Optimal Monetary and Fiscal Policy in a New Keynesian Model with a Dutch Disease: The Case of Complete Markets *

Constantino Hevia
Universidad Torcuato Di Tella
The World Bank

Pablo Andrés Neumeyer
Universidad Torcuato Di Tella
CONICET

Juan Pablo Nicolini
Universidad Torcuato Di Tella
Federal Reserve Bank of Minneapolis

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Abstract

We analyze optimal policy in New Keynesian model of a small open economy with access to complete asset markets and *"Dutch Disease"* periods, in which terms of trade shocks reallocate resources away from the manufacturing sector. Following the policy debate, we introduce an externality in the manufacturing sector that makes the Dutch disease periods inefficient. We show theoretically that if the government has access to standard taxes that can be made time and state dependent, the optimal monetary policy implies complete price stability. The optimal intervention to deal with the externality in manufacturing is a subsidy. We next assume that taxes do not respond to temporary shocks and study monetary policy as the sole stabilization instrument. Using a calibrated version of the model we show that the externality and the lack of other policy instruments do not justify sizeable departures from price stability.

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1 Introduction

The most fundamental role of a Central Bank is to achieve price stability. On this account, the current inflation targeters of Latin American have accomplished much more than anyone would have believed two decades ago. Indeed, while Latin America was the kingdom of inflation in the early 1990s, inflation rates today in countries such as Brazil, Chile, Mexico, Peru and others are in the single digits, and many of them indistinguishable from developed countries' performance. This amazing success deserves proper credit.

True, the beast was not domesticated within an inflation targeting regime: nominal exchange rate controls have been used during the transition time. But once inflation rates were relatively quickly brought down (the speed varied across countries), the inflation targeting regime was the one used to maintain it within the desirable range for over a decade now. In the war against inflation in Latin America, the inflation targeting regimes have been extremely successful occupation forces. The war has been won.[1]

Once the main free lunch monetary policy can give to a society is ready and on the table, is there an additional role for monetary policy? This is the main question addressed by the New Keynesian literature in the last two decades. By explicitly modeling frictions in the setting of prices in a tractable way, we can use these models to address the role of stabilization policy, understood as cyclical and state contingent short lived deviations from perfect price stability.

Addressing this question is at the heart of monetary policy design, even within the context of inflation targeting regimes. Indeed, the main characteristic of inflation targeting is to specify explicitly the target for inflation within a relatively long period of time, like two years. But there is room for alternative specifications of what policy can do for short periods of time, say half a year, subject to the constraint that long run inflation must be within the target. The purpose of this paper is to study optimal temporary deviations from the inflation target in a model where there are temporary terms of trade shocks, with a particular focus on commodity exporting small open economies. Many Latin American countries fall in this category and we will apply our model to three of them: Brazil, Chile, and Mexico.

Concern regarding shocks to commodity prices runs very high in the political agenda of these countries. For small open economies (say Chile) a drop in the exportable commodity price (cooper) is seen as recessionary; the same happens following an increase in the price

[1] Not all countries in the region adopted inflation targeting and not all countries in the region have low inflation rates for developed countries standards. But the high inflation of today is lower than the low inflation two decades ago and the successful countries - the majority in the region - are living proofs of success.

of the importable commodity (oil) [2] It is precisely to hedge against this uncertainty that, in recent years, countries in which the government either owns or taxes the firms that produce a particular commodity, like Norway (oil) and Chile (cooper), passed legislation forcing the Treasury to save in foreign assets in periods when the commodity prices are "high," in order to be able to spend more in times in which the prices are "low." While it is clear that volatility of international commodity prices can give rise to fiscal policies like the one just described, it is less clear what are its implications, if any, regarding monetary and exchange rate policy. In small open economies (SOE), movements in the nominal exchange rate are important shock absorbers. In a world with fully flexible prices, this should not be important. But in the presence of nominal rigidities, as emphasized in the "New open economy macroeconomics" literature, shocks to the terms of trade could lead to inefficient real effects. This is the main theme of our paper.

The one we address is a central question for policy design in small open economies. For example, both New Zealand and Chile have explicitly adopted an inflation targeting policy. This means that the Central Bank defines an inflation rate on the consumer price index as its main policy objective. In a hard inflation targeting regime, where the only objective of monetary policy is to achieve the target, the Central Bank should abstain from foreign exchange interventions and let the nominal exchange rate be fully market determined. It turns out, however, that the resulting volatility of the nominal exchange rate is very high which, in the context of an inflation targeting regime, translates into real exchange rate volatility. This translates into very volatile local costs evaluated in foreign currency, leading to a Dutch disease cycle. It is this concern regarding Dutch disease episodes that drive most of the policy debate in Latin-American countries. And it is certainly the one that poses most of the pressures on Central Bankers.

It is precisely because of the high real exchange rate volatility and the Dutch disease episodes that follow, that the institutional frameworks allow Central Banks to deviate from the pure inflation targeting policy under " special circumstances", even in explicit inflation targeting regimes. The Central Bank of Chile did so in April 2008 and announced a program for buying international reserves (for an amount close to 40 percent of the existing stock) after the nominal exchange rate went from over 750 pesos per dollar in March 2003 to below 450 in March 2008. The program was suspended with only 70 percent of the announced purchases completed in September 2008, once the exchange rate jumped back to around 650 pesos. A new program to buy reserves was announced in January 2011 with a total amount over 40 percent of the existing stock. At that time, the exchange rate was around 475 pesos per dollar. The exchange rate in December 2012 was again around 475 pesos per dollar.

[2]Chile imported over 90% of the oil consumed during the last 10 years.

The justification used by the board of the Central Bank of Chile was that "The international economy presents an unusual state, characterized by high commodity prices, low interest rates, slow recovery of the developed economies, and depreciation of the US dollar." [3]

Is this an optimal policy in a small open economy facing large shocks to commodity prices? The model we analyze in this paper builds from the existing literature and provides a step forward in providing an answer to that question.

The current literature that studies optimal monetary policy with price frictions in small open economies has totally ignored commodities, it is therefore unable to reproduce these facts, so it provides no useful guide to the policy questions we study in this paper. The two exceptions are Catão and Chang (2013) and Hevia and Nicolini (2013). The first is an empirical investigation about the performance of simple linear rules for monetary policy in an environment with incomplete markets. The second is a theoretical investigation using a similar model but with complete markets. The main finding in Hevia-Nicolini is that for the preferences typically used by the open economy models with price frictions, price stability is optimal independently of the shocks to terms of trade, even if fiscal instruments are restricted to be time and state independent. Thus, even though the model exhibits the periodic recurrence of Dutch disease episodes, they are indeed optimal.

In this paper, we modify the model in Hevia-Nicolini to allow for an explicit inefficiency in the reallocation of resources brought about by the Dutch disease and study how an inflation targeting regime should respond to terms of trade shocks in the short run, while still aiming at reaching the target in the long run.

Our approach in designing the model is very pragmatic and pretends to be a first step in studying quantitatively optimal monetary policy in economies facing Dutch disease episodes. The typical justification for intervention when currencies appreciate following an improvement in the price of the exportable commodity is that local costs in foreign currency go up, reducing competitiveness in manufacturing, hurting its ability to export. This is exactly what happens in the model we develop. But, as we show, these reallocations across sector are in general optimal. One may obviously consider reasonable departures from efficient markets that could make the private and social returns of these reallocations different, so there could be a role for policy, and the policy debate is full of candidates.

Our pragmatism explains why we chose to allow for an external effect in the production of manufactures.[4] Modeling the particular frictions - like matching models of labor reallocation, irreversibility of investment, etc. - is cumbersome. In this first exploration into this issue, we

[3]The statement can be found in http://www.estrategia.cl/detalle_noticia.php?cod=36317. The translation to English has been made by the authors.

[4]The explicit treatment of exportable manufactures implies that the model we use is substantially more complicated than the one in Hevia-Nicolini. A side advantage is that it allows for more serious calibration.

take this externality as a reduced form for all the imaginable sources of departures between social and private returns. Our objective is to provide an answer to the following question: how large should an external effect be to justify a sizable departure from full price stability?

The answer was as a surprise to us: implausibly large. Therefore, we conclude, as long as the model captures the main features of these economies, there is little reason to depart from full price stability.

On the methodological front, we depart from the literature in that we consider distorting fiscal instruments, as in Lucas and Stokey (1983) and Correia, Nicolini and Teles (2008). This approach has the advantage of making explicit all the existing distortions in the economy. The analysis thus provides a minimal set of monetary and fiscal instruments required to achieve the second best allocation. We then use the model to evaluate the welfare cost of imposing restrictions on the available instruments.

We abstract from the question of the best intermediate target for monetary policy and also from the question of implementability. We characterize sequences of nominal exchange rates, $\{S_t\}_{t=0}^{\infty}$, that are consistent with the optimal allocation, but we abstract from the bigger question of how to implement that allocation. Implicit in the solution of the optimal policy there is a sequence of nominal interest rates $\{R_t\}_{t=0}^{\infty}$ that is consistent with the allocation. We also abstract from time inconsistency and assume full commitment.

The paper proceeds as follows. In Section 2 we present the model and find the conditions for an equilibrium. In Section 3 we solve for the optimal fiscal an monetary policy. In Section 3 we discuss the restrictions on policy instruments such that full price stability is not optimal. In Section 4, we discuss how the equilibrium works once we impose those restrictions in the policy instruments and also discusses some simple linear policy rules. In Section 6 we discuss the functional form and the calibration of the model for three countries in the region, Brazil, Chile and Mexico. Section 7 presents and discusses the results, and Section 8 concludes.

2 The model

We consider a New Keynesian model of a small open economy that trades commodities and intermediate manufacturing goods with the rest of the world. Time is discrete and denoted by $t = 0, 1, 2, ...$ There is a continuum of non-tradable final goods produced by retailers, each of whom has access to an identical technology but produces a different variety of the final good. Retailers enjoy monopolistic power over the variety of goods they produce but there are constraints in their ability to change nominal prices. In particular, we use a model of Calvo pricing whereby, in any given period, only a fraction $\alpha \in [0, 1]$ of the retailers are able to change their nominal prices. There is a manufacturing sector subject to a potential Dutch disease problem. As mentioned in the introduction, we model the Dutch disease problem through an externality by assuming that total factor productivity in the manufacturing sector is a function of the aggregate amount of labor used in the sector. Importantly, each individual firm does not internalize that their labor choices affect aggregate productivity. There is, in addition, a sector that produces an exportable commodity that is subject to exogenous commodity price shocks and an importable commodity produced in foreign markets that can be traded at an exogenously given price. We now describe the model in detail.

2.1 Households

There is a representative household that has preferences over contingent sequences of final consumption goods C_t and labor N_t. The utility function is represented by

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, N_t) \tag{1}$$

where $0 < \beta < 1$ is a discount factor.

The final good C_t is a Dixit-Stiglitz composite good defined by

$$C_t = \left[\int_0^1 c_{it}^{\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}},$$

where c_{it} are the different varieties of consumption goods and $\theta > 1$ is the elasticity of substitution between any pair of varieties.

Taking as given the final good price, P_t, and the prices of each individual variety of intermediate goods, P_{it} for $i \in (0, 1)$, cost minimization by consumers implies

$$c_{it} = C_t \left(\frac{P_{it}}{P_t} \right)^{-\theta} \tag{2}$$

for all $i \in (0, 1)$. Integrating this condition over all varieties and using the Dixit-Stiglitz aggregator gives a price index relating the final good price and the prices of the individual varieties,

$$P_t = \left(\int_0^1 P_{it}^{1-\theta} di \right)^{\frac{1}{1-\theta}}. \tag{3}$$

Financial markets are complete. We let $B_{t,t+1}$ and $B^*_{t,t+1}$ denote one-period discount bonds denominated in domestic and foreign currency respectively. These are bonds issued at period t that pay one unit of the corresponding currency at period $t + 1$ on a particular state of the world and zero otherwise. Households own the monopolistic competitive firms and also own the capital stock and natural resources (or land) which are fixed and exogenous.

We assume, for reasons explained in the next section, that all profits and rents are fully taxed. It then follows that the period budget constraint of the households is given by

$$\begin{aligned} & P_t C_t + E_t \left[Q_{t,t+1} B_{t,t+1} + S_t Q^*_{t,t+1} \tilde{B}^*_{t,t+1} \right] \\ \leq \; & W_t \left(1 - \tau^n_t\right) N_t + B_{t-1,t} + S_t \frac{\tilde{B}^*_{t-1,t}}{1 + \tau^*_t}, \end{aligned} \tag{4}$$

where S_t is the nominal exchange rate between domestic and foreign currency, W_t is the nominal wage rate, τ^n_t is a labor income tax, τ^*_t is a tax on the return of foreign denominated bonds (a tax on capital flows), $Q_{t,t+1}$ is the domestic currency price of the one period contingent domestic bond normalized by the conditional probability of the state $\pi\left(\mu_{t+1}|\mu_t\right)$, and $Q^*_{t,t+1}$ is the analogous foreign currency price of the foreign bond.[5] We assume that dividends are fully taxed.

Using the budget constraint at periods t and $t+1$ and rearranging gives the no-arbitrage condition between domestic and foreign bonds

$$Q_{t,t+1} = Q^*_{t,t+1} \left(1 + \tau^*_{t+1}\right) \frac{S_t}{S_{t+1}}. \tag{5}$$

It is convenient to work with the present value budget constraint. To that end, for any integer $k > 0$, we let $Q_{t,t+k} = Q_{t,t+1} Q_{t+1,t+2} ... Q_{t+k-1,t+k}$ be the price of one unit of domestic currency at a particular history μ^{t+1} in terms of domestic currency at time t, and an analogous definition holds for $Q^*_{t,t+k}$. Iterating forward on (4) and imposing the no-Ponzi condition $\lim_{t\to\infty} E_0 \left[Q_{0,t} B_t + S_t Q^*_{0,t} \tilde{B}^*_t \right] \geq 0$ gives

$$E_0 \sum_{t=0}^{\infty} Q_{0,t} \left(P_t C_t - W_t \left(1 - \tau^n_t\right) N_t\right) \leq 0, \tag{6}$$

where we have assumed that initial financial wealth is zero, or $B_{-1,0} = \tilde{B}^*_{-1,0} = 0$.

The household maximizes (1) subject to (6). The optimality conditions are given by

$$\frac{U_C\left(C_t, N_t\right)}{-U_N\left(C_t, N_t\right)} = \frac{P_t}{W_t\left(1 - \tau^n_t\right)} \tag{7}$$

$$\frac{U_C\left(C_t, N_t\right)}{P_t} = \beta \frac{1}{Q_{t,t+1}} \frac{U_C\left(C_{t+1}, N_{t+1}\right)}{P_{t+1}} \tag{8}$$

[5] We use the notation $\tilde{B}^*_{t,t+1}$ instead of simply $B^*_{t,t+1}$ to distinguish foreign bonds held by the household sector from foreign bonds held by the aggregate economy.

Replacing the first order conditions (7), and (8) into the present value budget constraint (6), we can summarize the necessary and sufficient conditions for the household's optimization in the following condition

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[U_C\left(C_t, N_t\right) C_t + U_N\left(C_t, N_t\right) N_t\right] = 0$$

2.2 Government

The government sets monetary and fiscal policy and raises taxes to pay for exogenous consumption of the home final good, G_t. The final good is also a Dixit-Stiglitz aggregator of all individual varieties

$$G_t = \left[\int_0^1 g_{it}^{\frac{\theta-1}{\theta}} di\right]^{\frac{\theta}{\theta-1}}.$$

The present value of government fiscal deficits must be equal to its initial stock of assets, denoted by B_0^*.[6]

Monetary policy consists of rules for the nominal exchange rate S_t. Fiscal policy consists of labor taxes τ_t^n; taxes on capital flows τ_t^* (formally, a tax on the return of foreign assets); a labor subsidy in the manufacturing sector, τ_t^s, and taxes on all pure rents that will be set at 100%. We assume full taxation of profits because, otherwise, the Ramsey government will use other instruments to partially tax those rents. We deliberately abstract from those effects in the optimal policy problem.

The labor subsidy deserves an explanation. As described below, we model a potential Dutch disease problem by introducing an externality in the manufacturing sector. In particular, we assume that total factor productivity in the manufacturing sector depends on the aggregate employment in the same sector. This effect of aggregate employment on productivity is an external effect because individual firms do not internalize that their choices affect aggregate employment in the sector. In deriving theoretical results, it is convenient to add an instrument–the labor subsidy–that the planner could use to correct the externality problem. After analyzing the optimal allocation when the government has enough instruments, we consider restrictions on the set of fiscal instruments (for example, eliminating the labor subsidy) and solve for the optimal monetary policy using numerical methods.

[6] We don't explicitly discuss the government's budget constraint as, in equilibrium, it will hold due to Walras' law.

2.3 Retail non-traded sector

Each variety $i \in [0,1]$ is produced by a monopolistic competitive firm that uses labor and the two tradable intermediate goods with the technology

$$y_{it} = \frac{A_t^y}{\bar{\eta}} x_{it}^{\eta_1} z_{it}^{\eta_2} \left(n_{it}^y\right)^{\eta_3} \tag{9}$$

where x_{it} is produced domestically and z_{it} is imported, n_{it}^y is labor, A_t^y denotes the level of productivity, $\eta_1, \eta_2, \eta_3 \geq 0$, $\eta_1 + \eta_2 + \eta_3 = 1$, and $\bar{\eta} = \eta_1^{\eta_1} \eta_2^{\eta_2} \eta_3^{\eta_3}$.[7]

Because intermediate goods can be freely traded, the law of one price holds:

$$\begin{aligned} P_t^x &= S_t P_t^{x*} \\ P_t^z &= S_t P_t^{z*} \end{aligned} \tag{10}$$

where P_t^j and P_t^{j*} are the domestic and foreign currency prices of the intermediate goods $j = x, z$, and S_t is the nominal exchange rate.

Cost minimization implies

$$\frac{x_{it}}{n_{it}^y} = \frac{\eta_1}{\eta_3} \frac{W_t}{P_t^x} \text{ and } \frac{z_{it}}{x_{it}} = \frac{\eta_2}{\eta_1} \frac{P_t^{x*}}{P_t^{z*}} \quad \text{for all } i \in (0,1), \tag{11}$$

which delivers the following nominal marginal cost function that is common across retailers

$$MC_t = \frac{\left(P_t^x\right)^{\eta_1} \left(P_t^z\right)^{\eta_2} W_t^{\eta_3}}{A_t^y}. \tag{12}$$

Each monopolist $i \in (0,1)$ faces the downward sloping demand curve (2). We follow the standard tradition in the New Keynesian literature and impose Calvo price rigidity. Namely, in each period, firms in the retail sector are able to reoptimize nominal prices with a constant probability $1 - \alpha$, where $0 < \alpha < 1$. Using standard results, it can be shown that all those firms that get the chance to set a new price will set it according to[8]

$$p_t = \frac{\theta}{\theta - 1} E_t \sum_{j=0}^{\infty} \omega_{t,j} MC_{t+j}, \tag{13}$$

where $\omega_{t,j}$ are weights that add up to one and are defined as

[7] Our results generalize to any constant returns to scale technology.

[8] The optimal price is not indexed by i because all firms that change prices face the same marginal cost function and, therefore, set the same price.

$$\omega_{t,j} = \frac{\alpha^j Q_{t,t+j} \left(P_{t+j}\right)^{\theta} Y_{t+j}}{E_t \sum_{j=0}^{\infty} \alpha^j Q_{t,t+j} \left(P_{t+j}\right)^{\theta} Y_{t+j}}. \tag{14}$$

The price level in (3) can therefore be written as

$$P_t = \left[(1-\alpha) \left(p_t\right)^{1-\theta} + \alpha \left(P_{t-1}\right)^{1-\theta} \right]^{\frac{1}{1-\theta}}. \tag{15}$$

with the price p_t given by (12) and (13).

2.4 Manufacturing traded sector

Manufacturing is a perfectly competitive sector. The technology to produce manufacturing goods is given by

$$X_t = \frac{A_t^x \left(\bar{n}_t^x\right)}{\bar{\zeta}} \left(n_t^x\right)^{\zeta_n} \left(q_t^x\right)^{\zeta_q} K^{1-\zeta_n-\zeta_q} \tag{16}$$

where $\bar{\zeta} = \zeta_n^{\zeta_n} \zeta_q^{\zeta_q} \left(1-\zeta_n-\zeta_q\right)^{1-\zeta_n-\zeta_q}$, n_t^x is labor in the manufacturing sector, q_t^x is the commodity used in the manufacturing sector, and K is a fixed factor of production (capital).

We allow for the possibility that productivity, $A_t^x \left(\bar{n}_t^x\right)$, depends on the aggregate amount of labor allocated to the manufacturing sector, which we denote denoted by $\bar{n}_t^x$. Importantly, firms do not internalize that productivity changes with the level of aggregate employment in the sector choosing their production plans. This externality is the source of the potential Dutch-disease problem.

It is precisely to address this externality that we allow for the labor subsidy τ_t^s in the manufacturing sector. This assumption is in line with the dynamic Ramsey tradition. We identify all sources of distortions by allowing for a rich enough set of fiscal instrument and solve for the second best Ramsey allocation. We next impose restrictions on the ability of the planner to make those tax instruments responds to the shocks hitting the economy and study to which extent can monetary policy alone achieve the same outcome.

The subsidy τ_t^s implies that the wage paid by manufacturing firms is $W_t \left(1-\tau_t^s\right)$. Therefore, the optimality conditions of a representative firm in the sector are given by

$$W_t \left(1-\tau_t^s\right) = P_t^{x*} S_t \frac{A_t^x \left(\bar{n}_t^x\right)}{\bar{\zeta}} \zeta_n \left(n_t^x\right)^{\zeta_n-1} \left(q_t^x\right)^{\zeta_q} K^{1-\zeta_n-\zeta_q} \tag{17}$$

$$P_t^{q*} = P_t^{x*} \frac{A_t^x \left(\bar{n}_t^x\right)}{\bar{\zeta}} \zeta_q \left(n_t^x\right)^{\zeta_n} \left(q_t^x\right)^{\zeta_q-1} K^{1-\zeta_n-\zeta_q}. \tag{18}$$

2.5 Commodities sector

The economy produces a tradable commodity, denoted by q_t, with a technology given by

$$q_t = A_t^q \left(n_t^q\right)^\rho T^{1-\rho}, \tag{19}$$

where n_t^q is labor, A_t^q is the level of productivity, T is fixed factor of production (land or natural resources), and $0 < \rho \leq 1$.

Profit maximization then requires

$$\rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho} = \frac{W_t}{P_t^q}. \tag{20}$$

where P_t^q is the domestic price of the commodity.

Because the commodity can be freely traded, the law of one price holds:

$$P_t^q = S_t P_t^{q*}, \tag{21}$$

where, P_t^{q*} denotes the foreign currency prices of the commodity.

2.6 Revisiting the marginal cost in retail

The retail sector exhibits price frictions and monopolistic power. For reasons that will become apparent below, we find it convenient to express the marginal cost function as a function of the exogenous shocks and of the allocation of labor across sectors. Write $MC_t = S_t MC_t^*$, where MC_t^* denotes the nominal marginal cost measured in foreign currency. Equations (10), (20), and (21) imply that MC_t^* is given by

$$MC_t^* = \frac{\left(P_t^{x*}\right)^{\eta_1} \left(P_t^{z*}\right)^{\eta_2} \left[P_t^{q*} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho}\right]^{\eta_3}}{A_t^y}. \tag{22}$$

That is, the marginal cost in foreign currency depends on the international commodity prices, on technological factors, and on the equilibrium allocation of labor in the commodities sector.

It is also convenient to express output in the retail sector as a function of the same variables. Using (10), (20), and (21) in (11) delivers the following expression for the ratio of inputs in the retail sector,

$$\frac{x_{it}}{n_{it}^y} = \frac{\eta_1}{\eta_3} \frac{P_t^{q*}}{P_t^{x*}} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho} \text{ and } \frac{z_{it}}{n_{it}^y} = \frac{\eta_2}{\eta_3} \frac{P_t^{q*}}{P_t^{z*}} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho},\ i \in (0,1)\,.$$

Introducing these expressions into the production function in retail and rearranging gives retail production as a function of exogenous shocks and of the allocation of labor in the retail and commodity sectors

$$y_{it} = \frac{A_t^y}{\eta_3} \frac{\left[P_t^{q*} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho}\right]^{1-\eta_3}}{\left(P_t^{x*}\right)^{\eta_1} \left(P_t^{z*}\right)^{\eta_2}} n_{it}^y. \tag{23}$$

In equation (23), the i^{th} variety output as a linear function of labor employed in the i^{th} industry. This follows from the assumption of constant returns to scale.

2.7 Aggregate consistency

There are three aggregate consistency conditions that have to be met in this model: labor market clearing, clearing in the market for retail (non-traded) goods and the aggregate budget constraint for the country, which summarizes the feasibility conditions for the manufacturing and commodity markets.

Labor market clearing requires the aggregate supply of labor to be equal to the aggregate demand of labor across sectors, or

$$N_t = \int_0^1 n_{it}^y di + n_t^q + n_t^x, \tag{24}$$

Likewise, the domestic market for final goods clears when

$$Y_t = C_t + G_t. \tag{25}$$

The country's net foreign assets (owned by the government), denoted by $B_{t,t+1}^*$, evolve according to

$$B_{t-1,t}^* + nx_t^* = E_t B_{t,t+1}^* Q_{t,t+1}^*. \tag{26}$$

Solving this equation from period 0 forward, gives the economy foreign sector feasibility constraint measured in foreign currency at time 0

$$E_0 \sum_{t=0}^{\infty} Q_{0,t}^* nx_t^* = -B_0^*. \tag{27}$$

Net exports measured in foreign currency are given by

$$nx_t^* = P_t^{q*}\left[q_t - q_t^x\right] + P_t^{x*}\left[X_t - \int_0^1 x_{it} di\right] - P_t^{z*} \int_0^1 z_{it} di, \tag{28}$$

where the first term represents the net exports of the commodity, the second term the net exports of the manufactured good and the third one the imported intermediate input. It is convenient to write this expression as a function of prices and labor allocations.

3 The Ramsey problem with flexible taxes

In this section we characterize the optimal policy assuming that the government is able to commit to a particular policy chosen at the initial period and never deviates from it. To characterize the optimal policy, the Ramsey taxation literature finds necessary and sufficient conditions that an allocation has to satisfy to be implementable as equilibrium (Lucas and Stokey, 1983). In our model, however, these sufficient conditions cannot be characterized in terms of the allocation alone.

The constraints imposed by the price setting restrictions on the equilibrium allocation make the equilibrium set a difficult object to analyze. We thus follow a different approach and consider a relaxed set of allocations that contains the set of equilibrium allocations for any degree of price stickiness, characterized by the parameter α. The relaxed set is defined in terms of necessary conditions that any equilibrium allocation must satisfy, but ignores some of the constraints imposed by the price stickiness assumption. In Appendix A we show that the optimality condition for households and firms in the retail, manufacturing, and commodity sectors imply the following four necessary conditions for an allocation to be an equilibrium allocation:

$$E_0 \sum_{t=0}^{\infty} Q_{0,t}^* \left[P_t^{q*} A_t^q \left(n_t^q\right)^{\rho} T^{1-\rho} - P_t^{q*} q_t^x + P_t^{x*} \frac{A_t^x \left(\bar{n}_t^x\right)}{\bar{\zeta}} \left(n_t^x\right)^{\zeta_n} \left(q_t^x\right)^{\zeta_q} K^{1-\zeta_n-\zeta_q} \right. \\ \left. - P_t^{q*} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho} \frac{1-\eta_3}{\eta_3} \left(N_t - n_t^x - n_t^q\right) \right] = -B_0^* \tag{29}$$

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[U_C \left(C_t, N_t\right) C_t + U_N \left(C_t, N_t\right) N_t \right] = 0 \tag{30}$$

$$P_t^{x*} \frac{A_t^x \left(\bar{n}_t^x\right)}{\bar{\zeta}} \zeta_q \left(n_t^x\right)^{\zeta_n} \left(q_t^x\right)^{\zeta_q - 1} K^{1-\zeta_n-\zeta_q} - P_t^{q*} = 0 \quad \text{for all } t \tag{31}$$

$$\left[Z_t \left(n_t^q\right)^{(\rho-1)(1-\eta_3)} \right] \left(N_t - n_t^x - n_t^q\right) - D_t \left[C_t + G_t\right] = 0 \quad \text{for all } t \tag{32}$$

where $Z_t = \frac{A_t^y}{\eta_3} \frac{\left[P_t^{q*} \rho A_t^q T^{1-\rho}\right]^{1-\eta_3}}{(P_t^{x*})^{\eta_1}(P_t^{z*})^{\eta_2}}$ and

$$D_t \equiv \int \left(\frac{P_{it}}{P_t}\right)^{-\theta} di, \tag{33}$$

which, following Yun (2005), can be shown to evolve recursively according to

$$D_t = (1-\alpha)\left[\frac{1-\alpha\pi_t^{\theta-1}}{1-\alpha}\right]^{\frac{\theta}{\theta-1}} + \alpha\pi_t^{\theta} D_{t-1}. \tag{34}$$

The first equation, (29), is the implementability condition for the country's aggregate budget constraint, which set the present value of net exports equal to the country's outstanding foreign debt. The second constraint, (30), implements the households' allocation combining its first order conditions and intertemporal budget constraint. Equation (31) sets the the marginal product of the commodity in manufacturing equal to its cost, P_t^{q*}. The last equation, (32), is the resource feasibility constraint for the retail sector. The left hand side of the equation's first term is the aggregate production function for the non-traded good. It stems from aggregating each variety's production function, integrating equation (23) and using labor market clearing. The second term is the demand for the non-traded good multiplied by the inefficiency introduced by the price stickiness. The term D_t is a measure of the dispersion of prices in the retail sector and, be Jensen's inequality, $D_t \geq 1$. The price frictions imply that, in equilibrium, otherwise identical firms may be setting different prices. Production efficiency is attained when all firms set the same price, that is, when $D_t = 1$.

The relaxed Ramsey problem is to choose the allocations $C_t, N_t, n_t^x, n_t^q, q_t^x$ and the price distortion D_t that maximize the household's utility (1) subject to the implementability constraints (29)-(32). Note that the relaxed Ramsey problem ignores the constraint (34). Arguments similar to those used in Correia, Nicolini and Teles (2008) and Hevia and Nicolini (2013) can be used to show that the allocation that solves the relaxed Ramsey problem can be implemented as an equilibrium with sticky prices as long as the government has access to flexible (i.e. state-contigent) labor income and capital flow taxes.

As it is well know in Ramsey problems, the presence of the constraint (30) implies that the problem is not necessarily convex, so first order conditions are not sufficient for a maximum. However, if the solution is interior, the conditions are necessary, so the optimal allocation must satisfy them. Appendix B summarizes the first order conditions of the relaxed Ramsey problem.

3.1 Price Stability

The first result in the paper is that production efficiency requires price stability.

Proposition 1: *The Ramsey allocation exhibits full price stability.*

This result follows immediately by noting that $D_t = 1$ maximizes the household's utility subject to the constraints (29)-(32). The intuition of this result is that production efficiency requires all firms in the retail sector to have the same price. That is, monetary policy must be such that firms that are able to reoptimize prices will choose to set the same constant price in every period. In this case we have that $p_{it} = p$ for all i and for all t.

Note that under this zero inflation policy $D_t = 1$ for all t and recall that $D_t \geq 1$. As D_t only appears in the Ramsey problem in (32), setting D_t at its minimum value is optimal. Given a level of output of home final goods (the first term of equation (32), consumption of home final goods is maximized when $D_t = 1$. Production efficiency is a property of the second best, as it has been pointed by Diamond and Mirrlees (1971).

Finally notice that implementing price stability, $D_t = 1$ for all t, can only occur if monetary policy is able to implement constant marginal costs. This follows from the pricing equation (13). Also, recall that the domestic currency marginal cost on which retail firms set a markup is equal to marginal cost in foreign currency multiplied by the exchange rate. The foreign currency marginal cost, by (22), is a function of the foreign prices of the tradable goods, productivity shocks, and employment in the commodity sector. Thus, price stability is attained only if the monetary authority sets the exchange rate S_t so that $MC_t = MC^*/S_t$ is constant.

3.2 The Optimal Allocation of Labor and the Externality in the Manufacturing Sector

We now turn to the optimal allocation of labor in the commodity and manufacturing sectors, n_t^q and n_t^x. The first order conditions of the relaxed Ramsey problem with respect to n_t^x and n_t^q yield the expression

$$\rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho} = \frac{q_t^x}{n_t^x} \frac{\zeta_n + \varepsilon_{xt}}{\zeta_q}, \tag{35}$$

where ε_{xt} denotes the elasticity of total factor productivity in manufacturing with respect to total manufacturing labor, defined as

$$\varepsilon_{xt} = \frac{\partial A_t^x \left(\bar{n}_t^x\right)}{\partial n_t^x} \frac{n_t^x}{A_t^x \left(\bar{n}_t^x\right)}.$$

The behavior of this elasticity will be crucial to determine the optimal policy.

To interpret equation (35), note that the externality in the manufacturing sector typically creates a wedge between the *social* and *private* marginal product of labor. Indeed, while the planner internalizes that aggregate labor decisions affect the overall productivity in the manufacturing sector, private firms do not. In particular, the right hand side of equation(35) is the social marginal product of labor, while the private marginal product of labor is the same expression but with $\varepsilon_{xt} = 0$. On the other hand, in the commodities sector the social and private marginal products of labor coincide. Therefore, the optimal allocation requires the social marginal cost of labor to be equated across sectors.

To decentralize the optimal Ramsey allocation, the planner needs to provide private agents with the correct relative prices. In the current framework, this is done with the labor subsidy in the manufacturing sector. In particular, equations (17), (18), and (20) imply that, in the decentralized equilibrium, the allocation of inputs across sectors satisfy

$$\rho A_t^q (n_t^q)^{\rho-1} T^{1-\rho} = \frac{q_t^x}{n_t^x} \frac{\zeta_n}{\zeta_q} \frac{1}{1-\tau_t^s}$$

By appropriately choosing the labor subsidy τ^s, it is possible to make private agents face the correct relative price and induce firms to choose the Ramsey allocation in (35). In particular, comparing the last two equations it is apparent that the optimal labor subsidy satisfies

$$\tau_t^s = \frac{\varepsilon_{xt}}{\varepsilon_{xt} + \zeta_n}.$$

The sign of the subsidy depends on whether the externality is positive or negative. Consider the case of a positive externality, so that aggregate labor increases aggregate productivity in the manufacturing sector. In this case, the subsidy is positive to induce private firms to increase their labor demands. In addition, given a value for the elasticity term ε_{xt}, note that the optimal labor subsidy is decreasing in the labor share parameter ζ_n. To understand this result, it is convenient to think of the extreme case when ζ_n is close to zero. In this case, absent the labor subsidy, private firms have little incentives to demand labor as its (private) marginal product is also close to zero. The external effect, however, is present and aggregate productivity increases with aggregate labor in the sector. Therefore, the subsidy has to be large enough to induce firms to demand labor even though the marginal productivity of labor that they observe is low. We summarize this result in the following proposition.

Proposition 2: *The optimal Ramsey allocation is decentralized by a labor subsidy in the manufacturing sector that depends only on the elasticity of total factor productivity on manufacturing with respect to employment (the external effect) and the share of labor on* *manufacturing.*

Corollary: *If the external effect is given by $A_t^x \cdot (\bar{n}_t^x)^{\varepsilon_x}$, so the elasticity of total factor productivity with respect to labor in manufacturing is constant, then a constant subsidy, independent of the shocks, decentralizes the Ramsey Allocation.*

Proposition 2 is important because it makes clear that the existence of an external effect is not, on itself, a justification for departing from full price stability. As long as the government has access to sufficiently flexible instruments, price stability is still the optimal second best policy to implement. As we show below, however, restricting policy instruments changes this result.

3.3 Optimal Labor Income and Capital Flow Taxes

In this section we characterize the optimal labor income and capital flow taxes that decentralize the optimal allocation. To that end, it is convenient to define the following "distorted" utility function,

$$V(C, N; \lambda) \equiv U(C, N) + \lambda \left(U_C(C, N)C + U_N(C, N)N \right),$$

where λ is the Lagrange multiplier associated with the constraint (30). We can interpret $V(C, N; \lambda)$ as the utility function used by the planner to evaluate different allocations. In particular, the term $\lambda(U_C C + U_N N)$ is a measure of the utility cost of having to finance government expenditures through the use of distortionary taxes.

Appendix B.1 proves that the optimal labor income and capital flow taxes that decentralize the optimal allocation satisfy

$$\frac{V_{Ct}/V_{N_t}}{U_C/U_N} = \frac{(1 - \tau_t^n)}{\frac{\theta}{\theta - 1}} \tag{36}$$

and

$$\frac{V_{Ct+1}/V_{Ct}}{U_{Ct+1}/U_{Ct}} = 1 + \tau_{t+1}^*. \tag{37}$$

While, in general, the labor income taxes and capital flow taxes that decentralize the optimal allocation must be state-contingent, there is a class of utility functions, commonly used in applied work, for which the optimal labor income tax is constant and the optimal capital flow tax is zero.

Proposition 3: *Consider a utility function of the form*

$$U(C,N) = \frac{C^{1-\sigma}}{1-\sigma} - \kappa\frac{N^{1+\phi}}{1+\phi}, \quad \sigma, \phi, \kappa > 0.$$

Then, the optimal policy sets a constant labor tax, $\tau_t^n = \tau^n$, and zero taxes on capital flows, $\tau_t^* = 0$, across dates and states of nature.

Proof: See Appendix B.2

To summarize, in this section we showed, first, that if the labor income tax, the capital flows tax and the subsidy to labor in manufacturing, where the externality is, can be made state and time contingent, then price stability is optimal and interventions in the foreign exchange market are sub-optimal. Second, we showed that for particular preferences, the optimal taxes on income and capital flows are time and state invariant. In addition, we showed that if the external effect is characterized by an exponential function, such that the elasticity is constant, then a constant subsidy decentralizes the optimal allocation. Thus, even if fiscal instruments lack the flexibility of monetary policy, fully floating is the optimal policy.

4 The case for foreign currency market intervention: optimal unconventional monetary policy

In this section we assume that the government is unable to choose state contingent labor income and capital flow taxes, nor state contingent subsidies in the manufacturing sector. Therefore, the government does not have the natural instrument–the subsidy–to deal with the Dutch disease problem in the manufacturing sector. Due to the constraints imposed on the fiscal instruments, the resulting constrained optimal allocation could be interpreted as a "third" best allocation instead of the second best associated with standard Ramsey problems. In this third best problem, price stability ceases to be (constrained) optimal because the government uses monetary policy, its only state contingent instrument, to minimize several distortions or, in the terms of the public finance literature, Harberger triangles.

In this section we evaluate the case for foreign currency market intervention solving for the constrained Ramsey problem and calibrating the model using data from Brazil, Chile, and Mexico. The Ramsey optimal policy for the nominal exchange rate is typically a function of all the state variables of the model (including, as argued above, a set of Lagrange multipliers) and, therefore, might be difficult to implement in practice. For this reason, we also consider optimal simple policies, as defined by Schmitt-Grohé and Uribe (2007), whereby we postulate that the nominal devaluation rate is a linear function of easily observable variables, namely, the inflation rate, GDP, the price of the exportable commodity, the real exchange rate, and the trade balance. These simple rules can be interpreted as belonging to a class of extended Taylor type rules. Moreover, because we allow the simple rules to depend on variables other than inflation and output (the usual variables considered in Taylor rules), we can interpret them as belonging to a class of "unconventional" monetary policy rules.

When the government does not have access to flexible fiscal instruments, as assumed in this section, the model does not have a known analytic solution. We therefore need to solve the model using numerical approximations to the rational expectations equilibrium. A standard approach to numerically solve New Keynesian models is using log-linear approximations to the policy rules around the non-stochastic steady state. The resulting log-linear policy functions are a good approximation to the true, non-linear, policy functions as long as the shocks hitting the economy are relatively small. In our context, however, log-linear approximations are inappropriate for two reasons. First, we are interested in analyzing the optimal monetary response to commodity price shocks in small open economies, and commodity price shocks are large. Second, we are also interested in making welfare comparisons of different policy rules, and linear methods are useless for that purpose. For those two reasons, we follow Schmitt-Grohé and Uribe (2004) and solve the model using a second order perturbation method whereby the logarithm of the policy functions are approximated using second order polynomials. Second order approximations are known to be much more accurate than first order approximation around relatively large neighborhoods of the non-stochastic steady state

5 The model without flexible fiscal instruments

The model that we consider in this section is identical to that described above except for two difference. First, we set labor income taxes, capital flow taxes, and labor subsidies in manufacturing to zero. Thus, the government does not have a natural instrument to eliminate the external effect in the manufacturing sector. Second, following the tradition of a large part of the New Keynesian literature, we set the model so that the non-stochastic steady state is optimal. Suboptimality only happens when shocks move the economy out of the steady state. To obtain an efficient steady state, we assume that the externality is zero at the steady state and that the government is able to subsidize production in the retail sector using a constant subsidy to all inputs of production in this sector. This subsidy is used to eliminate the monopolistic mark-up at the steady state in the retail sector. Without this assumption, the Ramsey planner will use monetary policy to partially tax monopolistic rents, an issue that we do not want to analyze in the current paper. Moreover, because in this section we want to focus exclusively in the role of monetary policy, we also assume that the government is able to impose lump-sum taxes on household's. While this modification is equivalent to setting the Lagrange multiplier associated with the implementability condition (30) to zero, lump-sum taxes are useless to fix the monopolistic distortion in the retail sector or the externality in the manufacturing sector. Solving those problems requires manipulating relative prices, which cannot be done with lump-sum taxes.

Therefore, we set $\tau_t^n = 0$, $\tau_t^* = 0$, and $\tau_t^s = 0$ for all t, and add a lump-sum tax T_t to the left hand side of equation (4). Moreover, the government gives proportional constant subsidy of ν to all inputs of production in the retail sector, so that the effective marginal cost faced by the producer is $(1-\nu)MC_t$. In particular, the subsidy that eliminates the steady state monopolistic mark-up satisfies

$$(1-\nu)\frac{\theta}{\theta-1} = 1$$

a condition that we assume to hold in what follows.

We also assume that foreign asset prices are $Q^*_{t,t+1} = \beta$ for all dates and states so that there are no dynamics coming from fluctuations in asset prices or differences between the domestic and foreign discount factor.

In Appendix C we show that the equilibrium conditions that constrain the Ramsey planner without flexible tax instruments are summarized by the following system of expectational difference equations, where we define $s_t = S_t/P_t$ and $w_t = W_t/S_t$, which hold for $t = 0, \ldots$

$$\frac{U_{Ct}}{U_{C0}} = \frac{s_0}{s_t} \tag{38}$$

$$-\frac{U_{Nt}}{U_{Ct}} = w_t \; s_t \tag{39}$$

$$w_t = \left[\frac{P_t^{x*}}{\left(P_t^{q*}\right)^{\zeta_2}} \frac{A_t^x \left(n_t^x\right)}{\left(n_t^x\right)^{\zeta_3}} \left(\frac{\zeta_1}{\zeta_3}\right)^{\zeta_3} K^{\zeta_3} \right]^{\frac{1}{1-\zeta_2}} = P_t^{q*} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho} \tag{40}$$

$$D_t \left[C_t + G_t\right] = \left[\left(n_t^q\right)^{(\rho-1)(1-\eta_3)} Z_t \right] \left(N_t - n_t^x - n_t^q\right) \quad \text{for all} \quad t \tag{41}$$

$$D_t = (1-\alpha) \left[\frac{1 - \alpha \pi_t^{\theta-1}}{1-\alpha} \right]^{\frac{\theta}{\theta-1}} + \alpha \pi_t^{\theta} D_{t-1} \tag{42}$$

$$\Phi_t \left[\frac{1 - \alpha \left(\pi_t\right)^{\theta-1}}{1-\alpha} \right]^{\frac{1}{1-\theta}} = U_{Ct} \left(C_t + G_t\right) MC_t^* s_t \tag{43}$$

$$+ \alpha \beta E_t \left[\pi_{t+1}^{\theta} \left[\frac{1 - \alpha \left(\pi_{t+1}\right)^{\theta-1}}{1-\alpha} \right]^{\frac{1}{1-\theta}} \Phi_{t+1} \right]$$

$$\Phi_t = U_{Ct} \left(C_t + G_t\right) + \alpha \beta E_t \left[\pi_{t+1}^{\theta-1} \Phi_{t+1} \right] \tag{44}$$

This is a system of eight non-linear difference equations with nine unknowns: C_t, N_t, s_t, w_t, Φ_t, π_t, n_t^q, n_t^x, D_t.[9] To gain intuition, note that, by counting equations and unknowns, we observe that there is one free variable that needs to be set to find the rational expectations equilibrium. We can interpret the real exchange rate s_t as the free variable that the Ramsey planner controls to maximize the household's welfare. Given that prices are sticky, the government is able to affect the real exchange rate s_t by appropriately choosing the nominal exchange rate S_t. The latter is the policy instrument that we consider in this paper.

When S_t moves and P_t adjusts slowly, this affects the dynamics of consumption and the marginal rate of transformation between labor and consumption. Observe that foreign currency wages, w_t, are pinned down by the marginal product of labor in the commodity and manufacturing sector by (40). As preferences are separable in consumption and labor, combining (38) and (39), we can derive employment dynamics from $U_{Nt}/U_{N0} = w_t/w_0$.

The constrained Ramsey problem consists of maximizing the utility function (1) subject to (38)–(44) and an initial condition for the distribution of prices in the retail sector, which we take to be $D_{-1} = 1$. This means that at time $t = -1$ there is no price dispersion in the retail sector. Assuming that the logarithm of the exogenous stochastic processes (namely,

[9]Please note that line (40) contains two equations.

u_t^*, G_t, P_t^{q*}, P_t^{z*}, A_t^x, A_t^q, and A_t^y) satisfy a first order vector autoregressive process, we can view the Ramsey problem as a standard constrained optimization problem. The natural state variables of this problem at time t is the vector of exogenous shocks and the index of price dispersion D_{t-1}. These state variables, however, are typically not enough to write the solution to the Ramsey problem in recursive fashion. Indeed, as was shown by Marcet and Marimon (2011), to write this problem recursively, one needs to include the time $t-1$ value of the Lagrange multipliers associated with the forward looking constraints (43) and (44) as additional state variables. Expanding the set of state variables as described allows us to use standard numerical methods to find time invariant policy functions of the Ramsey problem for all $t \geq 1$. At time $t = 0$, however, the first order conditions that characterize the solution to the Ramsey problem are different because there is no time $t = -1$ counterpart to equations (43) and (44). This is the source of the time inconsistency problem of the Ramsey policy. Following Woodford (2003), we rule out this time inconsistency problem by pretending that at time $t = 0$ the planner has been operating for an arbitrary number of periods in the past. Moreover, the government is assumed to honor previous commitments, as summarized by the value of the Lagrange multipliers associated with the constraints (43) and (44). This approach, often referred to as *optimal policy from the timeless perspective*, allows us to focus on the time invariant policy functions derived from the Ramsey problem ignoring possibly different actions during the initial period.

We use perturbation techniques to solve for the time invariant policy functions of the Ramsey problem. As we mentioned above, however, standard first order perturbations around the non-stochastic steady state are inadequate in our setting. We therefore use a second order perturbation approach whereby the policy functions are approximated around the steady state using quadratic polynomials. For this purpose, we use the software developed by Schmitt-Grohé and Uribe (2004, 2006).

5.1 Optimal simple policies

The optimal Ramsey policy is typically a complicated function of all the state variables of the model, including previous Lagrange multipliers. It is of interest to consider simple policies in the tradition of Taylor rules, but in terms of the nominal depreciation rate of the domestic currency as a linear function of a set of variables. In particular, we consider policies of the form

$$\log \frac{S_{t+1}}{S_t} = a_1 \log \pi_t + a_2 \log \frac{GDP_t}{\widetilde{GDP}} + a_3 \log \frac{s_t}{\tilde{s}} + a_4 \log \frac{P_t^{q*}}{\tilde{P}^{q*}} + a_5 \left(nx_t - \widetilde{nx}\right) \qquad (45)$$

where nx_t denotes the ratio of net exports to GDP and a '$\sim$' above a variable denotes its non-stochastic steady state value. The steady state inflation rate and, therefore, the steady state depreciation rate are both zero. This is a simple policy that is similar to a Taylor rule but for the depreciation rate and includes characteristics of unconventional monetary policy, as the depreciation rate depends not only on inflation and output, but also on the real exchange rate, the commodity price, and the trade balance.

Adding this equation to (38) - (44) creates a system of nine equations with nine unknowns (we derive expressions for net exports and GDP in terms of the variables in the system (38) - (44).) The problem of finding the optimal simple rule consists of finding the numbers a_1, a_2, a_3, a_4 that maximize the household's welfare (1) subject to (38)-(44) and (45), and, at the same time, making sure that the resulting equilibrium allocation is locally stable around the non-stochastic steady state.

6 Functional forms and calibration

Each time period is interpreted to be one quarter. We are interested in analyzing how changes in the foreign price of the exportable commodity P_t^{q*} might induce an inefficient allocation through the Dutch disease channel. We thus shut down all other shocks and consider only a log-linear process for the commodity price,

$$\log\left(P_{t+1}^{q*}/\tilde{P}^{q*}\right) = \rho_q \log\left(P_t^{q*}/\tilde{P}^{q*}\right) + \varepsilon_{t+1}^q, \tag{46}$$

where $|\rho| < 1$ and ε_t^q is normally and independently distributed with mean zero and variance σ_q^2. Table 1 reports the estimated parameters of (46) for Brazil, Chile and Mexico. The commodity export price for Brazil is an index of soybeans and oil with a weight of 53 percent for the former, for Chile it is the price of copper and for Mexico it is the price of oil.[10] Nominal US Dollar prices are deflated with the US CPI.

The functional form for preferences is $U(C,N) = \frac{C^{1-\sigma}}{1-\sigma} - \kappa\frac{N^{1+\phi}}{1+\phi}$. We set $\sigma = 1$ so that preferences are consistent with a balanced growth path in which consumption and wages grow at the same rate and labor is stationary. $\phi = 1/3$ so that it corresponds to the macroeconomic estimate of the labor supply elasticity of approximately 3. (See, Chetty, Guren, Manoli and Weber (2011) and Hall (2008)). The parameter κ is set so that the marginal rate of transformation between labor and consumption equals the real wage at a steady state, in which the fraction of time spent working is 0.22, labor's share of income is

[10] Soybeans and oil are the commodities with the largest shares in Brazil's commodity exports. The weights for the commodity price index are constructed based on the relative share of soybeans and oil in Brazil's exports.

2/3 and the consumption share of expenditure is the one reported in table 1. The discount factor is set so that $\beta(1+r) = 1$, where we assume $r = 0.05$. The elasticity of substitution between goods is set at $\theta = 6$, consistent with a markup of 20% over marginal cost, following Galí (2008).

We assume a quadratic externality function that is exactly zero at the steady state:

$$A_t^x\left(n_t^x\right) = A^x\left(1 - \frac{\psi}{2}\left(\log\left(\frac{n_t^x}{\tilde{n}^x}\right)\right)^2\right).$$

As there is no empirical guidance for calibrating the strength of the externality, we simulate the model for different values of ψ.

The parameters of the production functions for the three sectors, (9), (16), and (19), are calibrated using the input-output matrices of Brazil, Chile, and Mexico and reported in table 1. We interpret the commodity sector in the model as agriculture, fishing and mining in the national accounts (NIPA). The manufacturing sector corresponds to the same sector in the NIPA. The retail sector in the model includes all the other sectors in the NIPA, which are usually interpreted as the non-traded sector. In the calibration of the retail sector non-traded good we set η_1 equal to the ratio of the value of manufacturing intermediate inputs in the non traded sector plus the final consumption of manufactured goods to the value of production of non traded goods. That is, we treat the final consumption consumption of manufactured goods as an input to the retail sector as consumers do not buy manufactured goods directly from producers. This is consistent with the fact that the production of manufactured goods in the input-output table is equal the value of intermediate uses of manufactured goods plus final uses. η_3 is the ratio of the value of the imported intermediate inputs of the non traded sector to the value of production in the sector. The residual parameter, $\eta_3 = 1 - \eta_1 - \eta_2$, includes the share of labor, capital and other intermediate inputs in the production of non-traded goods. In the manufacturing sector we assign the shares of labor and of commodities inputs in production to ζ_n and ζ_n, respectively. The parameter ρ is the labor share of value added in agriculture, fishing and mining. The labor share in manufacturing and in commodities is probably underestimated as it does not include any "mixed" income (Gollin, 2002).[11] The residual share ζ_k includes capital, as well as, other intermediate inputs.

The remaining parameters, namely the productivity parameters A^x y A^q, the level of public expenditure G, and the marginal utility of wealth are estimated by minimizing the distance between a set of long run averages of key variables observed in the data and the equivalent long run (steady state) values generated by the model. In particular, we pick

[11] This might be a serious problem in agriculture

Table 1: **Calibration**

	Brazil	Chile	Mexico
Shock Process for Commodity Price			
Persistence: ρ_q	0.91	0.95	0.94
Volatility: σ_q	0.10	0.14	0.16
Input Shares in Non-Traded Sector			
Manuf inputs: η_1	0.40	0.42	0.48
Imported inputs: η_2	0.01	0.04	0.01
Input Shares in Manufacturing Sector			
Labor input ζ_n	0.14	0.09	0.11
Commodity input ζ_q	0.22	0.28	0.13
Input Shares in Commodities Sector			
Labor input ρ	0.18	0.18	0.12
Labor allocation (shares of total employment)			
Commodities	0.21	0.13	0.18
Manufacturing	0.13	0.11	0.18
Non-traded	0.66	0.75	0.65
Demand Shares of GDP			
Private Consumption	0.60	0.61	0.68
Government Consumption	0.20	0.11	0.12

Data Sources: Input output tables (Brazil:2005, Chile:2008, Mexico:2003) are obtained from official sources in each country. Commodity prices are US Dollar prices deflated by US CPI. Commodity prices are from World Bank's Global Economic Monitor, and US CPI is from Federal Reserve Economic Data, from the Federal Reserve Bank of St. Louis. Data have been deseasonalized using X12 ARIMA. Commodity price indexes are: Soybean (53%) and oil (47%) for Brazil, Copper for Chile, and Oil for Mexico.

the parameters that minimize a loss function that penalizes deviations of the steady state values from the following sample moments: labor share of non-traded goods, labor share of primary goods, share of public expenditure in GDP, and the share of private in GDP. The loss function is defined as the sum of the absolute value of the differences between model and empirical moments. The four target moments are reported in table 1. The underlying assumption behind the calibration is that, since there is no investment in the model, we treat investment as capital accumulation abroad so that the national accounts *add up*. The share of labor employed in each sector is from the input-output matrices of each country. In Mexico and in Brazil most of the labor producing primary goods is employed in agriculture. This procedure deliver the following calibrated parameter values: for Brazil, $A^x = 1.8$, $A^q = 1.2$, and $G = 0.19$; for Chile, $A^x = 1.64$, $A^q = 1.9$, and $G = 0.12$; and for Mexico, $A^x = 1.6$, $A^q = 2.8$, and $G = 0.25$.[12]

Finally, we set the parameter α in the Calvo pricing equation (15) to match the fact that in low inflation economies the expected duration of prices is two quarters. See, for example, Klenow and Malin (2010) and Alvarez, Beraja, Gonzalez-Rozada and Neumeyer (2013). This implies $\alpha = 0.5$.

7 Numerical experiments

In this section we study the optimal monetary policy in the case in which flexible fiscal instruments are unavailable. We analyze how the economy responds to a one standard deviation increase in the price of the commodity. This can be interpreted as a terms of trade shock as well, since we normalized the price of the other traded goods to one. According to Table 1, these shocks are 10% of the mean price for Brazil, 14% for Chile and 16% for Mexico.

We think of the Ramsey monetary policy with flexible fiscal instruments in which the monetary authority sets the inflation rate to zero and lets the exchange rate adjust to any level to attain this goal as of conventional inflation targeting. When the central bank abandons the zero inflation target to attain other goals, such as avoiding an inefficient fall in manufacturing employment manipulating the real exchange rate, we think of its exchange rate policy as unconventional monetary policy.

Before discussing the results, we would like to highlight a property of the model. As a result of a positive shock to the terms of trade, consumption goes down in the model–a clearly counterfactual behavior. The reason is that, for tractability, we assumed that the country has access to a complete set of financial markets. The positive terms of trade shock

[12] We do not report the calibrate value of the marginal utility of wealth.

has two effects: a wealth effect and a reallocation effect. In our model the wealth effect disappears due to the assumption that financial markets are complete. When this shocks hits, the country makes a payment to its financial trading partners equivalent to the wealth shock. The change in relative prices calls for reallocating resources to the commodity sector. Labor has to flow from retail and manufacturing to the commodity sector. Consumption falls in order to free labor in the retail sector and reallocate it to the commodity sector.

The dynamics of consumption and employment in the non-traded sector in our model are slightly different from the traditional "dutch disease" problem in which resources flow from the manufacturing sector not only to the commodity sector, but also to retail (because of the wealth shock). Ideally, one would like to solve a model with incomplete markets, as in Catão and Chang (2013). The complexity of such an enterprise in an environment with optimal Ramsey policies is well beyond the scope of this project.

The results are presented in Figures 1 to 3 for the case of Brazil, Chile, and Mexico, respectively. The figures report the impulse response functions of the model calibrated for each country for the main macro variables under four assumptions: The Ramsey policy, the optimal simple rule, an exchange rate peg, and the empirical rule. [13] For the empirical rule, we tried with several specifications–see Tables 2 to 4)–and report the impulse responses with the one that delivered the highest R^2. All vertical axes measure percentage points deviations from steady state values. In all cases, we simulate the model for a value of the externality parameter, ψ, equal to 5. We will first discuss the results for the optimal policy, and then discuss the rest of the exercises.

7.1 The Ramsey optimal policy

In this section we ask if the unconventional monetary policy in the absence of flexible fiscal instruments is to depart from price stability. Recall that conventional monetary policy calls for the central bank to keep inflation at zero to attain production efficiency in the non-traded sector in which due to sticky prices there might be a production inefficiency.

We start by looking at the optimal inflation rate chosen by the constrained Ramsey planner, reported in the bottom left plot with a solid blue line. Let us focus first on this inflation plot for Brazil, in Figure 1. The most remarkable feature of the figure is that the Ramsey solution for inflation is extremely small every period following the terms of trade shock: It is less than 0.1% for 3 quarters, so it gives an accumulated value the year following the shock of less than 0.3%. This is well within the margin of yearly error in an

[13]Because the policy functions are nonlinear, it is not obvious how to define the impulse response function. We use the concept of nonlinear impulse response function developed by Gallant, Rossi and Tauchen (1993) and evaluate the required conditional expectations through simulation.

inflation targeting regime. It may even be within the standard error of the CPI's sampling uncertainty. For any practical purpose, the result implies that one could neglect the effect of the externality. This result will be at the heart of the lessons derived from this model, so it is important to analyze it in detail.

An immediate consequence of the Corollary of Proposition 2 and Proposition 3 is that, in the case in which $\psi = 0$, the optimal policy is to maintain price stability (zero inflation) and let the exchange rate to freely float, independently of the value taken by the terms of trade–or, for that matter, any of the shocks. It is precisely to consider the robustness of this policy to the presence of an externality in the manufacturing sector that we developed the model in this paper. The solution shows that the departure from price stability is minimal for Brazil, even in the presence of the externality. The externality depends on how large is the change in labor in manufacturing. This is indeed very large, as it can be seen in the left panel in the second row. The drop is close to 5% of total employment. The difference between $\psi = 0$, where price stability is optimal and $\psi = 5$, can be represented by computing the wedge between actual productivity and what it would have been if we impose $\psi = 0$. The result is depicted in middle panel of the first row of the same Figure 1. Given the functional form assumed and $\psi = 5$, the implied drop in productivity is around$-0,4\%$ on impact, and it takes about 2 years and a half to go back to normal. On average, it is around 0.3% below its steady state value and around 0.1% the second year. Thus, the total accumulated loss is equivalent to 0.5% of a yearly production. This is not a negligible number.

This is the main message of the paper: The presence of a sizable externality, with large and sub-optimal changes in the allocation of labor across sectors, does not justify significant deviations from perfect price stability. In the remaining of this section, we briefly discuss the behavior of the other two countries and discuss other results in order to try to provide an explanation for this very surprising (at least to us) result.

In Figure 2, we report the case of Chile. Notice that in this case, there is a larger deviation from full price stability in the optimal Ramsey solution, as depicted in the left-bottom panel. Still, the optimal inflation picks at less than 0.2%, with an overall annualized effect of around 0.5%. Again, a number clearly within the random variations that inflation has around is target level in Chile. On the other hand, the wedge is substantially larger, picking at $-1,5\%$ and lasting substantially longer. Overall, the accumulated effect is close to 1% on average the first two years and 0.05% on average the third and fourth year. Overall, it is equivalent to a yearly drop of 3% of total manufacturing production. Finally, the case of Mexico is very similar to the one from Brazil. The optimal deviations from full price stability are minimal.

To summarize: we shock the model economy with a large (but not unusual) terms of trade shock that creates an important expansion and with a large externality in manufacturing.

Still, the deviations of the optimal policy from full price stability are negligible.

Even though the policy lesson is remarkable stark–i.e., stick to price stability and let the real exchange rate fluctuate with terms of trade shocks–it is interesting to discuss why do we obtain different results for Chile, where the fall in manufacturing employment and the production inefficiency in manufacturing are larger and where the deviation from price stability, even though it is very small, is larger than in Mexico and Brazil.

The model economy is very complex and there are many dimensions in which the simulations for each country may depart, since all the parameters are different.

There are several potential reasons why the responses in the manufacturing sector may be quantitatively different for Chile. The first, is heterogeneity on the nature of price frictions. This explanation is ruled out by assumption: We used the same Calvo parameter in all simulations.[14] The second is on the nature of the shock. However, as Table 1 shows, the volatility of the terms of trade shock is not substantially larger for Chile than for Mexico. A third reason could be the transmission mechanism of the shock to total economic activity. This could also be potentially important, since the input-output matrices of these countries do differ significantly. However, on a first pass, it would appear that the combined effect of these features more or less compensate in the aggregate. Note that in spite of all those differences, the size of the expansions generated by the model are remarkably similar between Brazil and Chile (a bit larger for Mexico). This is not a feature built into the simulations. The model was fed with a shock that was one standard deviation increase in the price of the exportable commodity. The combined effect of all parameters implied that this shock had a very similar effect on employment and output. We take this to imply that, to a first approximation, we are comparing shocks or "similar" size in terms of the aggregate effect.

Our best guess for the difference between Chile's response and that of Brazil and Mexico is that in Chile the commodity price shock is large at the same time that the share of employment in manufacturing is small. The combination of these two features of the Chilean economy results in the fact that when there is a one standard deviation shock in the commodity price the extra demand of labor in the commodity sector is larger in relation to the smaller manufacturing sector (see Table 1), so that the labor reallocation as a share of the steady state employment in manufacturing is large. In Mexico, commodity price shocks are also large but manufacturing employment accounts for 18% of the labor force as opposed to only 11% of Chile. In Brazil, manufacturing employment is also low (13%), but commodity price shocks are smaller.

[14] We did not do this out of a real country-specific calibration, but out of comparative purposes. We want to know which features of an economy are relevant to justify intervention in the exchange rate market beyond heterogeneity in price frictions.

Note also that the deviation from price stability means that the real exchange rate movements are damped in the optimal solution. In fact, for Brazil, the optimal solution for the real exchange rate is substantially more volatile than the solution with a peg. However, in Chile, the volatility of the optimal solution and the peg are similar.

Our interpretation then, is that the presence of the externality implies deviations from price stability. However, at least in this model, an implausible large externality is required to obtain significant departures from price stability (on the order of 3% to 5% of inflation).

7.2 Optimal simple, peg, and empirical rules

The coefficients of the optimal simple policies are reported in Table 5. Interestingly, these coefficients are roughly similar, both in sign and size, in the three countries. The only notable exception is the elasticity of the optimal devaluation rule with respect to inflation in Brazil. The positive and large coefficient suggests an amplified response whereby, everything else constant, the exchange rate is devalued when inflation goes up. Of course, not everything else is constant which makes it difficult to interpret each individual coefficient. In any case, the optimal rules requires a devaluation when the real exchange rate is appreciated and, surprisingly, there is a muted response of the nominal exchange rate to commodity price shocks. While shocks to commodity prices have a direct impact on the costs of retailers, it seems that responding to the other variables, like the real exchange rate, is enough to dampen the terms of trade shock.

Perhaps surprisingly, Figures 1 to 3 show that the optimal simple policy and the exchange rate peg produce impulse responses that match closely those under the optimal Ramsey policy. Only the empirical rule seems to generate substantially different impulse responses, particularly so for the nominal variables and for the real exchange rate. These findings suggest that the costs of deviating from the Ramsey policy should be small.

In effect, when computing welfare measures, we recover the usual result in models with time and state separable preferences that welfare costs of deviating from the Ramsey policy are very small (see, for example, Lucas (2003)). In particular, the optimal simple policy delivers welfare levels indistinguishable from those under the optimal Ramsey policy. Even the exchange rate peg produces welfare costs of the order of a tenth of 1% in terms of consumption relative to the Ramsey allocation. Moreover, with the exception of Mexico, even the empirical rules delivers small welfare costs, as displayed in Panel B of Tables 2-4. In the case of Mexico, the welfare cost of the empirical rule with the largest R^2 is large, of the order of 33%. Before jumping to the conclusion that the monetary rule followed by the Central Bank in Mexico is grossly inefficient, we note that ours is a very simplified model that ignores many shocks that could be relevant in more complex situations.

8 Concluding remarks

In this paper we have studied optimal monetary and fiscal policies in a medium scale new Keynesian model with a *Dutch Disease* under the assumption of complete financial markets. The model is one of a multisector economy in which labor has competing uses in the commodity export sector, in the manufacturing sector and in the retail non-traded sector. The Dutch Disease problem is modeled as a an inefficiency that occurs in the manufacturing sector when its employment level experiences transitory falls below its steady state.

We found that when the government has access to flexible fiscal and monetary instruments the optimal monetary policy is price stability. As prices in the retail sector exhibit Calvo style rigidities, non-zero inflation creates production inefficiencies because it will cause otherwise identical firms to charge different prices. This zero inflation policy is the conventional monetary policy of an inflation targeting regime in a small open economy.

The main question addressed in this paper is whether the lack of flexible fiscal instruments and the potential inefficiency in manufacturing due to the externality warrant deviations of the conventional policy of zero inflation. Does the monetary authority have to manipulate the nominal exchange rate and depart from price stability in periods of commodity price booms when the manufacturing sector contracts? The conclusion of this paper is NO.

One important assumption in our analysis is that the small open economy has access to a complete set of financial assets. We can only speculate about the interaction between the incomplete markets assumption and the trade off between the price frictions and the externality. With incomplete financial markets, a positive terms of trade shock will have a positive wealth effect that will induce households to increase their demands for non-tradable goods. This higher consumption of non-tradables will require a reallocation of resources from the tradable sectors (manufacturing and commodities) to the retail sector. The external effect due to the drop in manufacturing employment driven by the wealth effect could interact with the price frictions in such a way that the planner may want to use the nominal exchange rate (and, give the price rigidities, the real exchange rate) to manipulate the equilibrium allocation. It is not clear the importance of this effect, which we leave for future research.

On the other hand, Diamond and Mirrlees (1971) classical homogeneous taxation result implies that the size of the distortion between marginal rates of substitution and marginal rates of transformation is not a reason to deviate from production efficiency. Thus, one could also speculate that no matter how distorted the margin between aggregate final consumption and work effort is, production efficiency is still a feature of the optimal allocation. Clearly,

Table 2: **Empirical devaluation rules and welfare costs in Brazil**

	Empirical devaluation rules					
Panel A	(1)	(2)	(3)	(4)	(5)	(6)
Inflation	-0.45	0.02	-0.80	-0.45	-0.01	-0.83
	(0.331)	(0.969)	(0.164)	(0.332)	(0.980)	(0.148)
GDP	0.73**			0.74**		
	(0.022)			(0.034)		
REER		-0.11			-0.10	
		(0.102)			(0.125)	
Unemployment			-0.22*			-0.21*
			(0.063)			(0.069)
Term of trade	-0.00	0.00	0.02			
	(0.948)	(0.944)	(0.644)			
Price comm.				-0.00	0.02	0.03
				(0.916)	(0.496)	(0.367)
Net exports	-0.54	-0.55	-0.34	-0.53	-0.59	-0.30
	(0.327)	(0.349)	(0.642)	(0.333)	(0.309)	(0.670)
constant	0.00	0.00	0.00	0.00	0.00	0.00
	(0.583)	(0.883)	(0.779)	(0.583)	(0.867)	(0.748)
R^2	0.17	0.13	0.13	0.17	0.14	0.14

	Welfare costs (% of consumption)					
Panel B	(1)	(2)	(3)	(4)	(5)	(6)
$\psi = 0$	0.734	1.969	-	0.800	1.205	-
$\psi = 5$	0.732	1.967	-	0.799	1.203	-
$\psi = 10$	0.730	1.966	-	0.797	1.202	-

Panel A reports OLS regressions of the devaluation of the nominal exchange rate on a number of variables. P-values are denoted in parentheses and *,**,*** mean significance at the 10%, 5%, and 1% levels respectively. Panel B displays the welfare costs associated with the empirical rules for different value of the externality parameter ψ. The welfare cost of an empirical rule is measured as the fraction of the Ramsey consumption allocation that the representative agent would be willing to give up to be as well off under the economy associated the Ramsey policy as under that associated with the empirical rule.

Table 3: **Empirical devaluation rules and welfare costs in Chile**

	Empirical devaluation rules					
Panel A	(1)	(2)	(3)	(4)	(5)	(6)
Inflation	0.40	0.52	0.40	-0.03	-0.11	-0.16
	(0.353)	(0.160)	(0.338)	(0.924)	(0.756)	(0.662)
GDP	-0.04			-0.32		
	(0.871)			(0.123)		
REER		-0.28***			-0.09	
		(0.002)			(0.330)	
Unemployment			0.01			0.02
			(0.848)			(0.496)
Term of trade	0.17*	-0.01	0.17**			
	(0.054)	(0.876)	(0.031)			
Price comm.				0.11***	0.08***	0.10***
				(0.000)	(0.004)	(0.000)
Net exports	-0.58***	-0.29	-0.57***	-0.66***	-0.59***	-0.64***
	(0.009)	(0.145)	(0.007)	(0.000)	(0.000)	(0.000)
constant	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
	(0.816)	(0.788)	(0.816)	(0.813)	(0.822)	(0.827)
R^2	0.24	0.38	0.24	0.49	0.48	0.48

	Welfare costs (% of consumption)					
Panel B	(1)	(2)	(3)	(4)	(5)	(6)
$\psi = 0$	5.829	1.631	-	0.039	0.077	-
$\psi = 5$	5.829	1.627	-	0.037	0.075	-
$\psi = 10$	5.832	1.626	-	0.036	0.075	-

Panel A reports OLS regressions of the devaluation of the nominal exchange rate on a number of variables. P-values are denoted in parentheses and *,**,*** mean significance at the 10%, 5%, and 1% levels respectively. Panel B displays the welfare costs associated with the empirical rules for different value of the externality parameter ψ. The welfare cost of an empirical rule is measured as the fraction of the Ramsey consumption allocation that the representative agent would be willing to give up to be as well off under the economy associated the Ramsey policy as under that associated with the empirical rule.

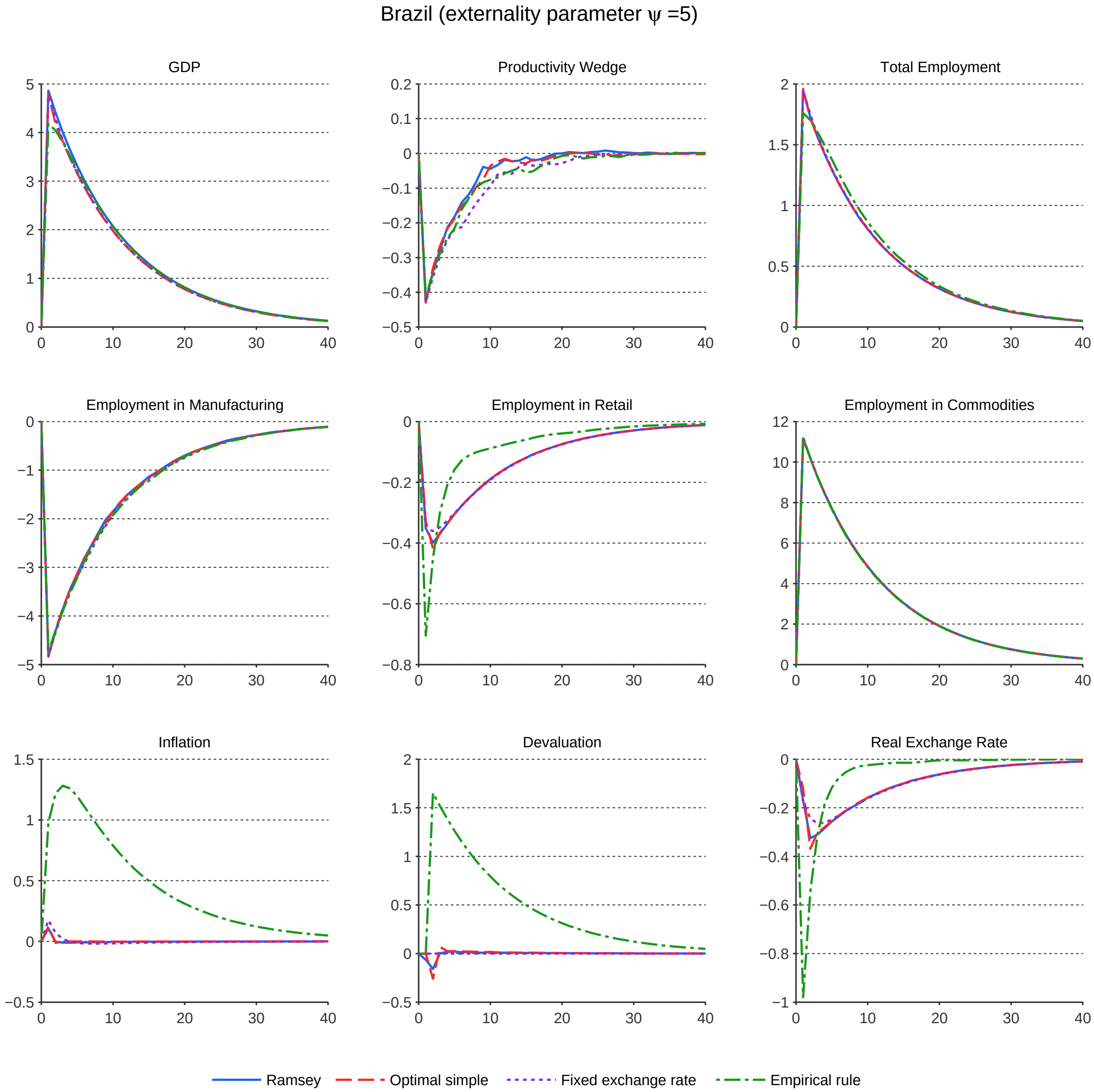
Table 4: **Empirical devaluation rules and welfare costs in Mexico**

	Empirical devaluation rules					
Panel A	(1)	(2)	(3)	(4)	(5)	(6)
Inflation	0.08	0.14	-0.04	0.01	0.09	-0.05
	(0.853)	(0.721)	(0.929)	(0.987)	(0.835)	(0.926)
GDP	-0.25			0.11		
	(0.151)			(0.435)		
REER		-0.20***			-0.24***	
		(0.008)			(0.000)	
Unemployment			-0.02			-0.05
			(0.523)			(0.126)
Term of trade	0.28***	0.05	0.17**			
	(0.003)	(0.539)	(0.019)			
Price comm.				-0.02	0.01	-0.02
				(0.526)	(0.584)	(0.411)
Net exports	-2.61***	-2.04***	-2.17***	-1.76**	-1.78***	-1.87***
	(0.000)	(0.001)	(0.001)	(0.015)	(0.004)	(0.008)
constant	0.00	0.00	0.00	0.00	0.00	0.00
	(0.432)	(0.446)	(0.372)	(0.440)	(0.413)	(0.401)
R^2	0.32	0.39	0.29	0.17	0.39	0.39

	Welfare costs (% of consumption)					
Panel B	(1)	(2)	(3)	(4)	(5)	(6)
$\psi = 0$	0.128	33.077	-	35.271	32.730	-
$\psi = 5$	0.125	33.077	-	35.271	32.730	-
$\psi = 10$	0.123	33.077	-	35.271	32.731	-

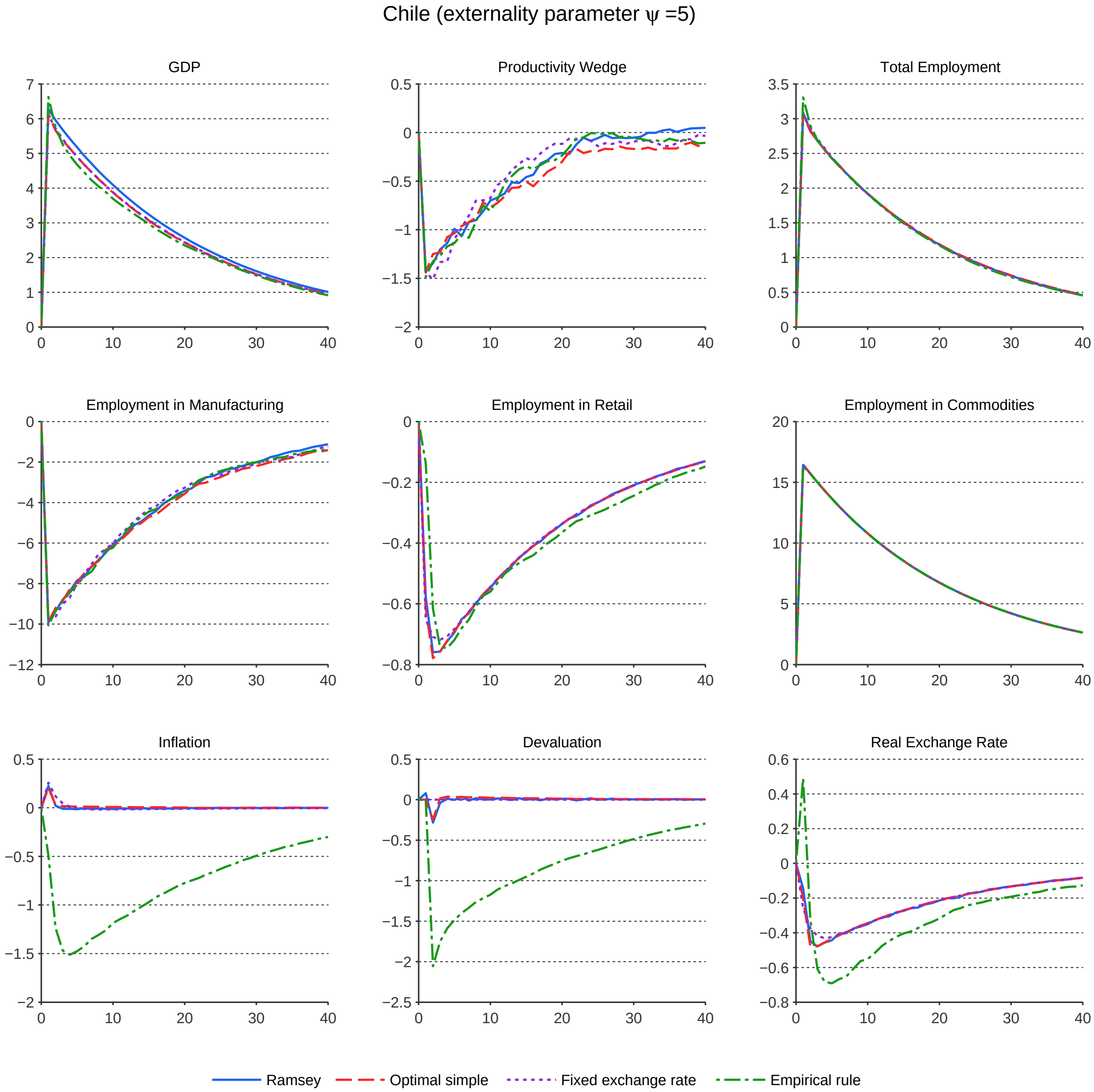
Panel A reports OLS regressions of the devaluation of the nominal exchange rate on a number of variables. P-values are denoted in parentheses and *,**,*** mean significance at the 10%, 5%, and 1% levels respectively. Panel B displays the welfare costs associated with the empirical rules for different value of the externality parameter ψ. The welfare cost of an empirical rule is measured as the fraction of the Ramsey consumption allocation that the representative agent would be willing to give up to be as well off under the economy associated the Ramsey policy as under that associated with the empirical rule.

Figure 1: Impulse responses to a one standard deviation shock to commodity price



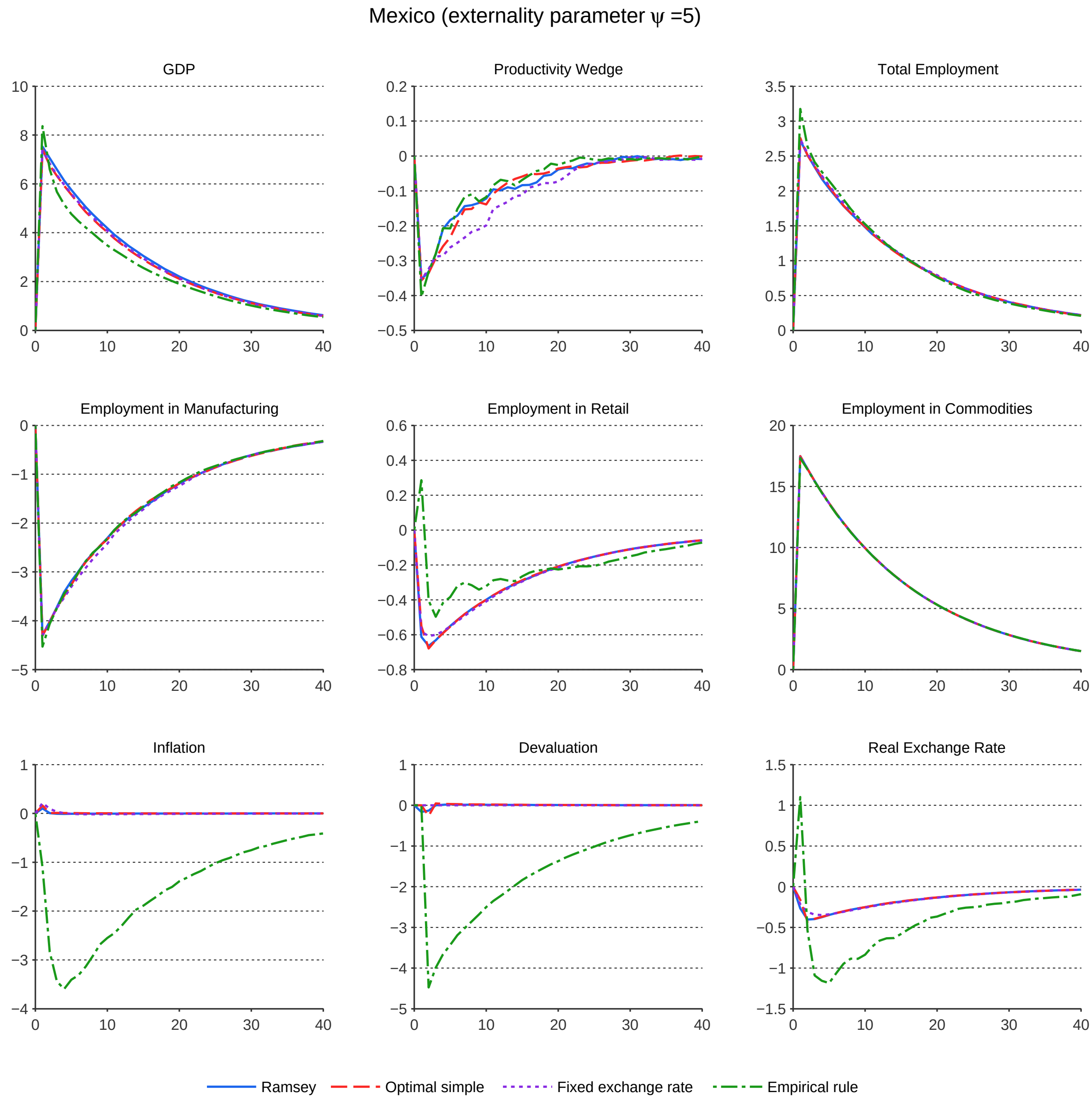
This figure displays selected impulse response functions to a one standard deviation shock to the price of the exportable commodity in Brazil and for the case without externality ($\psi = 5$). Solid blue lines represent the impulse responses associated with the Ramsey policy; dashed red line represent those associated with the optimal simple rule; dotted purple lines represent those associated with a fixed nominal exchange rate; and the dashed-dotted green lines are the impulse responses associated with the empirical devaluation rule. Among the empirical rules, we chose the one with the largest R^2. Because policy functions are non-linear, impulse responses where computed through Montecarlo simulations with using repetitions.

Figure 2: Impulse responses to a one standard deviation shock to commodity price



This figure displays selected impulse response functions to a one standard deviation shock to the price of the exportable commodity in Chile and for the case without externality ($\psi = 5$). Solid blue lines represent the impulse responses associated with the Ramsey policy; dashed red line represent those associated with the optimal simple rule; dotted purple lines represent those associated with a fixed nominal exchange rate; and the dashed-dotted green lines are the impulse responses associated with the empirical devaluation rule. Among the empirical rules, we chose the one with the largest R^2. Because policy functions are non-linear, impulse responses where computed through Montecarlo simulations with using repetitions.

Figure 3: Impulse responses to a one standard deviation shock to commodity price



This figure displays selected impulse response functions to a one standard deviation shock to the price of the exportable commodity in Mexico and for the case without externality ($\psi = 5$). Solid blue lines represent the impulse responses associated with the Ramsey policy; dashed red line represent those associated with the optimal simple rule; dotted purple lines represent those associated with a fixed nominal exchange rate; and the dashed-dotted green lines are the impulse responses associated with the empirical devaluation rule. Among the empirical rules, we chose the one with the largest R^2. Because policy functions are non-linear, impulse responses where computed through Montecarlo simulations with using repetitions.

Table 5: **Optimal simple policies**

Devaluation rule	Brazil	Chile	Mexico
Inflation	0.88	-0.36	-0.54
GDP	-0.17	-0.16	-0.27
REER	-0.93	-0.93	-1.62
Price commodity	0.04	0.04	-0.05
Net exports	-0.21	-0.22	-0.36

This table reports the optimized coefficients a_1, a_2, a_3, a_4, and a_5 of the devaluation rule (45) from Brazil, Chile, and Mexico. These constants are chosen to maximize the household's utility among all the policy rules in the proposed class.

however, we are deviating from the conditions required for Diamond and Mirrlees (1971), that now only hold in the steady state. Thus, one cannot be sure, but one can certainly hope that the answer provided by the model is robust to that modification.

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Appendix A Equilibrium and implementability conditions

This appendix summarizes the equilibrium conditions and reduces them to a set of implementability conditions that represent constraints to the Ramsey planner. We first discuss the conditions arising from the consumers' problem and from the profit maximization problem of firms in all sectors. We then focus on the intertemporal restriction faced by the small open economy.

The equilibrium conditions of the household can be summarized by the following implementability constraint

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[U_C \left(C_t, N_t \right) C_t + U_N \left(C_t, N_t \right) N_t \right] = 0,$$

which is a restriction to the planner.

It is convenient to write the pricing equation (13) in the retail sector in recursive form. For that purpose, use equation (8) to rewrite pricing condition as

$$p_t = \frac{\frac{\theta}{\theta-1} E_t \sum_{j=0}^{\infty} \left(\alpha\beta\right)^j U_{Ct+j} \left(\frac{P_{t+j}}{P_t}\right)^{\theta-1} Y_{t+j} MC_{t+j}}{E_t \sum_{s=0}^{\infty} \left(\alpha\beta\right)^s U_{Ct+s} \left(\frac{P_{t+s}}{P_t}\right)^{\theta-1} Y_{t+s}}.$$

Dividing this expression by P_t and using the definitions

$$\begin{aligned} mc_{t+j} &= \frac{MC_{t+j}}{P_{t+j}} \text{ and} \\ \tilde{p}_t &= \frac{p_t}{P_t}, \end{aligned}$$

the pricing equation can be written as

$$\tilde{p}_t = \frac{\frac{\theta}{\theta-1} E_t \sum_{j=0}^{\infty} \left(\alpha\beta\right)^j U_{Ct+j} Y_{t+j} \left(\frac{P_{t+j}}{P_t}\right)^{\theta} mc_{t+j}}{E_t \sum_{j=0}^{\infty} \left(\alpha\beta\right)^j U_{Ct+j} Y_{t+j} \left(\frac{P_{t+j}}{P_t}\right)^{\theta-1}}.$$

We now define two variables that allow us to find a recursive representation for the optimal pricing decision of firms. Denote the denominator of the previous equation by Φ_t and the numerator by Ψ_t, so that $\tilde{p}_t = \Psi_t / \Phi_t$. Letting $\pi_{t+1} = P_{t+1}/P_t$ denote gross inflation, it is a standard result to show that Ψ_t and Φ_t satisfy the recursive equations

$$\Psi_t = \frac{\theta}{\theta-1} U_{Ct} Y_t mc_t + \alpha\beta E_t \left[\pi_{t+1}^{\theta} \Psi_{t+1} \right] \text{ and} \tag{A.1}$$

$$\Phi_t = U_{Ct} Y_t + \alpha\beta E_t \left[\pi_{t+1}^{\theta-1} \Phi_{t+1} \right]. \tag{A.2}$$

Therefore, the pricing decisions of firms in the retail sector is is summarized by equations

(A.1), (A.2), and

$$\tilde{p}_t = \frac{\Psi_t}{\Phi_t}. \tag{A.3}$$

In terms of the new notation, the evolution of nominal prices in the retail sector can be written as

$$(1-\alpha)\,\tilde{p}_t^{1-\theta} + \alpha\,(\pi_t)^{\theta-1} = 1. \tag{A.4}$$

Output in the three sectors as a function of $n_t^y, n_t^q, n_t^x, q_t^x$ are given by

$$y_t = n_t^y \frac{A_t^y}{\eta_3} \frac{\left[P_t^{q*} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho}\right]^{1-\eta_3}}{\left(P_t^{x*}\right)^{\eta_1} \left(P_t^{z*}\right)^{\eta_2}}$$

$$X_t = \frac{A_t^x\left(\bar{n}_t^x\right)}{\bar{\zeta}} \left(n_t^x\right)^{\zeta_n} \left(q_t^x\right)^{\zeta_q} K^{1-\zeta_n-\zeta_q}$$

$$q_t = A_t^q \left(n_t^q\right)^{\rho} T^{1-\rho},$$

The optimality condition from the commodity sector

$$\rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho} = \frac{W_t}{P_t^{q*} S_t}$$

is used to obtain the wage that decentralizes the optimal allocation. The optimality conditions from manufacturing are given by

$$W_t\left(1-\tau_t^s\right) = P_t^{x*} S_t \frac{A_t^x\left(\bar{n}_t^x\right)}{\bar{\zeta}} \zeta_n \left(n_t^x\right)^{\zeta_n-1} \left(q_t^x\right)^{\zeta_q} K^{1-\zeta_n-\zeta_q}$$

$$P_t^{q*} = P_t^{x*} \frac{A_t^x\left(\bar{n}_t^x\right)}{\bar{\zeta}} \zeta_q \left(n_t^x\right)^{\zeta_n} \left(q_t^x\right)^{\zeta_q-1} K^{1-\zeta_n-\zeta_q}$$

The first one is used to obtain the subsidy to labor in manufacturing that decentralizes the optimal allocation, while the second remains as a constraint for the planner.

Market clearing for final goods, (25), can be written as a function of labor allocations, the price setting distortion and exogenous variables. To see this, note first that market clearing for each final good requires

$$y_{it} = c_{it} + g_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\theta} \left[C_t + G_t\right]$$

Using (23) the last equation can be written as

$$\left(\frac{P_{it}}{P_t}\right)^{-\theta} \left[C_t + G_t\right] = n_{it}^y \left(n_t^q\right)^{(\rho-1)(1-\eta_3)} \frac{A_t^y}{\eta_3} \frac{\left[P_t^{q*} \rho A_t^q T^{1-\rho}\right]^{1-\eta_3}}{\left(P_t^{x*}\right)^{\eta_1} \left(P_t^{z*}\right)^{\eta_2}}.$$

Integrating this expression over $i \in (0,1)$ gives

$$\left(\frac{P_{it}}{P_t}\right)^{-\theta}[C_t+G_t]=\left(\int n_{it}^y di\right)(n_t^q)^{(\rho-1)(1-\eta_3)}\frac{A_t^y}{\eta_3}\frac{\left[P_t^{q*}\rho A_t^q T^{1-\rho}\right]^{1-\eta_3}}{(P_t^{x*})^{\eta_1}(P_t^{z*})^{\eta_2}}$$

Moreover, using labor market clearing (24) and letting

$$D_t \equiv \int \left(\frac{P_{it}}{P_t}\right)^{-\theta} di.$$

gives

$$D_t[C_t+G_t]=(N_t-n_t^x-n_t^q)(n_t^q)^{(\rho-1)(1-\eta_3)}\frac{A_t^y}{\eta_3}\frac{\left[P_t^{q*}\rho A_t^q T^{1-\rho}\right]^{1-\eta_3}}{(P_t^{x*})^{\eta_1}(P_t^{z*})^{\eta_2}}$$

or

$$D_t[C_t+G_t]=Z_t(n_t^q)^{(\rho-1)(1-\eta_3)}(N_t-n_t^x-n_t^q) \tag{A.5}$$

where

$$Z_t=\frac{A_t^y}{\eta_3}\frac{\left[P_t^{q*}\rho A_t^q T^{1-\rho}\right]^{1-\eta_3}}{(P_t^{x*})^{\eta_1}(P_t^{z*})^{\eta_2}}$$

is a function of exogenous shocks.

Jensen's inequality implies $D_t \geq 1$ with equality if and only if $P_{it}=P_t$ for all $i \in (0,1)$. Moreover, following Yun (2005), the timing assumption in Calvo pricing implies that the index D_t evolves according to

$$D_t=(1-\alpha)\left[\frac{1-\alpha\pi_t^{\theta-1}}{1-\alpha}\right]^{\frac{\theta}{\theta-1}}+\alpha\pi_t^{\theta}D_{t-1}. \tag{A.6}$$

Foreign sector and feasibility

The foreign sector feasibility conditions are (26)-(28). The first term, for commodity net exports, in (28) can be written as

$$P_t^{q*}[q_t-q_t^x]=P_t^{q*}A_t^q(n_t^q)^{\rho}T^{1-\rho}-P_t^{q*}q_t^x$$

using the production function (19).

Using the first order condition for the commodity sector (20) in the cost minimization formulas for the retail sector (11), and later integrating over final goods and replacing the demand for commodities in manufacturing, q_t^x, we obtain the following expression

$$\begin{aligned}
& P_t^{x*}\left[X_t-\int_0^1 x_{it}di\right]-P_t^{z*}\int_0^1 z_{it}di \\
= \quad & P_t^{x*}\frac{A_t^x(\bar{n}_t^x)}{\bar{\zeta}}(n_t^x)^{\zeta_n}(q_t^x)^{\zeta_q}K^{1-\zeta_n-\zeta_q}-P_t^{q*}\rho A_t^q(n_t^q)^{\rho-1}T^{1-\rho}\frac{1-\eta_3}{\eta_3}(N_t-n_t^x-n_t^q)
\end{aligned}$$

Therefore, net exports measured in foreign currency can be written as a function of exogenous variables and the allocation of labor across sectors

$$\begin{aligned} nx_t^* &= P_t^{q*} A_t^q \left(n_t^q\right)^\rho T^{1-\rho} - P_t^{q*} q_t^x + P_t^{x*} \frac{A_t^x \left(\bar{n}_t^x\right)}{\bar{\zeta}} \left(n_t^x\right)^{\zeta_n} \left(q_t^x\right)^{\zeta_q} K^{1-\zeta_n-\zeta_q} \\ &\quad - P_t^{q*} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho} \frac{1-\eta_3}{\eta_3} \left(N_t - n_t^x - n_t^q\right) \end{aligned}$$

Appendix B The relaxed Ramsey problem

In view of the optimality of price stability discussed in the text, in this appendix we consider the Ramsey problem under constant prices and set $D_t = 1$ for all t. The Ramsey planner chooses $C_t, N_t, n_t^x, n_t^q, q_t^x$ to maximize the household's utility subject to the implementability constraints (30), (29), and (32) to which we attach multipliers λ, ϕ, and $\beta^t \delta_t$, respectively. Note that we are ignoring constraint (31). We show below, however, that this constraint is not binding, so we discard it. To solve the Ramsey problem, we define the "distorted" utility function

$$V\left(C, N; \lambda\right) \equiv U\left(C, N\right) + \lambda \left(U_C\left(C, N\right) C + U_N\left(C, N\right) N\right),$$

which is a function of the allocation and of the multiplier λ. The first order conditions with respect to C_t, N_t, q_t^x, n_t^q, and n_t^x are, respectively,

$$\beta^t V_{Ct} = \beta^t \delta_t$$

$$0 = \beta^t V_{Nt} - \phi Q_{0,t}^* P_t^{q*} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho} \frac{1-\eta_3}{\eta_3} + \beta^t \delta_t Z_t \left(n_t^q\right)^{(\rho-1)(1-\eta_3)}$$

$$0 = \phi Q_{0,t}^* \left[\zeta_q P_t^{x*} \frac{A_t^x \left(\bar{n}_t^x\right)}{\bar{\zeta}} \left(n_t^x\right)^{\zeta_n} \left(q_t^x\right)^{\zeta_q-1} K^{1-\zeta_n-\zeta_q} - P_t^{q*}\right]$$

$$\begin{aligned} 0 &= \phi Q_{0,t}^* \left[\begin{array}{c} \rho P_t^{q*} A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho} - (\rho-1) P_t^{q*} \rho A_t^q \left(n_t^q\right)^{\rho-2} T^{1-\rho} \frac{1-\eta_3}{\eta_3} \left(N_t - n_t^x - n_t^q\right) \\ + P_t^{q*} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho} \frac{1-\eta_3}{\eta_3} \end{array}\right] \\ &\quad + \beta^t \delta_t \left[(\rho-1)(1-\eta_3) Z_t \left(n_t^q\right)^{(\rho-1)(1-\eta_3)-1} \left(N_t - n_t^x - n_t^q\right) - Z_t \left(n_t^q\right)^{(\rho-1)(1-\eta_3)}\right] \end{aligned}$$

$$\begin{aligned} 0 &= \phi Q_{0,t}^* \left[\begin{array}{c} P_t^{x*} \frac{A_t^x(\bar{n}_t^x)}{\bar{\zeta}} \zeta_n \left(n_t^x\right)^{\zeta_n-1} \left(q_t^x\right)^{\zeta_q} K^{1-\zeta_n-\zeta_q} + P_t^{x*} \frac{1}{\bar{\zeta}} \frac{\partial A_t^x(\bar{n}_t^x)}{\partial n_t^x} \left(n_t^x\right)^{\zeta_n} \left(q_t^x\right)^{\zeta_q} K^{1-\zeta_n-\zeta_q} \\ + P_t^{q*} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho} \frac{1-\eta_3}{\eta_3} \end{array}\right] \\ &\quad - \beta^t \delta_t Z_t \left(n_t^q\right)^{(\rho-1)(1-\eta_3)} \end{aligned}$$

Note that the first order condition with respect to q_t^x proves that constraint (31) is indeed not binding. The reason is that, at the second best, it is not optimal to distort the amount of the locally produced commodity used in the production of local manufactures. This is a generalization of the result of Diamond and Mirrlees (1971) to a small open economy.

B.1 Decentralization of optimal taxes

The first order conditions with respect to consumption and labor of the Ramsey problem are, respectively,

$$\beta^t V_{Ct} = \beta^t \delta_t$$

$$0 = \beta^t V_{Nt} - \phi Q_{0,t}^* P_t^{q*} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho} \frac{1-\eta_3}{\eta_3} + \beta^t \delta_t Z_t \left(n_t^q\right)^{(\rho-1)(1-\eta_3)}$$

As we showed above, the ratio of the multipliers

$$\frac{\beta^t \delta_t}{\phi Q_{0,t}^*} = \frac{P_t^{q*} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho}}{Z_t \left(n_t^q\right)^{(\rho-1)(1-\eta_3)}} \frac{1}{\eta_3}.$$

Therefore, the first order condition with respect to employment of the Ramsey problem becomes

$$-\beta^t V_{Nt} = \beta^t \delta_t Z_t \left(n_t^q\right)^{(\rho-1)(1-\eta_3)} \eta_3$$

Using the first order condition for consumption then gives

$$-\frac{V_{Ct}}{V_{N_t}} = \frac{1}{Z_t \left(n_t^q\right)^{(\rho-1)(1-\eta_3)} \eta_3}$$

But using the definition

$$Z_t = \frac{A_t^y}{\eta_3} \frac{\left[P_t^{q*} \rho A_t^q T^{1-\rho}\right]^{1-\eta_3}}{\left(P_t^{x*}\right)^{\eta_1} \left(P_t^{z*}\right)^{\eta_2}}$$

gives

$$-\frac{V_{Ct}}{V_{N_t}} = \frac{MC_t^*}{P_t^{q*} \rho A_t^q \left(n_t^q\right)^{(\rho-1)} T^{1-\rho}}$$

On the other hand, in equilibrium,

$$\begin{aligned} -\frac{U_C\left(C_t, N_t\right)}{U_N\left(C_t, N_t\right)} &= \frac{P_t}{W_t\left(1-\tau_t^n\right)} \\ &= \frac{\left(P_t / S_t\right)}{\left(W_t / S_t\right)\left(1-\tau_t^n\right)} \\ &= \frac{\frac{\theta}{\theta-1} MC_t^*}{P_t^{q*} \rho A_t^q \left(n_t^q\right)^{(\rho-1)} T^{1-\rho}\left(1-\tau_t^n\right)} \end{aligned}$$

Putting together these expression we obtain the optimal labor tax 36.

Now using the relation of multipliers we can write the Ramsey first order condition with respect to C_t as

$$\beta^t V_{Ct} = \frac{\phi Q_{0,t}^* P_t^{q*} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho} \frac{1}{\eta_3}}{Z_t \left(n_t^q\right)^{(\rho-1)(1-\eta_3)}}$$

Evaluating the above expression at time $t+1$ and t can be used to obtain the following intertemporal marginal rate of substitution between consumption at t and $t+1$ using the planner's preferences,

$$\frac{V_{Ct}}{\beta V_{Ct+1}} = \frac{1}{Q^*_{0,t+1}} \frac{\frac{P_t^{q*}\rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho}\frac{1}{\eta_3}}{Z_t\left(n_t^q\right)^{(\rho-1)(1-\eta_3)}}}{\frac{P_{t+1}^{q*}\rho A_{t+1}^q \left(n_{t+1}^q\right)^{\rho-1} T^{1-\rho}\frac{1}{\eta_3}}{Z_{t+1}\left(n_{t+1}^q\right)^{(\rho-1)(1-\eta_3)}}}.$$

But using the relation between Z_t and MC^*_{t+1} we can write the last equation as

$$\frac{\beta V_{Ct+1}}{V_{Ct}} = Q^*_{t,t+1}\frac{MC^*_t}{MC^*_{t+1}}.$$

On the other hand, using the no-arbitrage condition between home and foreign bonds, that under the Ramsey policy prices are constant, and the pricing equation with constant prices, the household's intertemporal Euler equation (8) in equilibrium becomes

$$\frac{\beta U_{Ct+1}}{U_{Ct}} = (1+\tau^*_t)Q^*_{t,t+1}\frac{MC^*_t}{MC^*_{t+1}}.$$

The last two expression deliver the optimal tax on capital flows (37).

B.2 Proof of Proposition 3

The proposed preferences imply

$$V(C,N;\lambda) = \frac{C^{1-\sigma}}{1-\sigma}\left(1+\lambda\left(1-\sigma\right)\right) - \kappa\frac{N^{1+\phi}}{1+\phi}\left(1+\lambda\left(1+\phi\right)\right),$$

Therefore,

$$\frac{V_{Ct}\left(C,N;\lambda\right)/V_{Nt}\left(C,N;\lambda\right)}{U_{Ct}\left(C,N\right)/U_{Nt}\left(C,N\right)} = \frac{\left(1+\lambda\left(1-\sigma\right)\right)}{\left(1+\lambda\left(1+\phi\right)\right)}$$

Using this expression into (36) gives

$$1-\tau^n_t = \left(\frac{\theta}{\theta-1}\right)\frac{1+\lambda\left(1-\sigma\right)}{1+\lambda\left(1+\phi\right)}.$$

proving that the optimal labor income tax is constant.

Likewise, the proposed utility function implies

$$\frac{V_{Ct+1}}{V_{Ct}} = \frac{U_{Ct+1}}{U_{Ct}}.$$

Expression (37) then implies $\tau^*_t = 0$ for all t.

Appendix C Constrained Ramsey implementability conditions

This appendix derives the implementability conditions (38)–(44) of the Ramsey problem with no flexible tax instruments. We use the equilibrium conditions derived in the text and in Appendix A. First, using the proposed subsidy, equation (A.1) becomes

$$\Psi_t = U_{Ct} Y_t mc_t + \alpha\beta E_t \left[\pi_{t+1}^{\theta} \Psi_{t+1}\right].$$

Moreover, equation (A.4) can be written as

$$\tilde{p}_t = \left[\frac{1-\alpha\left(\pi_t\right)^{\theta-1}}{1-\alpha}\right]^{\frac{1}{1-\theta}}.$$

Next, using (A.3) and the previous equation gives

$$\Psi_t = \Phi_t \left[\frac{1-\alpha\left(\pi_t\right)^{\theta-1}}{1-\alpha}\right]^{\frac{1}{1-\theta}}$$

Inserting this condition into the law of motion for Ψ_t we obtain

$$\Phi_t \left[1-\alpha\left(\pi_t\right)^{\theta-1}\right]^{\frac{1}{1-\theta}} = (1-\alpha)^{\frac{1}{1-\theta}} U_{Ct} Y_t mc_t + \alpha\beta E_t \left[\pi_{t+1}^{\theta}\left[1-\alpha\left(\pi_{t+1}\right)^{\theta-1}\right]^{\frac{1}{1-\theta}} \Phi_{t+1}\right].$$

We are now ready to summarize all equilibrium conditions that constitute constraints for the Ramsey planner without flexible tax instruments. Using that in equilibrium $\bar{n}_t^x = n_t^x$, an allocation and price system constitute an equilibrium of the model if they satisfy the following equations

$$U_{Ct} = \mu u_t^* \frac{P_t}{S_t}$$

$$-\frac{U_{Nt}}{U_{Ct}} = \frac{W_t}{P_t}$$

$$\Phi_t \left[1-\alpha\left(\pi_t\right)^{\theta-1}\right]^{\frac{1}{1-\theta}} = (1-\alpha)^{\frac{1}{1-\theta}} U_{Ct}\left(C_t+G_t\right) mc_t + \alpha\beta E_t \left[\pi_{t+1}^{\theta}\left[1-\alpha\left(\pi_{t+1}\right)^{\theta-1}\right]^{\frac{1}{1-\theta}} \Phi_{t+1}\right]$$

$$\Phi_t = U_{Ct}\left(C_t+G_t\right) + \alpha\beta E_t \pi_{t+1}^{\theta-1}\Phi_{t+1}$$

$$q_t = A_t^q \left(n_t^q\right)^{\rho} T^{1-\rho} \tag{C.7}$$

$$P_t^{q*} \rho A_t^q \left(n_t^q\right)^{\rho-1} T^{1-\rho} = \frac{W_t}{S_t}$$

$$X_t = \frac{A_t^x\left(n_t^x\right)}{\bar{\zeta}} \left(n_t^x\right)^{\zeta_1} \left(q_t^x\right)^{\zeta_2} K^{\zeta_3} \tag{C.8}$$

$$W_t = P_t^{x*} S_t \frac{A_t^x (n_t^x)}{\bar{\zeta}} \zeta_1 (n_t^x)^{\zeta_1 - 1} (q_t^x)^{\zeta_2} K^{\zeta_3} \tag{C.9}$$

$$P_t^{q*} = P_t^{x*} \frac{A_t^x (n_t^x)}{\bar{\zeta}} \zeta_2 (n_t^x)^{\zeta_1} (q_t^x)^{\zeta_2 - 1} K^{\zeta_3} \tag{C.10}$$

$$D_t [C_t + G_t] = (N_t - n_t^x - n_t^q) (n_t^q)^{(\rho - 1)(1 - \eta_3)} Z_t$$

$$D_t = (1 - \alpha) \left[\frac{1 - \alpha \pi_t^{\theta - 1}}{1 - \alpha} \right]^{\frac{\theta}{\theta - 1}} + \alpha \pi_t^{\theta} D_{t-1}$$

$$E_0 \sum_{t=0}^{\infty} Q_{0,t}^* \left[P_t^{q*} [q_t - q_t^x] + P_t^{x*} X_t - P_t^{q*} \rho A_t^q (n_t^q)^{\rho - 1} T^{1-\rho} \frac{1 - \eta_3}{\eta_3} [N_t - n_t^q - n_t^x] \right] = -B_0^*, \tag{C.11}$$

where B_0^* is the initial level of assets. The above equations constitutes a non-linear dynamical system of twelve equations with thirteen unknowns: C_t, N_t, S_t, P_t, W_t, Φ_t, π_t, q_t, n_t^q, X_t, n_t^x, q_t^x, D_t. The nominal exchange rate S_t is the free variable that the Ramsey planner uses to maximize the household's welfare.

We now simplify the above system of equations. First, following Schmitt-Grohé and Uribe (2003), we ignore the last equation, set a value for μ, and then solve for the equilibrium of the model given the value for μ. The B_0^* that makes the resulting allocation an equilibrium follows implicitly from equation (C.11). We discipline the model by choosing μ to match the observed average net exports - GDP ratio in the group of countries that we consider.

Once we eliminate (C.11), we can simplify the system further by getting rid of equations (C.7) and (C.8) since they can be viewed as defining the quantities q_t and X_t. Moreover, we use (C.10) to solve for q_t^x as a function of the other variables and replace the result into (C.9) in which case the system is reduced to the system of equations (38)–(44).