t^{T*}, c_t^{N*}) A_T(c_t^{T*}, c_t^{N*})\) to satisfy (7). Choose \(\tau_t^{d*}\) to satisfy (6) as: \(\tau_t^{d*} = 1 - \frac{E_t \lambda_t^{T+1} + \mu_t^* + \eta_t^*}{\lambda_t^*}\). Choose \(T_t^* = \frac{d_{t+1}}{R_t} \tau_t^{d*} + p_t^* \tau_t^{N*} c_t^{N*}\) to satisfy (52).

C Data Appendix

Argentina. The following data for Argentina were used to estimate the model (27), calibrate the model economy, and compare the predictions of the model with the data.

1. Sectoral data: Constructed using data on value added from agriculture, manufacturing, and services from the WDI dataset. The tradable sector was defined as the sum of agriculture and manufacturing sectors. The nontradable sector was defined as services. Data on relative prices were constructed using current and constant value added on each sector.

2. Measured TFP: Obtained from Aravena and Fuentes (2013) and Penn World Table datasets.\(^{22}\)

3. Interest rates: Since 1994, the country interest rate on external debt was measured as the sum of country EMBI spreads and the US Treasury Bill rate, obtained, respectively, from Datastream and the Federal Reserve of Saint Louis datasets. The series were extended back to 1983 using the Neumeyer and Perri (2005) dataset, which uses a measure similar to the one considered here. The risk-free rate was measured with the Treasury Bill rate. The interest rate series is then deflated with a measure of expected dollar inflation. In particular, \(R_t\) is measured as \(R_t^{\text{dis}} = \mathbb{E}_t \left(\frac{1}{1 + \pi_t^{\text{d}} + 1}\right)\), where \(R_t^{\text{dis}}\) denotes the interest rate on Argentinean external debt in US dollars, and \(\pi_t^{\text{d}}\) denotes US CPI. \(\mathbb{E}_t \left(\frac{1}{1 + \pi_t^{\text{d}} + 1}\right)\) is obtained as the one-step-ahead forecast of an estimated AR(1). US CPI data was obtained from the Federal Reserve of Saint Louis dataset.

4. External debt: Measured using net foreign assets, obtained from the Lane and Milesi-Ferreti (2007) dataset.

\(^{22}\)I am grateful to Claudio Aravena for sharing the data on measured TFP.
5. National accounts: Output, consumption, and net exports, obtained from the WEO dataset.


8. Balance of payments: Current account and factor services obtained from the IFS dataset.

To estimate model (27), data on tradable value added and measured TFP were log-linearly detrended. The following OLS estimates were obtained:

\[
\hat{\Phi} = \begin{bmatrix}
-0.21 & -0.30 & 0.69 \\
0.94 & 0.92 & -0.71 \\
-0.50 & -0.28 & 0.99 \\
\end{bmatrix}, \quad
\hat{\Omega} = \begin{bmatrix}
0.0022 & -0.0009 & 0.0018 \\
-0.0009 & 0.0010 & -0.0007 \\
0.0018 & -0.0007 & 0.0018 \\
\end{bmatrix}, \quad \hat{R} = 1.113.
\]

**Exchange-Rate Policy in EMs – Lehman Episode.** The following data were used in Figure 4:

1. Interest rates: Spreads were measured with the EMBI, obtained from Datastream.

2. Nominal exchange rates and international reserves, EMs: Obtained from the IFS dataset.

Nominal exchange rate and international reserves figures were computed as the simple average for the countries included in the EMBI, except countries with no separate legal tender (Ecuador, El Salvador, and Panama). The countries included in the sample are Algeria, Argentina, Belarus, Belize, Brazil, Bulgaria, Chile, China, Colombia, Cote d’Ivoire, Croatia, Czech Republic, Dominican Republic, Egypt, Gabon, Georgia, Hungary, Indonesia, Jamaica, Jordan, Kazakhstan, Korea, Lebanon, Lithuania, Malaysia, Mexico, Morocco, Namibia, Nigeria, Pakistan, Peru, Philippines, Poland, Romania, Russia, Senegal, South Africa, Sri Lanka, Thailand, Trinidad and Tobago, Tunisia, Turkey, Ukraine, Uruguay, Venezuela, and Vietnam. Data sources and detail of countries included in the sample: See Data Appendix.

**Euro Area.** The countries of the Euro Area included in the quantitative analysis of Section 5.3 are Bulgaria, Cyprus, Estonia, Greece, Ireland, Italy, Latvia, Lithuania, Portugal, Spain, Slovenia and Slovakia. The following data were used to estimate the model (27), calibrate the model economy, and compare the model’s predictions with the data:23

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23Estonia was excluded from the estimation of model (27) because interest-rate data are not available in the data sources used for the other countries.
1. Tradable value added: For Greece, Ireland, Italy, Portugal, and Spain, measured as industrial production, obtained from OECD (available since 1980). For the other countries, constructed as the sum of value added from agriculture and manufacturing, from the WDI dataset.

2. Measured TFP: Obtained from the Penn World Table dataset.

3. Interest rates: Measured as the Maastricht criterion bond yields obtained from Eurostat. For Ireland, the series were extended back using the OECD dataset. The interest rate series were then deflated with a measure of expected inflation from Germany. In particular, since 1999, \( R_{i,t} \) is measured as \( R_{i,t} = R_{i,t}^{eu}E_t \left( \frac{1}{1+\pi_{eu,t+1}} \right) \), where \( R_{i,t}^{eu} \) denotes the interest rate for country \( i \) in Euros, and \( \pi_{eu,t+1}^{*} \) denotes Germany’s CPI. Prior to 1999, \( R_{i,t} \) is measured as \( R_{i,t} = R_{i,t}^{lc}E_t \left( \frac{1}{1+\pi_{t+1}^{*}} \right) \), where \( R_{i,t}^{lc} \) denotes the interest rate for country \( i \) in local currency. \( E_t \left( \frac{1}{1+\pi_{eu,t+1}} \right) \) and \( E_t \left( \frac{1}{1+\pi_{t+1}^{*}} \right) \) were obtained as the one-step-ahead forecast of an estimated AR(1). Germany’s CPI data was obtained from Eurostat.

4. External debt: Measured using net foreign assets, obtained from the Lane and Milesi-Ferreti (2007) dataset.

5. Unemployment rate: Obtained from the WEO dataset.

To estimate model (27), data on tradable value added and measured TFP were log-linearly detrended. The following pooled-OLS estimates were obtained (including in the estimation country fixed effects):

\[
\hat{\Phi} = \begin{bmatrix}
0.69 & -0.28 & 0.28 \\
0.04 & 0.69 & -0.08 \\
-0.08 & -0.12 & -0.89
\end{bmatrix}, \quad \hat{\Omega} = \begin{bmatrix}
0.0022 & -0.0004 & 0.0007 \\
-0.0004 & 0.0005 & -0.0002 \\
0.0007 & -0.0002 & 0.0005
\end{bmatrix} \quad \hat{R} = 1.113.
\]

To estimate the wage rigidity parameter, \( \gamma \), for Latvia and GIPS economies, I follow Schmitt-Grohé and Uribe, 2014 in using data on nominal wages for the period 2008–2011, adjusted by foreign inflation and for long-run growth. Foreign inflation is measured with Germany CPI and long-run growth is measured with average TFP growth. The values of wage rigidity resulting from this estimation are \( \gamma = 0.96 \) for Latvia and \( \gamma = 0.99 \) for GIPS economies. Most of the difference in the wage rigidity parameter between Latvia and GIPS economies is driven by long-run productivity growth, consistent with previous findings of the Latvia recent financial crisis (see Blanchard, Griffiths, and Gruss, 2013).

D Sensitivity Analysis and Extensions

This appendix studies the effect of alternative parametrizations of the model, alternative shocks, alternative modeling assumptions, and the availability of alternative policy instruments on the characterization of the optimal exchange-rate policy during financial crises.
D.1 Parameter Values

This section studies how the characterization of the optimal exchange-rate policy changes with alternative parameter values. In particular, Figure 12 shows the average values of nominal exchange-rate depreciation, real exchange rate, unemployment, and tradable consumption under the optimal exchange-rate policy during periods in which the collateral constraint binds for alternative parameter values. The focus is on financial crises since, as shown in Proposition 1, periods of nonbinding collateral constraint are always characterized by full employment under the optimal exchange-rate policy, independent of parameter values.

I begin by studying alternative values for the intratemporal elasticity of substitution, considering values in the range used in the literature, \( \xi \in [0.4, 0.83] \) (see Section 3.2 for a survey). The value of this parameter used in the baseline calibration is \( \xi = 0.44 \), following the estimates of González-Rozada et al. (2004) for Argentina. As explained in Section 3.2, this parameter determines the extent to which exchange-rate depreciations decrease collateral values. If \( \xi \geq 1 \), a currency depreciation has no negative effect on collateral values, and the optimal policy is always to achieve full employment. As expected from this, Figure 12 shows lower the unemployment rate for the higher values of the intratemporal elasticity of substitution under the optimal exchange-rate policy. In this sense, the conclusions obtained in the baseline calibration are conservative with respect to this parameter value: A higher intratemporal elasticity of substitution would imply an optimal policy even closer to full employment.

I then study alternative values for \( \kappa \), the parameter that governs the collateral constraint. To the best of my knowledge, there is no empirical estimate available of this parameter. In the baseline calibration, this parameter was set to \( \kappa = 0.23 \) to match the probability of sudden stops. I now consider alternative values for the collateral parameter ranging from \( \kappa = 0.2 \) (average debt-to-GDP ratio in Argentinean data) to \( \kappa = 0.32 \) (value considered in Bianchi, 2011). The results shown in Figure 12 indicate that, in this range of parameter values, higher values of the collateral parameter yield lower depreciation rate and higher unemployment and tradable consumption under the optimal exchange-rate policy. The difference is nontrivial: For instance, with \( \kappa = 0.28 \) the average unemployment rate in a period of financial crisis is is 5 percent (which compares to 2 percent in the baseline scenario). The intuition for this result is that higher values of the collateral parameter yield greater effects of containing real exchange-rate depreciation on collateral values and, thus, higher benefits of containing depreciation.\(^{24}\)

Next, I study the sensitivity of the optimal policy during financial crises with respect to the intertemporal elasticity of substitution. In the baseline calibration, the inverse of the inter-

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\(^{24}\)It worth mentioning that the exercise conducted in this section changes only one parameter at a time, maintaining the others as in the baseline calibration. If all of the calibrated parameters (\( \{\beta, a\} \)) were adjusted to match, the average debt-to-GDP ratio and the share-of-tradables results would be closer to those of the baseline calibration.
tertemporal elasticity of substitution was set to $\sigma = 2$, a standard value in the business-cycle literature. Since, as studied in Section 3.2, the benefits of credit-market access are related to the intertemporal allocation of consumption, this is a key parameter in the optimal exchange-rate policy. I consider values of the inverse of the intertemporal elasticity of substitution from $\sigma^{-1} = 2$ to $\sigma^{-1} = 5$, the value estimated in Reinhart and Vegh (1995) for Argentina. Results for this range of parameter values are shown in Figure 12. Quantitatively, the conclusions are similar to those obtained in the baseline calibration.

Finally, it worth mentioning that $\gamma$, the degree of wage rigidity, does not affect the allocation under the optimal exchange-rate policy, except for the value of the optimal nominal depreciation rate, $\epsilon_t$. This can be seen from the fact that $\gamma$ does not enter in the Bellman equation (19) describing the dynamics of $\{d_{t+1},c^T_t,h_t\}$ under the optimal exchange-rate policy. It follows that the real exchange-rate depreciation, under the optimal exchange-rate policy, also does not depend on $\gamma$. The only variable under the optimal exchange-rate policy that is affected by $\gamma$ is the nominal exchange-rate depreciation: A lower $\gamma$ requires a lower average nominal exchange-rate
depreciation to implement the optimal allocation during a financial-crisis episode, as illustrated
in Figure 12.

**D.2 Stochastic Structure**

The baseline quantitative analysis (Section 4) includes interest-rate shocks and uses the contractual interest rate to calibrate these shocks. This section considers instead three alternative stochastic structures: i) an economy with interest-rate shocks calibrated to the risk-free rate, ii) an economy with no interest-rate shocks, and iii) an economy with no interest-rate shocks but shocks to the parameter $\kappa$ governing the collateral constraint. These alternative environments are important because, in the presence of credit constraints, calibrating the model using the EM’s contractual interest rate (as in the baseline calibration), which incorporates default risk, could overestimate the costs of borrowing during crises.

The first case considers an economy with interest-rate shocks calibrated to those of the risk-free rate. As in the baseline calibration, it is assumed that the three exogenous driving forces—tradable endowment, interest rates, and TFP—follow a first-order VAR of the form in (27), with the risk-free rate taking the place of the country’s interest rate. The risk-free rate is measured by a US real interest rate (Treasury-bill rate, deflated with a measure of expected dollar inflation, constructed as detailed in the Data Appendix C). Following Uribe and Yue (2006), I assume that the risk-free rate follows a univariate process (i.e., $\Phi_{21} = 0$) and estimate the parameters of the stochastic process for the same period and using the same methodology as in the baseline calibration. I use the parameters $\{\beta, a, \kappa\}$, as in the baseline calibration, to match the average level of external debt-to-GDP ratio, the share of tradable output in GDP, and the frequency of sudden stops observed in the data. The remaining parameters are set as in the baseline calibration (Table 1).

The second case considers an economy with no interest-rate shocks. In this economy, tradable endowment shocks are the only source of uncertainty and are assumed to follow the same stochastic process as in the baseline calibration. The fixed gross interest rate is set to 1.018, the average US real interest rate from 1980 to 2011. Again, as in the baseline calibration, the parameters $\{\beta, a, \kappa\}$ are used to match the average level of external debt to GDP, the share of tradable output in GDP, and the frequency of sudden stops observed in the data, with the other parameters set as in the baseline calibration (Table 1).

Finally, the third case considers an economy with no interest-rate shocks, but instead with shocks to the parameter $\kappa$, which governs the collateral constraint. These types of shocks have been used in the literature to capture sudden stops driven by shocks to foreign investors’ confidence in EMs (see, for example, Benigno and Fornaro, 2012; Bianchi, Hatchondo and
Martinez, 2013). Formally, the collateral constraint (18) is now replaced with
\[
d_{t+1} \leq \kappa_t \left( y_t^T + \left( \frac{1-a}{a} \right) (c_t^T)^{\frac{1}{2}} F(h_{t})^{\frac{1}{2}} \right),
\]
where \( \kappa_t \) follows a first-order Markov process. As is standard in this literature, I assume for simplicity that \( \kappa_t \in \{ \kappa^L, \kappa^H \} \), with \( \kappa^L < \kappa^H \). The value of \( \kappa^H \) is set to an arbitrarily high value such that the collateral constraint never binds in period \( t \) if \( \kappa_t = \kappa^H \). Similar to the baseline calibration, the parameters \( \{ \beta, a, \kappa^L \} \) are used to match the average external debt-to-GDP ratio, the share of tradable output in GDP, and the frequency of sudden stops observed in the data. Following Benigno and Fornaro (2012), the probability of entering a low-collateral-constraint state, denoted \( \pi^L_{\kappa} \), is set to 0.1 (Jeanne and Ranciere, 2011), and the probability of exiting a low-collateral-constraint state, denoted \( \pi^H_{\kappa} \), is set to 0.5 (Alfaro and Kanczuk, 2009). The other parameters are set as in the baseline calibration (Table 1).

Figure 13: Financial Crises – Optimal Policy under Alternative Stochastic Structures.

Note: Real exchange rate, real wage, and external debt expressed in log deviations from their sample means. Current account expressed in deviations from its sample mean. Devaluation rate and unemployment rate expressed in levels. See Section 4.3 for the definition of a financial-crisis episode.

Figure 13 displays the optimal nominal exchange rate and endogenous variables for the average financial-crisis episode (as defined in Section 4.3), under the baseline and the three alternative stochastic structures. Results indicate that the stochastic structure is a key factor to determining the optimal degree of “fear of floating” during financial crises. On the one hand,
when a financial crisis occurs with no increases in the interest rate but with an exogenous contraction in the income share that can be pledged as collateral, the optimal policy displays larger currency depreciation and current-account adjustment than in the baseline economy. On the other hand, when the financial crisis occurs with no significant increase in interest rates or with no contraction in the share of income that can be pledged as collateral, the optimal policy consists of avoiding currency depreciations and current-account adjustments. Therefore, increases of external interest rates or collapses in pledgeability can be relevant elements explaining the presence of sudden-stop episodes (or large current-account adjustments) in EMs.

D.3 Model Structure

This section studies the characterization of optimal exchange-rate policy after relaxing two assumptions of the baseline model: endowment in the tradable sector and inelastic labor supply.

D.3.1 Production in the Tradable Sector

This section relaxes the baseline model’s assumption of tradable endowment and instead considers production in the tradable sector. This a relevant modification to study since, as shown in Benigno et al. (2012a), labor reallocation is an important mechanism in dealing with financial crises in the presence of a collateral constraint like the one studied in this paper. To facilitate the reallocation, it will be assumed – in sharp contrast to the baseline model – that labor is perfectly mobile across sectors.

As in the nontradable sector, production in the tradable sector is now assumed to be conducted by firms that operate in competitive labor and product markets, each period hiring labor to produce the tradable good, $y_t^T$, and using an isoelastic production function. Profits each period, expressed in units of tradable goods, are given by

$$\Pi_t^T = Z_t^T \left( h_t^T \right)^{\alpha_T} - w_t h_t^T,$$

where $h_t^T$ denotes labor employed in the tradable sector and $Z_t^T$ denotes productivity in the tradable sector, assumed to be exogenous and stochastic.

The firms’ problem is to choose $h_t^T$ to maximize profits given prices $w_t$ and productivity $Z_t^T$. The first-order condition of this problem is

$$Z_t^T \alpha_T \left( h_t^T \right)^{\alpha_T - 1} = w_t. \quad (39)$$

Total hours worked is now given by the sum of hours worked in the tradable sector and hours worked in the nontradable sector (denoted $h_t^N$):

$$h_t = h_t^T + h_t^N. \quad (40)$$
The other equilibrium conditions are the same as in the baseline economy. To calibrate the model, the labor share in the tradable sector is set to $\alpha^T = 0.5$ following evidence in Uribe (1997). The parameters $\{\beta, a, \kappa\}$ are used, as in the baseline calibration, to match the average level of external debt to GDP, the share of tradable output in GDP, and the frequency of sudden stops observed in the data. The remaining parameters are set as in the baseline calibration (Table 1). Given the lack of historical sectoral data on measured TFP for Argentina, and to facilitate comparison with the baseline calibration, it is assumed that the stochastic process is the same as in (27), with $Z_t^T$ taking the place of $y_t^T$.

Figure 14 shows that the optimal exchange-rate policy in the economy with production in the tradable sector features less unemployment than in the baseline economy. This is because currency depreciations have a greater benefit in this modified setup than in the baseline economy, reallocating resources and increasing production in the tradable sector. This increase in tradable production, in turn, loosens the collateral constraint and reduces the required current-account adjustment. Therefore, in equilibrium, even if currency depreciation is smaller than in the baseline economy, unemployment is also smaller than that observed in the baseline economy. These results indicate that the degree of labor mobility across sectors is a key characteristic of the economy for determining the optimal degree of “fear of floating,” as well as the severity of financial crises in terms of unemployment and current-account adjustment.

### D.3.2 Endogenous Labor Supply

In this section, the assumption of inelastic labor supply is relaxed. I assume, instead of (1), that households’ preferences are given by the expected utility function

$$
\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t (U(c_t) - v(h_t)),
$$

where the function $v(\cdot)$ is assumed to be continuous, twice differentiable, strictly increasing and convex.

The first-order condition with respect to hours worked is given by

$$
v'(h^*_t) = w_t \lambda_t,
$$

where $h^*_t$ denotes the number of hours supplied by households to the labor market.

Actual hours worked cannot exceed labor supply, meaning that labor-market conditions (12) and (13) are replaced, respectively, by

$$
\begin{align*}
h_t &\leq h^*_t \text{ and } \\
\left( w_t - \gamma \frac{w_{t-1}}{\epsilon_t} \right) (h^*_t - h_t) &= 0.
\end{align*}
$$
The other equilibrium conditions are the same as in the baseline economy.

To calibrate the model, we assume the functional form
\[ v(h_h) = -\varphi \frac{(\bar{h} - h_h)^{1-\theta} - 1}{1 - \theta}, \]  
\[ (45) \]
where \( \varphi > 0 \) and \( \theta > 0 \). The values of \( \bar{h} \) and \( \varphi \), are set to 3 and 1.5 to match an average level of hours worked at unity (to preserve the size of the nontradable sector), assuming that households at full employment spend one third of their time working. The value of \( \theta \) is set to 1.6 which corresponds to an elasticity of labor supply of 1.25, following the estimates in Mendoza (2010). The parameters \( \{\beta, a, \kappa\} \) are used, as in the baseline calibration, to match the average external-debt-to-GDP ratio, the share of tradable output in GDP, and the frequency of sudden
stops observed in the data. The other parameters are set as in the baseline calibration (Table 1).

Figure 14 shows that the optimal exchange-rate policy in an economy with an endogenous labor supply features significantly more unemployment during financial crises than in the baseline economy, showing that labor elasticity is also a relevant characteristic of the economy for determining the optimal degree of “fear of floating.” The contraction in the level of employment is greater than in the baseline economy since, in this setup, decreasing employment has a benefit not only in terms of relaxing the credit constraint, but also in terms of increasing leisure. However, most of this increase in unemployment is driven by an increase in the labor supply: Unlike the Ramsey planner, agents do not incorporate the tightening effect that increasing employment has on the collateral constraint; they increase labor supply during financial crises because of the large contraction in consumption that occurs during these episodes.

D.4 No Capital-Control Taxes

So far, the paper has characterized the optimal exchange-rate policy as conditional on the use of an optimal capital-control tax. As discussed in Section 3, this optimal capital-control tax eliminates any inefficient borrowing that might stem from the collateral constraint or from the downward wage rigidity. This section studies the sensitivity of the optimal policy to this assumption by extending the analysis to the case where the only instrument available to the Ramsey planner is the nominal exchange rate.

The Ramsey planner is assumed to have access to a commitment technology. Since the household’s intertemporal optimality condition (6) is part of the set of restrictions, the Ramsey problem cannot, as in Section 3, be expressed with a standard recursive formulation. However, the method developed in Marcet and Marimon (2011) can be applied to reformulate the nonrecursive problem with forward-looking variables as a recursive saddlepoint problem. This approach implies the inclusion of the Lagrange multipliers associated with forward-looking constraints (in this case, equation (6)) as costate variables.

Without capital-control taxes, the general equilibrium dynamics are given by stochastic processes \( \{c_t^N, c_t^T, h_t, p_t, w_t, d_{t+1}, \lambda_t, \mu_t\}_{t=0}^{\infty} \) satisfying the set of equations (GE'): \( \{(5)-(9), (11)-(13), (15)-(18)\} \) given an exchange-rate policy \( \{\epsilon_t\}_{t=0}^{\infty} \), initial conditions \( w_{-1} \) and \( d_0 \), and exogenous stochastic processes \( \{s_t^X\}_{t=0}^{\infty} \). To characterize the allocation under the optimal exchange-rate policy, without optimal capital-control taxes, and under commitment, I begin by set-

\(^{25}\)This problem does not arise when the Ramsey planner has access to an optimal capital-control tax since, as shown in Appendix A, the capital-control tax can always be picked so that the optimal allocation satisfies the intertemporal optimality condition (6).

\(^{26}\)For related applications of the Marcet and Marimon (2011) method, see Adam and Billi (2005), Monacelli (2008), and Svensson (2010).
tting up the Ramsey problem and dropping constraints (8), (11), (13), and (15)–(16). Any \( \{ d_{t+1}, c^T_t, h_t, \lambda_t, \mu_t \} \) that satisfy (5)–(7), (9), (12), (17), and (18), also satisfy (GE'). To see this, pick \( c^N_t = Z_t F(h_t) \) to satisfy (15). Pick \( p_t = \left( \frac{1-a}{a} \right) \left( \frac{c^T_t}{c^N_t} \right) \) to satisfy (8). Pick \( w_t = \left( \frac{1-a}{a} \right) \left( c^T_t \right)^{1/2} Z_t^{1-1/2} Z_t^{1-1/2} F(h_t) \) to satisfy (16). Given \( w_{t-1} \), pick \( \epsilon_t \) to satisfy (11) with equality: \( \epsilon_t = \gamma \frac{w_{t-1}}{w_t} \). Finally, since (11) holds with equality, (13) always holds: \( (w_t - \gamma \frac{w_{t-1}}{w_t}) (\overline{h} - h_t) = 0 \). The Ramsey problem is then given by

\[
\max_{\{ d_{t+1}, c^T_t, h_t, \lambda_t, \mu_t \}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U \left( A \left( c^T_t, Z_t F(h_t) \right) \right) \\
\text{s.t. } d_{t+1} \leq d^N, \\
\lambda_t R_t^{-1} = \beta \mathbb{E}_t \lambda_{t+1} + \mu_t, \\
U_c \left( c^T_t, c^N_t \right) A_T \left( c^T_t, c^N_t \right) = \lambda_t, \\
\mu_t \geq 0, \\
\mu_t \left( \frac{1}{\overline{a}} + p_t Z_t F(h_t) \right) - d_{t+1} = 0, \\
h_t \leq \overline{h}, \\
d_{t+1} = d_t + c^T_t - y^T_t, \\
d_{t+1} \leq \kappa \left( y^T_t + \left( \frac{1-a}{a} \right) \left( c^T_t \right)^{1/2} Z_t^{1-1/2} Z_t^{1-1/2} F(h_t) \right) \left( \phi^D_t R_t - \tilde{\phi}^D_{t+1} \right) + \phi^D_t \mu_t. \\
\] (46)

To obtain the recursive formulation using the method of Marcet and Marimon (2011), the following steps are followed (as in Adam and Billi, 2005). First, set the Lagrangean of problem (46), denoting \( \phi^D_t \) the Lagrange multiplier associated with the forward-looking constraint (6). Since equation (6) is forward looking, some terms in the Lagrangean involve period \( t \) Lagrange multipliers multiplied by period \( t+1 \) controls (e.g., \( \phi^D_t R \mathbb{E}_t \lambda_{t+1} \)). Second, in these terms, relabel the Lagrange multipliers multiplied by period \( t+1 \) controls as \( \tilde{\phi}^D_{t+1} \). This relabeling defines a “transition” equation: \( \phi^D_t = \tilde{\phi}^D_{t+1} \). Third, define the period objective function:

\[
H \left( c^T_t, h_t, \mu_t, \phi^D_t, \tilde{\phi}^D_{t+1}, s^X_t \right) \equiv U \left( A \left( c^T_t, Z_t F(h_t) \right) \right) \\
- U_c \left( c^T_t, Z_t F(h_t) \right) A_T \left( c^T_t, Z_t F(h_t) \right) \left( \frac{\phi^D_t}{R_t} - \tilde{\phi}^D_{t+1} \right) + \phi^D_t \mu_t. \\
\] (47)

Fourth, using the equivalence results shown in Marcet and Marimon (2011), reexpress (46) as
an infinite-horizon saddlepoint problem:

\[
\min_{\phi_D} \max_{d_{t+1}, c_t^T, h_t, \mu_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t H \left( c_t^T, h_t, \mu_t, \phi_D^t, \phi_D, s_t^X \right)
\]

\[
\text{s.t. } \phi_D^{t+1} = \phi_D^t
\]
\[
d_{t+1} \leq d_N,
\]
\[
\mu_t \geq 0,
\]
\[
\mu_t \left( \kappa \left( y_t^T + p_t Z_t F (h_t) \right) - d_{t+1} \right) = 0,
\]
\[
h_t \leq h,
\]
\[
d_{t+1} R_t^{-1} = d_t + c_t^T - y_t^T,
\]
\[
d_{t+1} \leq \kappa \left( y_t^T + \left( \frac{1 - a}{a} \right) \left( \frac{1 - \xi}{\xi} \right) Z_t^{1-\frac{1}{\xi}} F (h_t)^{1-\frac{1}{\xi}} \right),
\]
\[
\tilde{\phi}_0 = 0.
\]

Finally, rewrite the infinite-horizon saddlepoint problem (48) in recursive form:

\[
W^{OP} \left( s^X, d, \tilde{\phi}^D \right) = \min_{\tilde{\phi}^{D'}} \max_{d', c_t^T, h, \mu} \left[ H \left( c_t^T, h, \mu, \tilde{\phi}^{D'}, s_t^X \right) + \beta \mathbb{E}_{s^X} W^{OP} \left( s'^{X_t}, d', \tilde{\phi}^{D'} \right) \right] 
\]

\[
\text{s.t. } d' R = d + c_t^T - y_t^T,
\]
\[
d' \leq \kappa \left( y_t^T + \left( \frac{1 - a}{a} \right) \left( \frac{1 - \xi}{\xi} \right) Z_t^{1-\frac{1}{\xi}} F (h)^{1-\frac{1}{\xi}} \right),
\]
\[
d' \leq d_N,
\]
\[
h \leq h,
\]
\[
\mu \geq 0,
\]
\[
\mu \left( \kappa \left( y_t^T + \left( \frac{1 - a}{a} \right) \left( \frac{1 - \xi}{\xi} \right) Z_t^{1-\frac{1}{\xi}} F (h)^{1-\frac{1}{\xi}} \right) - d' \right) = 0,
\]

where time subscripts for variables dated in period \( t \) have been dropped, and a prime is used to indicate variables dated in period \( t + 1 \).

To approximate the dynamics under the optimal exchange-rate policy, the functional equation (49) is solved numerically. The parameters used are the same as in Table 1. Figure 15 shows that the dynamics during financial-crisis episodes under the optimal exchange-rate policy without capital-control taxes are similar to those under the optimal exchange-rate policy with optimal capital-control taxes. The main difference is that, in the case without capital-control taxes, the presence of additional states and controls in the case of optimal policy without an optimal capital-control tax makes the numerical approximation computationally more demanding. For this reason, the approximation uses a grid of five equally spaced points for both \( \ln (y_t^T) \) and \( \ln (\frac{d_t}{R}) \), 51 equally spaced points for \( (d_t) \), and 21 equally spaced points for \( (\tilde{\phi}_0^D) \). For comparison purposes (in this section only), these grids were also used to solve numerically for the optimal exchange rate with optimal capital-control taxes.
taxes, the optimal allocation displays a higher nominal and real exchange-rate depreciation and, as a result, a smaller unemployment and a larger current-account adjustment. Therefore, without capital-control taxes, the optimal policy commits to make credit-access tighter during financial-crisis episodes, increasing the private cost of borrowing.

**Figure 15: Financial Crises – Optimal Policy with No Capital-Control Taxes.**

*Note*: Real exchange rate, real wage, and external debt expressed in log deviations from their sample means. Current account expressed in deviations of its sample mean. Devaluation rate and unemployment rate expressed in levels. See Section 4.3 for the definition of a financial-crisis episode.

### D.5 Fiscal Devaluations

This section compares exchange-rate to fiscal devaluations. Motivated by the recent financial crisis in the Euro area, a part of the related literature has focused on fiscal alternatives to exchange-rate devaluations, or *fiscal devaluations* (see, for example, Farhi, Gopinah, Itskhoki, 2014; Schmitt-Grohé and Uribe, 2014). A key result, in the case of an economy with a collateral constraint linking debt to the value of tradable and nontradable income, is the one obtained in Benigno et al. (2012b): Using taxes on nontradable or tradable consumption, the Ramsey planner can achieve the unconstrained first-best solution. A similar result can be shown in the setup of the present paper with the presence of a downward nominal wage rigidity, and even under a currency peg.

To study fiscal devaluations, I begin by expanding the setup of the model economy considered in Section 2 by assuming that the policymaker, in addition to the capital-control tax, has access
to a tax (subsidy) on nontradable consumption, $\tau_t^N$. Households’ sequential budget constraint is now given by
\[
\frac{d_{t+1}}{R_t} \left(1 - \tau_t^d\right) = d_t + c_t^T + p_t (1 + \tau_t^N) c_t^N - (y_t^T + w_t h_t + \Pi_t) - T_t. \tag{50}
\]

From this, the four equilibrium conditions that are modified in the system of equations (GE), defining the general equilibrium dynamics of the baseline economy (Section 2), are (a) the equilibrium price of nontradables (8), (b) the equation that defines the government balanced budget each period (14), (c) the firms’ optimality condition in equilibrium (16), and (d) the collateral constraint (18). These equations are replaced, respectively, by
\[
p_t = \frac{1}{1 + \tau_t^N} \left(1 - \frac{a}{a} \right) \left(\frac{c_t^T}{c_t^N}\right)^{\frac{1}{\xi}}, \tag{51}
\]
\[
\frac{d_{t+1}}{R_t} \tau_t^d + p_t \tau_t^N c_t^N = T_t, \tag{52}
\]
\[
w_t = \frac{1}{1 + \tau_t^N} \left(1 - \frac{a}{a}\right) \left(\frac{c_t^T}{c_t^N}\right)^{\frac{1}{\xi}} Z_t^{1-\frac{1}{\xi}} F'(h_t), \tag{53}
\]
\[
d_{t+1} \leq \kappa \left(y_t^T + \frac{1}{1 + \tau_t^N} \left(1 - \frac{a}{a}\right) \left(\frac{c_t^T}{c_t^N}\right)^{\frac{1}{\xi}} Z_t^{1-\frac{1}{\xi}} F'(h_t)\right). \tag{54}
\]

Thus, the general equilibrium dynamics in this expanded setup are given by stochastic processes $c_t^N, c_t^T, h_t, p_t, w_t, d_{t+1}, \lambda_t, \mu_t, \eta_t$, and $T_t$ satisfying the set of equations (GE’): (5, 6, 7, 9, 11, 12, 13, 15, 17, 51, 52, 53, 54) given an exchange-rate policy $\{\epsilon_t\}_{t=0}^\infty$, a capital-control tax policy $\{\tau_t^d\}_{t=0}^\infty$, a tax policy on nontradable consumption $\{\tau_t^N\}_{t=0}^\infty$, initial conditions $w_{-1}$ and $d_0$, and exogenous stochastic processes $\{s_t^X\}_{t=0}^\infty$.

The following proposition shows that, in an economy with a currency peg, a tax on nontradable consumption and a capital-control tax, the Ramsey planner can achieve the unconstrained first-best solution for the economy.

**Proposition 3.** Define the unconstrained first-best solution as processes $\{d_{t+1}^*, c_t^T*, h_t^*\}$ that solve
\[
\max_{\{d_{t+1}, c_t^T, h_t\}} \mathbb{E}_0 \sum_{t=0}^\infty \beta^t U \left(A \left(c_t^T, Z_t F(h_t)\right)\right)
\]
\[
\text{s.t.} \quad \frac{d_{t+1}}{R_t} = d_t + c_t^T - y_t^T, \quad h_t \leq \overline{h}, \quad d_{t+1} \leq d_N^N.
\]

In an economy defined by (GE’) and (22), there exists a tax policy $\{\tau_t^N, \tau_t^d\}$ that decentralizes the unconstrained first-best solution.

---

28 The optimal allocation attained under a tax (subsidy) on nontradable consumption can alternatively be attained with a tax (subsidy) on tradable consumption.
Proof. See Appendix B.

This result implies that the credit-access–unemployment trade-off analyzed in this paper is a particular feature of exchange-rate policy, not necessarily present in some fiscal alternatives to exchange-rate policy that have been studied in the literature as fiscal devaluations. This is because, under binding wage rigidity, while an exchange-rate depreciation decreases real wages and expands the supply of nontradables (equation (10)), which is associated with an increase in employment and a decrease in the price of nontradable goods (real exchange-rate depreciation), an increase in a subsidy to nontradable consumption expands the demand for nontradables for every level of tradable consumption (equation (51)), which is associated with both an increase in employment and an increase in the relative price of nontradable goods. For this reason, while an exchange-rate devaluation decreases collateral values, a fiscal devaluation implemented with a subsidy on nontradable consumption implies an increase in collateral values and no trade-off between credit access and unemployment. Thus, with fiscal devaluations, the policymaker can simultaneously achieve full employment and ensure the collateral constraint does not bind, as implied by Proposition 3.

The implications of this analysis are twofold. First, from a theoretical perspective, it shows that the conclusions obtained from analyzing taxes on nontradable goods cannot in general be interpreted as conclusions for exchange-rate policy. Second, from a policy perspective, this analysis suggests that in the presence of collateral constraints in the form of tradable and nontradable output, fiscal devaluations might be a better instrument for responding to large negative shocks than exchange-rate devaluations.