

Monetary Policy in an Oil-Exporting Economy

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The sudden collapse of oil prices poses a challenge to inflation-targeting central banks in oil-exporting economies. In this article, the authors illustrate this challenge and conduct a quantitative assessment of the impact of changes in oil prices in a small open economy in which oil represents an important fraction of its exports. They build a monetary, three-sector, dynamic stochastic general equilibrium model and estimate it for the Colombian economy. They model the oil sector as an optimal resource extracting problem and show that in oil-exporting economies the macroeconomic effects vary according to the degree of persistence of oil price shocks. The main channels through which these shocks pass to the economy come from the real exchange rate, the country risk premium, and sluggish price adjustments. Inflation-targeting central banks in such economies face a policy dilemma: raise the policy rate to fight increased inflation coming from the exchange rate passthrough or lower it to stimulate a slowing economy. (JEL C61, E31, E37, E52, F41)

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One global event shaped the economic outcomes during 2014 and 2015: the sudden collapse of world oil prices. This event has been a source of instability in global financial markets, especially in emerging economies such as Russia, Brazil, Venezuela, Ecuador, and Colombia. This sudden collapse in oil prices has caught the attention of policymakers and academics as the macroeconomic consequences may be significant.

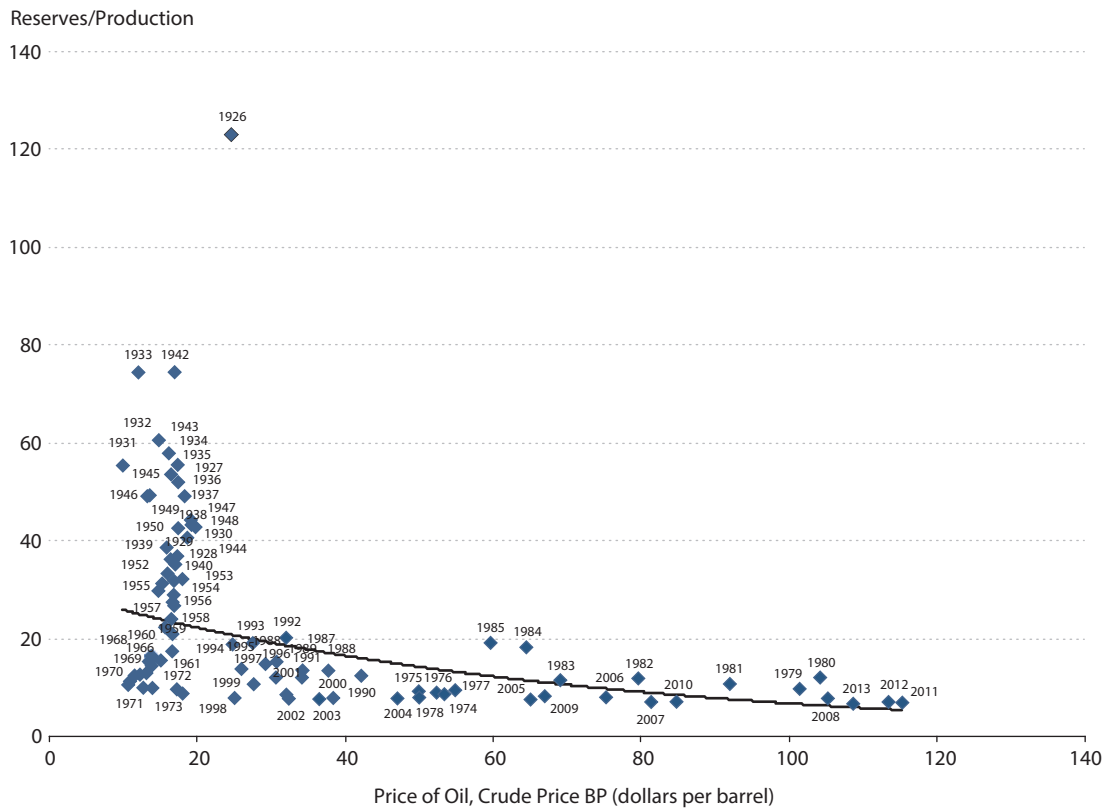
An analysis of the implications of such a collapse for monetary policy in small oil-exporting economies is needed for several reasons. First, the oil price shock is large and to some extent occurred earlier than expected. Oil prices increased steadily after 2009 from \$35 (U.S. dollars) per barrel to levels surpassing \$100 per barrel. In the last quarter of 2014, oil prices fell by 38 percent and country risk spreads and interest rates in oil-exporting economies jumped.

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Figure 1

International Oil Prices and the Oil Reserves-to-Production Ratio: Colombia



SOURCE: From Hamann, Bejarano, and Rodríguez (2015, Figure 2, p. 3).

Second, oil production in some countries is a significant portion of gross domestic product (GDP). For instance, Colombian oil production over the past 10 years increased from 5 percent of GDP to 11 percent in 2014; the share of oil exports in GDP jumped from 3 percent in 2002 to 8 percent in 2014. In turn, fiscal revenues from oil (as a share of total public revenues) increased from under 10 percent in 2002 to close to 20 percent in 2011. Foreign direct investment (FDI) in the oil sector represented 32 percent (as a share of the total FDI in Colombia), while FDI in mining represented 17 percent in 2014. Similar patterns emerge for other oil-exporting economies.

Third, persistent swings in oil prices do impact oil activity in Colombia. Figure 1 shows the linkage between international oil prices and the ratio of oil reserves to production in Colombia. The data for the figure support the idea that as prices increase, producers extract oil from the ground and reserves fall, *ceteris paribus*. On the contrary, when prices are low, there are fewer incentives for producers to extract oil.

Oil price shocks are also related to country risk spreads,¹ capital flows, and other macro-economic indicators at the business cycle frequency. Periods of high commodity prices have

been associated with lower spreads, capital inflows, and good macro performance, whereas the opposite is associated with periods of low prices. González, Hamann, and Rodríguez (2015) have documented some empirical regularities around *transitory* oil price shocks in Colombia.

These facts are consistent with the intuition shared by many economists who study small open economies in which resource sectors are important. Higher oil prices increase oil revenues but compress the risk premium, thereby (i) improving overall creditworthiness, (ii) creating a surge in demand for tradable and non-tradable goods, and (iii) inducing both a real exchange-rate appreciation and a shift of economic resources from the tradable sector to the non-tradable sector. Credit expands, especially in those sectors boosted by the real appreciation. Overall economic activity and demand booms move in tandem with asset prices. However, sharp oil price reversals truncate this process; resources are reallocated and asset prices and the currency collapse.

It is possible that current oil prices will remain low not just for a few quarters but for several years to come. Long-lasting changes in global conditions pose a different challenge for central banks in small open and commodity-dependent economies. Permanent changes in oil prices reduce permanent income, affect aggregate consumption and savings decisions, and have implications for resource allocations between tradable and non-tradable sectors. Resource allocations show up in the real exchange rate, wages, and the country's long-term net foreign asset position. Monetary policy is usually set to reach goals at a one- to two-year horizon. Long-term changes from lower oil prices may have different macroeconomic consequences than temporary shocks, as stressed by Rebucci and Spatafora (2006), Kilian (2009), and Kilian, Rebucci, and Spatafora (2009).

Still, nominal adjustment of the exchange rate may continue to be important because a flexible nominal exchange rate may partially compensate for the fall in oil prices. The importance of the role of nominal stickiness in small open economy models has been emphasized by Galí and Monacelli (2005); De Paoli (2009); Benigno and De Paoli (2010); Auray, de Blas, and Eyquem (2011); Gertler and Karadi (2011); and Schmitt-Grohé and Uribe (2013), to name a few. In the presence of nominal price and/or wage rigidities, the quantities of oil produced will likely further accommodate the adjustment. For instance, gasoline and other oil derivatives are key inputs of production; should these inputs become relatively cheaper, they could ease marginal cost pressure on firms and inflation. Finally, pass through from such shocks to inflation and inflation expectations may trigger a monetary policy response, which in the presence of nominal rigidities feeds back into economic activity.

In this article, we conduct a quantitative assessment of the impact of permanent oil price changes in a small open economy in which a commodity, such as oil, represents an important share of the economy. Our analysis takes into account the central bank's policy response to such changes. Here we use a highly persistent but transitory shock as a proxy for a permanent shock. In a more general setup, presented in Hamann, Bejarano, and Rodríguez (2015), we conducted the same experiment using a permanent shock that changes the long-run net foreign asset position of the economy; the results in that article are similar to those presented here.

To understand the basic mechanisms at work, we set up a monetary policy model with three sectors: non-tradable, tradable, and oil. The non-tradable sector uses labor and an

imported intermediate good (i.e., gasoline) in the production of a final good; this sector also has monopolistic competition and sticky prices. The tradable sector is modeled as an endowment, and oil is a fully exportable output whose production is endogenous and responds to economic incentives. We model the oil sector as a resource extraction problem as in Sickles and Hartley (2001) and Pesaran (1990). The economy owns a stock of oil and extracts the optimal portion of it to sell in international competitive commodity markets. Thus, optimal extraction rules depend on the stock of oil reserves, oil prices, interest rates, the marginal costs of oil operation, and the uncertain nature of oil discoveries.

We close the nominal portion of the model assuming a total inflation-targeting central bank. Our quantitative analysis indicates that this central bank is confronted with a policy dilemma: The permanent fall in oil revenues causes a permanent fall in consumption and GDP, but the nominal depreciation drives total inflation off target, causing the bank to tighten its policy stance. We also show, however, that this dilemma arises because the tradable sector features flexible prices,² whereas in the non-tradable sector prices are sticky. Therefore, the dilemma disappears if the central bank is able to identify exactly where the nominal rigidities reside (i.e., the non-tradable sector) and targets non-tradable inflation.

Both the nominal and the real exchange-rate adjustments are at the core of the adjustment mechanism since this plunge in oil prices incentivizes oil firms to cut extraction and increase oil reserves, which in turn reduces the availability of tradable goods in the economy. Reduced availability causes excess demand for tradable goods; this demand is adjusted through an increase in the relative price of tradable goods to non-tradable goods.

Also, at the core of the adjustment mechanism lies the external interest rate the economy faces in international financial markets. The model predicts a protracted period of higher external interest rates because of the higher risk premium caused by lower oil prices, which is in contrast to lower risk when oil reserves are high and accumulated endogenously. The interaction of these real adjustments with nominal rigidities is interesting because the model delivers nominal exchange-rate depreciation, which passes through to total inflation. This pass through is significant. It temporally but persistently raises annual inflation well above target, causing the model's total inflation-targeting central bank to tighten monetary policy to control inflation.

The rest of the article proceeds as follows. In the next section we present a monetary policy model for an oil-exporting economy and evaluate its quantitative predictions under both a permanent and a transitory oil price shock. In our concluding section we examine the implications of our framework for monetary policy.

AN OIL-EXPORTING, SMALL OPEN MONETARY ECONOMY

Structure of the Model

The model is a three-sector (oil, tradable, and non-tradable sectors) small open economy with an incomplete foreign financial assets market populated by households, producers, and the central bank. Households (i) supply labor to firms and consume final goods, (ii) save in

the form of foreign debt, and (iii) receive the revenues from the oil sector, which decides how to extract oil optimally. The tradable output is an endowment, but non-tradable output is produced in several stages in a monopolistic competitive environment with nominal rigidities. In addition, non-tradable output production needs an imported input of production (i.e., gasoline).

Households

More formally, there is a representative household that maximizes the expected discounted utility,

$$E_0 \left[\sum_{t=0}^{\infty} \beta^t \frac{\left[c_t - \frac{h_t^\omega}{\omega} \right]^{1-\sigma}}{1-\sigma} \right],$$

subject to

$$c_t + q_t b_t^* (1+r_t^*) + Q_{t,t+1} b_{t+1} \leq w_t h_t + q_t C(s, x) + \xi_t^N + p_t^T y^T + q_t \xi_t^X + q_t b_{t+1}^* + b_t,$$

where c_t is the consumption basket; h_t are the hours worked; w_t is the real wage; $C(s, x)$ is the revenue for supplying drilling and oil field services to the oil firm³; b_t^* is the real external debt expressed in terms of the foreign consumption basket; b_t is a real state-contingent domestic bond; q_t is the real exchange rate; $Q_{t,t+1}$ is the real price of the domestic bond; ξ_t^N are the profits for the non-tradable goods producers; y^T is a constant stream of income of an endowment of tradable goods (which can be consumed or exported)⁴; $p_t^T = q_t p_t^{T,*}$ with $p_t^{T,*}$ following an AR(1) process (described in the appendix); ξ_t^X are the profits from the oil firms; and r_t^* is the real interest rate this economy faces in international financial markets.

We model the external real interest rate as having two components: (i) the risk-free real interest rate and (ii) a risk component that we assume is a positive function of the deviations of the external debt-to-oil reserves ratio from its steady-state value. That is,

$$r_t^* = r_t^f + \psi \left[\exp \left(\frac{q_t b_t^*}{p_t^x s_t} - \frac{q b^*}{p^x s} \right) - 1 \right],$$

where $\psi > 0$ is a parameter that determines the elasticity of the risk component to deviations of the debt-to-oil reserves ratio from its steady state, s_t is the stock of oil reserves, and r_t^f represents the risk-free real interest rate. This reduced form is similar to that presented by Neumeyer and Perri (2005). As in Neumeyer and Perry (2005), this relation is introduced not to provide a satisfactory model of country risk, but rather to show that country risk may also depend on both internal and external conditions such as the domestic debt and the international oil price, respectively. The inclusion of the oil price in this specification may amplify the effects of an oil price shock beyond the usual income effect displayed in this family of models.

Assuming that the law of one price holds for oil,

$$p_t^x = q_t p_t^{x,*},$$

where p_t^x is the real price of oil and $p_t^{x,*}$ is the real price of oil in terms of a foreign consumer price index (CPI).

To simplify the (paper and pencil) calculation of the deterministic steady state of this model, we depart from the constant elasticity of substitution specification of consumption and assume that the consumption goods basket for the representative household is a Cobb-Douglas compound of tradable and non-tradable goods as follows:

$$c_t = (c_t^N)^\gamma (c_t^T)^{1-\gamma},$$

where c_t^T is the consumption of tradable goods and c_t^N is the basket of differentiated non-tradable goods, which is represented by a Dixit-Stiglitz aggregator:

$$c_t^N = \left[\int_0^1 c_t^N(j)^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}}.$$

Under these assumptions, the optimal household choices of consumption, hours worked, domestic bonds, and external debt are

$$\left[c_t - \frac{h_t^\omega}{\omega} \right]^{-\sigma} = \lambda_t$$

$$h_t^{\omega-1} = w_t$$

$$\beta E_t \lambda_{t+1} = Q_{t,t+1} \lambda_t$$

$$q_t \lambda_t = \beta E_t q_{t+1} (1+r_{t+1}^*) \lambda_{t+1}.$$

Also, as $Q_{t,t+1}$ is the present value of the domestic state-contingent bond, it has an inverse relationship with the real interest rate:

$$Q_{t,t+1} = \frac{1}{(1+r_t)} \text{ and}$$

$$1+r_t = \frac{1+i_t}{1+E_t \pi_{t+1}}.$$

Since preferences are separable across periods, the intratemporal optimal choice can be made independently of the intertemporal optimal choice; therefore, the optimal choices of non-tradable and tradable consumption are

$$c_t^N = \frac{\gamma c_t}{p_t^N} \text{ and}$$

$$c_t^T = \frac{(1-\gamma)c_t}{p_t^T},$$

where p_t^N and p_t^T are the non-tradable and tradable prices relative to the CPI, which is

$$P_t = \gamma^{-\gamma} (1-\gamma)^{-(1-\gamma)} (P_t^N)^\gamma (P_t^T)^{1-\gamma}.$$

The previous expression can be represented in real terms as follows:

$$1 = \gamma^{-\gamma} (1-\gamma)^{-(1-\gamma)} (p_t^N)^\gamma (p_t^T)^{1-\gamma}.$$

The optimal choice of non-traded good variety j is

$$c_t^N(j) = \left(\frac{p_t^N(j)}{p_t^N} \right)^{-\theta} c_t^N,$$

and the non-tradable goods price level aggregator is

$$(1) \quad p_t^N = \left[\int_0^1 p_t^N(j)^{1-\theta} dj \right]^{\frac{1}{1-\theta}}.$$

Oil Extraction. In addition to the tradable and non-tradable sectors, there is also an oil-exporting sector in the economy. Oil activities are modeled as in Sickles and Hartley (2001). There is a representative oil-extracting firm owned by agents that decides how much oil to extract from the ground. At the beginning of any given year, the country has s units of oil reserves and x units can be extracted to be exported and sold in a competitive international oil market at the given relative price $p_t^{x^*}$, which is a stochastic variable (in units of foreign CPI). The total cost of extracting x units of oil in any year, given that there are s units of oil at the beginning of the year, is $C(s,x)$. The cost function C is decreasing in s (the total extraction cost falls the larger the oil reserves) and increasing in x (the total cost rises the higher the extraction rate). The marginal cost of an additional unit of reserves, conditioned on not extracting oil, is zero: $C_s(s,0) = 0$.

The problem of the representative oil firm is to maximize the expected discounted future stream of profits. The firm decides in each period the amount of oil to extract, x_t , and the level of future reserves, s_{t+1} . That is,

$$(2) \quad \max_{\{x_t, s_{t+1}\}} E_t \left\{ \sum_{i=0}^{\infty} \beta^i \left[\xi_t^X \right] \right\},$$

subject to

$$(3) \quad s_{t+1} = s_t + d_t - x_t,$$

where d_t is a stochastic variable and represents oil discoveries. Profits are

$$(4) \quad \xi_t^X = p_t^{x,*} x_t - C(x_t, s_t).$$

Optimal extraction satisfies the following conditions:

$$[x_t]: E_t \left\{ p_t^{x,*} - \frac{\partial C}{\partial x_t} - \beta \Upsilon_t \right\} = 0$$

$$[s_{t+1}]: E_t \left\{ -\frac{\partial C}{\partial s_{t+1}} - \Upsilon_t + \beta \Upsilon_{t+1} \right\} = 0,$$

where Υ_t is the Lagrange multiplier associated with the oil reserves accumulation equation.

The first optimality condition states that the price of oil should compensate not only today's marginal cost of extraction but also the discounted marginal value of future profits, which will depend on the stock of future reserves. The second condition states that the shadow price of existing oil reserves should be equal to the marginal cost of existing reserves and the discounted marginal value of future reserves. Note that in the steady state reserves should be constant and, therefore, the optimal rate of extraction equals the rate of discovery of new oil resources. Yet the level of reserves may be higher or lower depending on the cost structure, the random nature of discoveries, the interest rate, and the oil price.

The function we use to perform the quantitative experiments is

$$(5) \quad C = \frac{\kappa}{2} \frac{x_t^2}{1 + s_t},$$

which satisfies some restrictions commonly used in the natural resource economics literature.⁵

Both oil prices and discoveries follow these processes:

$$\log(p_t^{x,*}) = \rho_{p^x} \log(p_{t-1}^{x,*}) + (1 - \rho_{p^x}) \log(\bar{p}^{x,*}) + \varepsilon_t^{p^{x,*}}$$

$$\log(d_t) = \rho_d \log(d_{t-1}) + (1 - \rho_d) \log(\bar{d}) + \rho^{d,p^x} \log(p_t^x) + \varepsilon_t^d,$$

where $\varepsilon_t^{p^{x,*}}$ and ε_t^d are i.i.d. $(0, \sigma^2)$.

In the "Calibration, Estimation, and Baseline Results" section, we show that discoveries are positively correlated with the international oil price.

Non-Tradable Goods Production. There is a representative firm producing a homogeneous non-tradable good in a perfectly competitive environment. The firm chooses two inputs—labor and oil—to produce the non-tradable good, which is also traded in competitive markets. The firm's objective is to minimize the total cost,

$$w_t h_t + p_t^x m_t,$$

subject to

$$y_t^N = A_t h_t^\alpha (m_t)^{1-\alpha},$$

where A_t represents the total factor productivity that follows an exogenous stochastic process, and m_t is the demand for oil from producers of non-tradable goods. Note that we have implicitly assumed that capital is fixed and equal to one unit for all t .

Under these assumptions, the firm's optimal choices of hours worked, oil, and real marginal cost are as follows:

$$w_t = \varphi_t A_t \alpha \left(\frac{m_t}{h_t} \right)^{\alpha-1}$$

$$p_t^x = \varphi_t A_t (1-\alpha) \left(\frac{m_t}{h_t} \right)^{-\alpha}$$

$$\varphi_t = A_t^{-1} \alpha^{-\alpha} (1-\alpha)^{-(1-\alpha)} w_t^\alpha (p_t^x)^{1-\alpha},$$

and the homogeneous non-tradable good's price is $p_t^{NH} = \varphi_t$ because the homogeneous good is produced in a perfectly competitive environment.

Price Setting. There is a continuum of retail firms that buy the homogeneous non-tradable good from the perfectly competitive firms at p_t^{NH} and transform this homogeneous good into a differentiated variety j . Therefore, each of these firms has monopoly power in its respective variety. We assume that there is Calvo price stickiness. Each retailer receives a random signal to adjust its prices with a probability of $1 - \epsilon$, setting a price $\tilde{p}_t^N(j)$ to maximize

$$(6) \quad E_t \sum_{i=0}^{\infty} \epsilon^i \Lambda_{t,t+i} \left[p_t^N(j) y_{t+i}^N(j) - \varphi_{t+i} y_{t+i}^N(j) \right],$$

subject to

$$(7) \quad y_t^N(j) = \left(\frac{p_t^N(j)}{p_t^N} \right)^{-\theta} y_t^N$$

since the market clearing condition for each non-tradable variety holds—that is, $c_t^N(j) = y_t^N(j)$. Here $\Lambda_{t,t+i} = \frac{\beta \lambda_{t+i}}{\lambda_t}$ is the stochastic discount factor for households since they own the firm.

Therefore, the retailer's optimal price setting is represented by the first-order condition of solving (6) subject to (7), which is

$$\tilde{p}_t^N(j) = \frac{\theta}{\theta - 1} \frac{\left\{ E_t \sum_{i=0}^{\infty} (\epsilon\beta)^i \lambda_{t+i} \varphi_{t+i} y_{t+i}^N (p_{t+i}^N)^\theta \right\}}{\left\{ E_t \sum_{i=0}^{\infty} (\epsilon\beta)^i \lambda_{t+i} y_{t+i}^N (p_{t+i}^N)^{\theta-1} \right\}}.$$

We assume that all retailers have the same cost structure and therefore set the same price, $\tilde{p}_t^N(j) = \tilde{p}_t^N$. By the law of large numbers, ϵ represents the fraction of retailers that keep their prices fixed and $1 - \epsilon$ the fraction of retailers that reoptimize their prices by choosing \tilde{p}_t^N ; then by using (1), the non-tradable good price index can be expressed as

$$1 = \left[\epsilon \left(\frac{1}{1 + \pi_t^N} \right)^{1-\theta} + (1-\epsilon) (\tilde{p}_t^N)^{1-\theta} \right]^{\frac{1}{1-\theta}},$$

which is the conventional Calvo-pricing equation for the determination of prices—in this case, the non-tradable good prices.

Central Bank. Since it is assumed that this economy has sticky prices, there is a role for monetary policy, which is characterized by the following nominal interest rate rule:

$$i_t = r_t^* + \bar{\pi} + \phi_\pi (\pi_t - \bar{\pi}),$$

where $\bar{\pi}$ is a fixed inflation target and ϕ_π is the degree of responsiveness of the central bank to deviations of inflation from its target. We use r_t^* as a proxy for a natural interest rate for a small open economy.

Market Clearing Conditions. From the household’s budget constraint, it can be shown that, by using the market clearing condition for the non-tradable sector, $c_t^N = y_t^N$, and for the domestic bond market, $b_t = 0$, and $c_t = p_t^N c_t^N + p_t^T c_t^T$, the balance of payments of the economy is

$$(8) \quad p_t^x m_t + p_t^T c_t^T + q_t b_t^* (1 + r_t^*) = p_t^T y_t^T + p_t^x x_t + q_t b_{t+1}^*.$$

Basic Mechanisms at Work. A permanent negative oil price shock reduces disposable income permanently and causes a permanent reallocation of resources between the tradable and non-tradable sectors. Since the excess supply of tradable goods can be exported but the fall in demand for non-tradable goods is permanent, there should be a permanent real exchange-rate depreciation. Since in this model only the non-tradable sector produces goods using labor and imported inputs (i.e., gasoline) and non-tradable demand falls, the demand for these inputs also falls. Thus, employment falls and imports fall. Some of these imports are intermediate inputs used in the production of non-tradable goods. Since the price of intermediate inputs is also the price of oil, the real marginal cost is reduced, which increases the quantity demanded of that input, acting in the opposite direction to the fall in demand for non-tradable goods. On balance, one can expect that the direction of the derived demand for the imported input will be ambiguous.

A key mechanism works through the country risk premium. This premium is endogenous in the sense that it depends not only on net external debt, but also on the value of the stock of

Table 1**Estimation**

Parameter/Std	Prior			Posterior				
	Distribution	Mean	Std	Mode	Std	Mean	HPD inf	HPD sup
ρ_d	β	0.500	0.150	0.3471	0.0774	0.3613	0.2243	0.4949
ρ_{p^x}	β	0.800	0.015	0.8633	0.0115	0.8618	0.8449	0.8812
$\rho_{p^x,d}$	\mathbb{N}	0.000	0.150	0.2023	0.1112	0.2085	0.0204	0.3959
κ	Γ	2.000	0.250	3.7889	0.1456	3.7717	3.5778	4.0213
ε_{p^x}	inv Γ	0.125	inf	0.7531	0.0754	0.7608	0.6315	0.8862
ε_d	inv Γ	0.125	inf	1.0416	0.1690	1.1025	0.8193	1.3690
ε_β	inv Γ	0.125	inf	1.1169	0.0102	0.1190	0.1022	0.1352

NOTE: HPD, highest posterior density; Std, standard deviation; HPD inf, lower bound of a 90 percent HPD interval; HPD sup, upper bound of a 90 percent HPD interval.

SOURCE: From Hamann, Bejarano, and Rodríguez (2015, Table 9, p. 39).

oil. On the one hand, external debt will be higher, pushing the risk premium up. On the other hand, country risk will fall with the *value* of the stock of oil reserves, p^x s. A collapse in oil prices increases the risk premium. However, this effect is partially compensated by the endogenous response of the stock of oil reserves to oil prices. Reserves will increase in the future, lowering the country risk premium.

Nominal adjustment is important because there are nominal rigidities. Since prices do not adjust fully to shocks, real variables such as consumption, employment, and output adjust even further compared with a flexible price economy. Therefore, real variables in the sticky price economy are likely to be more volatile than their counterparts in the flexible price economy. However, another key aspect of the nominal adjustment of the model is the role of a flexible nominal exchange rate. First, since oil export revenues are transferred to households in domestic currency, the nominal exchange-rate depreciation partially compensates the fall in the value of exports denominated in foreign currency. The nominal exchange rate eases pressure on the household's budget constraint. Second, there is pass through from the nominal depreciation to inflation. Total inflation shoots up from the central bank's target, calling for a monetary policy response. The central bank raises the nominal interest rate, which in the presence of nominal rigidities in the non-tradable sector, amplifies the fall in economic activity.

Calibration, Estimation, and Baseline Results. The parameters of the model's oil sector block are estimated, while the parameters of the model's macro block are calibrated. For the estimation of the oil's sector block, we use annual data relevant to the Colombian economy for the period 1921-2013, including the British Petroleum (BP) crude oil price,⁶ the change in oil reserves relative to total oil reserves, and the ratio of oil production to oil reserves.^{7,8} Since variables such as the discovery of new oil reserves and an exogenous shock process are not observed, we use the Kalman filter and Bayesian methods to estimate the standard deviations for unobservable variables, parameter values, and exogenous shocks (Table 1). The table

Table 2**Long-Run Ratios: Model Versus Data**

Relation		Model	Data
External debt/GDP	$\frac{qb^*}{y}$	-0.30	-0.30
Labor income/GDP	$\frac{wh}{y}$	0.36	0.36
Non-tradable output/ Tradable output	$\frac{p^N y^N}{p^T y^T}$	1.74	1.74
Oil reserves/Oil production	$\frac{s}{x}$	6.30	6.30

NOTE: The table shows the long-run ratios of key macro variables for the model and the Colombian economy using annual frequency data from the National Administrative Department of Statistics of Colombia (DANE).

SOURCE: From Hamann, Bejarano, and Rodríguez (2015, Table 10, p. 40).

Table 3**Key Calibrated Parameters of the Model**

Parameter		Value
Inverse Frisch elasticity	ω	1.6085
Long-run productivity level	A	0.0644
Long-run tradable GDP level	y^T	1.3389
Long-run tradable foreign relative price level	p^T	0.9438
Long-run oil foreign relative price level	\bar{p}^x	1.6896
Long-run discoveries level	\bar{d}	0.2113
Interest rate to debt elasticity	ψ	0.0544
Elasticity of substitution among varieties	θ	3.3571

SOURCE: Modified from Hamann, Bejarano, and Rodríguez (2015, Table 11, p. 40).

Table 4**Other Parameters of the Model**

Parameter		Value	Source
Non-tradable consumption share	γ	0.6000	DANE
Labor participation in non-tradable production function	α	0.9000	González et al. (2011)
Intertemporal elasticity of substitution	σ	4.0000	González et al. (2011)
Oil discount factor	β^{oil}	0.9661	González et al. (2011)
Long-run foreign real interest rate	\bar{r}^f	0.0350	González et al. (2011)

NOTE: DANE, National Administrative Department of Statistics of Colombia.

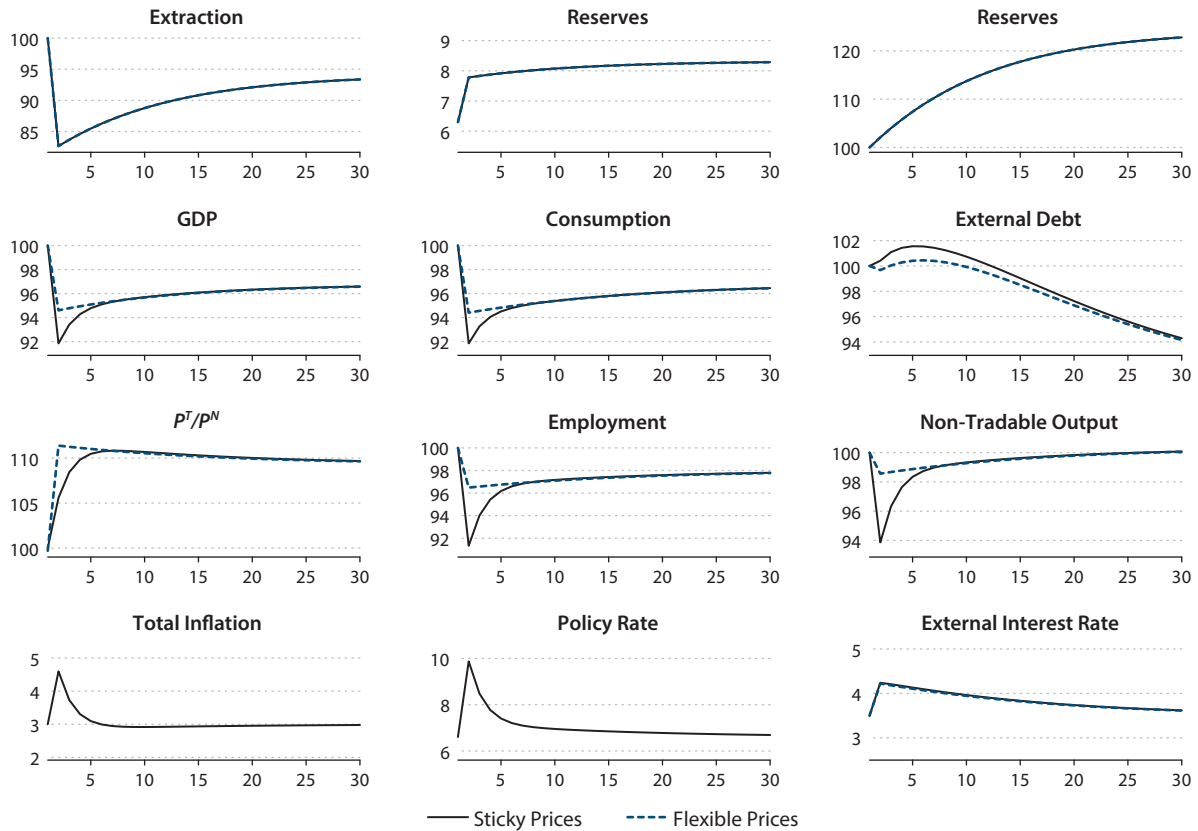
SOURCE: Modified from Hamann, Bejarano, and Rodríguez (2015, Table 12, p. 41).

reports prior and posterior distributions along with standard deviations for both parameters and shocks. The posterior distributions were computed using two Markov chains (the Markov chain Monte Carlo method) with 100,000 draws each.

Table 2 shows the long-run ratios of key macro variables for the model and the Colombian economy using annual frequency data from the National Administrative Department of Statistics of Colombia (DANE). Since the model has only labor in the non-tradable sector, we make the following calibrations: Total labor income is 60 percent of total output and non-tradable production weights 60 percent of total production. Therefore, we set the labor income share of the non-tradable sector at 0.36. Other values of the parameters used in the calibration of the model are reported in Table 3. The remaining parameters (reported in Table 4) are from previous studies of the Colombian economy.

Figure 2

Short-Run Macro Adjustment to a Permanent Fall in Oil Prices



NOTE: The inflation rate, policy (interest) rate, and external interest rate are expressed in levels; reserves are expressed in years; and the remaining variables are expressed as the deviation from their steady state, which is normalized to 100. The x-axis represents quarters.

SOURCE: Modified from Hamann, Bejarano, and Rodríguez (2015, Figure 11, p. 46).

Estimated Effects of Permanent Lower Oil Prices. To assess the monetary policy implications of permanent changes in oil prices, we perform an impulse response analysis by setting the persistence parameter, ρ_{p^o} , of the oil price stochastic process very close to 1. The quantitative results of the transitional dynamics exercise are reported in Figure 2. We report two cases: one with flexible prices and the other with sticky prices.

The collapse in oil prices has a large impact on the oil sector. Oil extraction is cut by nearly 20 percent, oil profits tank, and oil reserves increase by nearly 20 percent in the long run. As expected, most of the adjustment in the reaction to the permanent change in oil prices happens in the oil sector. As long as the current account is still another vehicle to smooth the permanent change in oil prices, the model predicts the current account will deteriorate slightly for a few years and then move into positive territory to eventually converge to its steady-state value, which is zero. In this model, no impatience is imposed on agents. Thus, private agents initially

borrow to mitigate the adjustment in consumption caused by the short-run negative overreaction in oil production.

Country risk increases by nearly 50 basis points on impact—a relatively small jump—to later fall back as oil reserves increase. Recall that on the one hand, external debt will be higher and lower oil prices will push the risk premium up, but on the other hand, reserves will increase in the future, lowering the country risk premium. As it turns out, with the baseline calibration the impact on country risk is small, especially in the long run.

Consumption falls on impact by 4 percent in the flexible price economy and by 6 percent in the sticky price economy. GDP also falls by similar magnitudes in both models. In the long run, consumption and GDP fall by about 4 percent. The collapse in total consumption triggers a real depreciation: Tradable consumption adjustment happens through the trade balance, while non-tradable consumption and activity tank. This fall in non-tradable consumption generates a contraction in non-tradable production and labor demand that, in turn, reduces the real wage.⁹ The result is a 6 percent depreciation in the real exchange rate on impact in the flexible price economy and a smooth real depreciation in the sticky price economy. Both models predict a permanent real depreciation of around 10 percent.

The real depreciation dynamics reflect an increase in inflation in the tradable sector and a decrease in inflation in the non-tradable sector caused by the fall in the real wage and the imported input price (Figure 3). This real depreciation is consistent with nominal depreciation passing through to total inflation. In the sticky price economy, total inflation jumps 1 percent away from the inflation target, triggering a central bank response of a 3.5 percent increase in its policy rate. In the flexible price economy, these effects are smaller in magnitude.

The model also highlights a monetary policy dilemma. In this economy, the exchange-rate pass through to total inflation turns out to be high. Thus, since the central bank is assumed to target total inflation, it raises the policy rate. The policy change manages to drive inflation back to target eventually, but it does so as the oil exports and non-tradable sectors are adjusting to the new condition. A key insight from this model is that monetary policy simply cannot accommodate part of the adjustment: The economy is permanently poorer and this effect is felt in both economies—those with and without sticky prices.

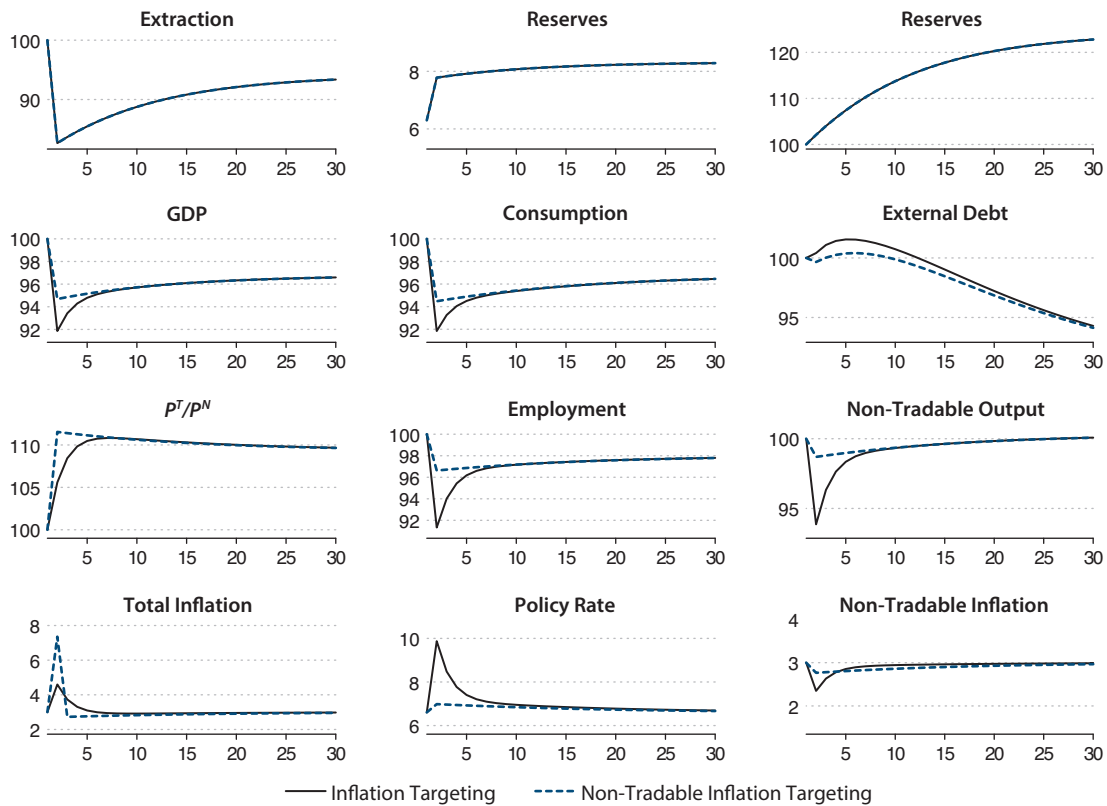
Of course, a central banker would be reluctant to raise interest rates in light of a permanent real shock with potentially large negative effects on the economy. The root of the problem is that in this economy, nominal depreciation is passing through to tradable inflation and thus driving total inflation off target. An alternative to targeting total inflation is for the central bank to target non-tradable inflation. This makes sense because in the model there is an extreme situation in which the only source of nominal rigidities resides in the non-tradable sector. Prices in the tradable sector are flexible. Thus, for the total inflation-targeting central bank, we implicitly assume that the bank ignores in which of the sectors the nominal rigidities lie.

We perform a counterfactual experiment in which we use the same shock to simulate what would have happened had the central bank targeted non-tradable inflation instead of total inflation. Figure 3 reports the results of this transitional dynamics experiment for the macroeconomic variables.

In this alternative economy, instead of hiking the policy rate the central bank barely raises it. Consumption, GDP, and employment fall by less initially, and external debt does

Figure 3

Short-Run Macro Adjustment to a Permanent Fall in Oil Prices: Total Inflation Target Versus Non-Tradable Inflation Target



NOTE: The inflation rate, policy (interest) rate, and external interest rate are expressed in levels; reserves are expressed in years; and the remaining variables are expressed as the deviation from their steady state, which is normalized to 100. The x-axis represents quarters.

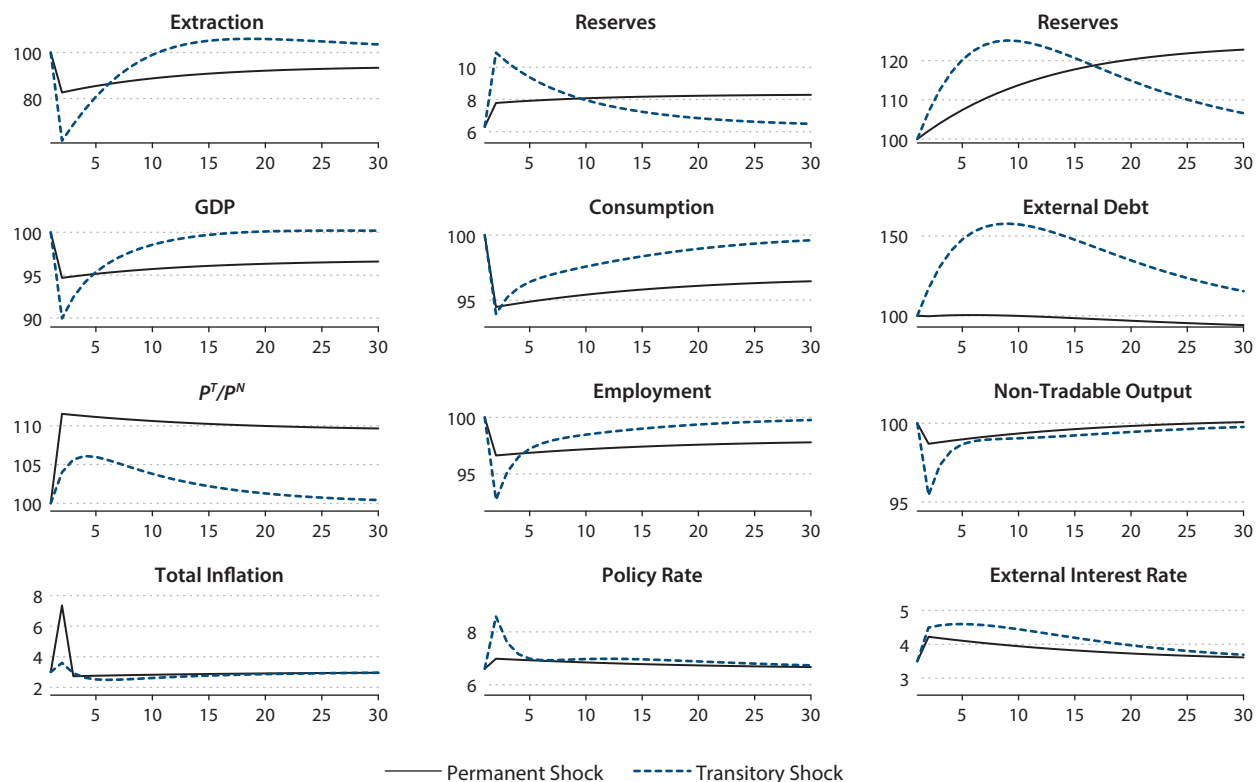
not expand as much as when policy targets total inflation. The long-run effects on both total inflation-targeting and non-tradable inflation-targeting regimes are identical. Obviously, total inflation skyrockets 400 basis points with respect to its long-run target. Once again, this intuitive result highlights the short- to medium-term policy dilemma for inflation-targeting central banks in oil-exporting economies.¹⁰ We are aware that our analysis is limited since we are not determining the central bank’s optimal policy rule.

Estimated Effects of Transitory Lower Oil Prices. To assess the monetary policy implications of transitory changes in oil prices, we perform an impulse response analysis by setting the persistence parameter, $\rho_{p_{oil}}$, of the oil price stochastic process at 0.8618.¹¹ The quantitative results of the transitional dynamics exercise are reported in Figure 4. We compare the effects of this transitory shock with those of a permanent shock.

In the short run, the transitory collapse in oil prices has a larger impact on the oil sector than a permanent collapse. Oil extraction is cut by nearly 60 percent, oil profits tank, and oil

Figure 4

Short-Run Macro Adjustment to a Transitory Fall in Oil Prices: Total Inflation Target



NOTE: The inflation rate, policy (interest) rate, and external interest rate are expressed in levels; reserves are expressed in years; and the remaining variables are expressed as the deviation from their steady state, which is normalized to 100. The x-axis represents quarters.

reserves increase by nearly 11 percent in the short run, but after 30 periods they return to their long-run values.

Country risk increases by nearly 160 basis points—a huge jump—on impact as a consequence of the huge depletion in net foreign assets in the short run. Unlike the permanent fall in oil prices, the impact on foreign debt is huge as long as households can smooth consumption. Note that here consumption falls less than when there is a permanent fall in oil prices because the drop in revenues from oil is transitory as the cut in oil extraction and the collapse in oil prices are transitory.

Unlike the case of a permanent fall in oil prices, the real and nominal depreciation here are smaller. As Figure 4 shows, the central bank increases its nominal interest rate because of the natural interest rate hikes caused by the huge increase in foreign debt. This allows the central bank to keep total inflation close to its target.

CONCLUSION

In this article, we analyzed the macroeconomic consequences and the monetary policy implications of permanent changes in oil prices for a small open economy from the perspective of a dynamic stochastic general equilibrium framework. We used a quantitative approach within this framework for an economy with three sectors (tradable, non-tradable, and oil), incomplete financial assets markets, nominal rigidities, market imperfections, endogenous oil production, and different monetary policy targets.

We found that the optimal response of the oil sector in these economies was to cut extraction significantly and increase prospective long-term oil reserves. We found that long-lived lower oil prices imply a challenge for an inflation-targeting central bank. On the one hand, the permanent fall in oil revenues causes a significant and permanent fall in consumption and GDP. On the other hand, the nominal depreciation of the exchange rate drives total inflation off target, calling for the central bank to tighten its policy stance. Thus, both the nominal and the real exchange rate adjustments are at the core of the adjustment mechanism.

Finally, we also found an important role for the external interest rate faced by the economy in international financial markets. The estimated large-scale financial frictions model predicts a protracted period of higher external interest rates because of a higher risk premium. This effect, induced by larger foreign financing needs and low oil prices, dominates the effect of the lower risk induced by the higher level of future oil reserves that accumulate endogenously in the economy. The interaction of these real adjustments with nominal rigidities is important because the model delivers a nominal exchange rate depreciation, which passes through to total inflation. The pass through may be significant. It temporally but persistently raises the annual inflation well above target, calling for the model's strict inflation-targeting central bank to tighten monetary policy to control inflation. If the central bank can identify that the price stickiness resides in the non-tradable sector and chooses to target non-tradable inflation instead of total inflation, the bank cuts the policy rate. However, the resulting total inflation will be even higher in this artificial economy. ■

APPENDIXES

Appendix A: Equations of Monetary Policy with Oil Sector

$$(A.1) \quad tb_t + q_t b_t^* = (1 + r_{t-1}^*) q_t b_{t-1}^*$$

$$(A.2) \quad tb_t = p_t^T y_t^T + p_t^x x_t - p_t^x m_t - p_t^T c_t^T$$

$$(A.3) \quad y_t^N = A_t h_t^\alpha (m_t)^{1-\alpha}$$

$$(A.4) \quad \beta E_t \lambda_{t+1} = Q_{t,t+1} \lambda_t$$

$$(A.5) \quad Q_{t,t+1} = \frac{1}{(1 + r_t)}$$

$$(A.6) \quad \left[c_t - \frac{h_t^\omega}{\omega} \right]^{-\sigma} = \lambda_t$$

$$(A.7) \quad r_t^* = r_t^f + \psi \left[\exp \left(\frac{q_t b_t^*}{p_t^x S_t} - \frac{q b^*}{p^x S} \right) - 1 \right]$$

$$(A.8) \quad \left[c_t - \frac{h_t^\omega}{\omega} \right]^{-\sigma} h_t^{\omega-1} = w_t^h \lambda_t$$

$$(A.9) \quad \log(A_t) = p^A \log(A_{t-1}) + (1 - \rho^A) \log(\bar{A}) + \varepsilon_t^A$$

$$(A.10) \quad tb_{share,t} = \frac{tb_t}{y_t}$$

$$(A.11) \quad ca_{share,t} = tb_{share,t} - \frac{r_t^* b_t^*}{y_t}$$

$$(A.12) \quad c_t^T = \frac{(1-\gamma)c_t}{p_t^T}$$

$$(A.13) \quad y_t^N = c_t^N$$

$$(A.14) \quad p_t^T = q_t p_t^{T,*}$$

$$(A.15) \quad \log(p_t^{T,*}) = \rho^{p^{T,*}} \log(p_{t-1}^{T,*}) + (1 - \rho^{p^{T,*}}) \log(\bar{p}^{T,*}) + \varepsilon_t^{p^{T,*}}$$

$$(A.16) \quad q_t = \frac{(1+r_t^*) E_t \lambda_{t+1} q_{t+1}}{(1+r_t) E_t \lambda_{t+1}}$$

$$(A.17) \quad r_t^f = \rho^{r^f} r_{t-1}^f + (1 - \rho^{r^f}) \bar{r}^f + \varepsilon_t^{r^f}$$

$$(A.18) \quad \tilde{p}_t^N = \frac{num_t}{den_t}$$

$$(A.19) \quad num_t = \frac{\theta \lambda_t \varphi_t y_t^N}{p_t^N} + \epsilon \beta num_{t+1} (1 + \pi_{t+1}^N)^\theta$$

$$(A.20) \quad den_t = (\theta - 1) \lambda_t y_t^N + \epsilon \beta den_{t+1} (1 + \pi_{t+1}^N)^{\theta-1}$$

$$(A.21) \quad \varphi_t = A_t^{-1} \alpha^{-\alpha} (1 - \alpha)^{-(1-\alpha)} w_t^\alpha (p_t^x)^{1-\alpha}$$

$$(A.22) \quad 1 = \epsilon \left(\frac{1}{1 + \pi_t^N} \right)^{1-\theta} + (1 - \epsilon) (\tilde{p}_t^N)^{1-\theta}$$

$$(A.23) \quad \frac{p_t^N}{p_{t-1}^N} = \frac{(1 + \pi_t^N)}{(1 + \pi_t)}$$

$$(A.24) \quad y_t = p_t^N y_t^N + p_t^T y_t^T + p_t^x x_t$$

$$(A.25) \quad i_t = r_t^* + \bar{\pi} + \phi_\pi (\pi_t - \bar{\pi}) + z_t^i$$

$$(A.26) \quad 1 = \gamma^{-\gamma} (1 - \gamma)^{-(1-\gamma)} (p_t^N)^\gamma (p_t^T)^{1-\gamma}$$

$$(A.27) \quad z_t^i = \rho^z x_{t-1}^i + (1 - \rho^A) \bar{z}^i + \varepsilon_t^z$$

$$(A.28) \quad (1 + r_t) = \frac{(1 + i_t)}{(1 + \pi_{t+1})}$$

$$(A.29) \quad c_t^N = \frac{\gamma c_t}{p_t^N}$$

$$(A.30) \quad p_t^{x,*} = \frac{2\kappa x_t}{1+s_{t-1}} - \beta \left(2\kappa \frac{x_{t+1}}{1+s_t} - p_{t+1}^{x,*} - \kappa \left(\frac{x_{t+1}}{1+s_t} \right)^2 \right)$$

$$(A.31) \quad s_t = s_{t-1} - x_t + d_t$$

$$(A.32) \quad \log(d_t) = \rho^d \log(d_{t-1}) + (1 - \rho^d) \log(\bar{d}) + \varepsilon_t^d$$

$$(A.33) \quad \log(y_t^T) = \rho \log(y_{t-1}^T) + (1 - \rho) \log(\bar{y}^T) + \varepsilon_t^{y^T}$$

$$(A.34) \quad \log(p_t^{x,*}) = \rho^{p^{x,*}} \log(p_{t-1}^{x,*}) + (1 - \rho^{p^{x,*}}) \log(\bar{p}^{x,*}) + \varepsilon_t^{p^{x,*}}$$

$$(A.35) \quad p_t^x = q_t p_t^{x,*}$$

$$(A.36) \quad p_t^x = \varphi_t (1 - \alpha) \left(\frac{m_t}{h_t} \right)^{-\alpha}$$

Appendix B: Dataset

Commercial Debt Portfolio. We used the commercial monthly real debt portfolio of the Colombian financial sector and converted it to a quarterly frequency using the value for the last month in the quarter. These data are available from 1998:Q4 to 2013:Q2.

Sectoral Commercial Debt Portfolio. We built a tradable and non-tradable commercial debt portfolio measure by adding the sectoral data. In particular, for the tradable measure, we used the commercial debt portfolio of the agriculture, fishing, mining, manufacturing, and wholesale and retail commerce sectors. For the non-tradable sector, we used these sectors: hotel and restaurant, transportation, financial intermediation, real estate, public administration, education, health, other social services, households with domestic service, and extraterritorial organs. These measures were then deflated using the CPI and were seasonally adjusted using Census X-12. These data are available from 1999:Q1 to 2013:Q2.

Oil Production. We used the monthly average of the daily crude oil production (in barrels) and averaged it for each quarter. These data are available from 1993:Q1 to 2013:Q2.

Oil Price. Quarterly prices were calculated from daily data by using an unweighted average of the daily closing spot prices for Brent Crude oil. We took the seasonally adjusted series and deflated it by the U.S. CPI. We used the cyclical component of oil prices after using a Hodrick-Prescott filter. These data are available from 1999:Q1 to 2013:Q2.

Consumption. We used disaggregated quarterly data of total private consumption from 2000:Q1 to 2013:Q2. In particular, this disaggregation divides consumption into non-

durable, durable, and semi-durable goods and services. We then approximated tradable consumption as the sum of consumption in durable and semi-durable goods and non-tradable consumption as the sum of consumption in nondurable goods and services.

Gross Fixed Capital Formation. We used disaggregated quarterly data of total gross fixed capital formation from 2000:Q1 to 2013:Q2. In particular, this disaggregation divides fixed capital formation by sector: agricultural, machinery, transportation, construction, civil project building, and services. We then approximated tradable fixed capital formation as the sum of this among the following sectors: agricultural, machinery, and transportation. We approximated non-tradable fixed capital formation as the sum of this among the following sectors: construction, civil project building, and services.

GDP. We built a measure of tradable and non-tradable GDP using sectoral data. Specifically, tradable GDP was approximated using the sum of agriculture, silviculture, hunting and fishing, mining, manufacture, air transportation, supplementary transportation services, mail and communication services, financial services to firms (excluding real estate), and total taxes. Non-tradable GDP was then computed as the difference between total and tradable GDP. We also computed a measure of tradable GDP excluding the mining sector. These data are available from 2000:Q1 to 2013:Q2.

Inflation. We built a measure of tradable and non-tradable inflation based on the CPI of the same sectoral data as those of the GDP. These CPI measures (tradable and non-tradable) were then seasonally adjusted using Census X-12 and converted to quarterly frequency by using the value for the last month in the quarter. These CPI data were then used to compute quarterly inflation. These inflation measures are available from 1999:Q2 to 2013:Q2.

Deposits. We used the quarterly savings account data starting in 1984:Q1 and ending in 2013:Q2. We then seasonally adjusted this measure using Census X-12.

Interest Rates. We used the monthly data for the interbank interest rate, the home building interest rate (different from social housing), and the corporate commercial interest rate and converted them to quarterly frequency using the value for the last month in the quarter. A measure for tradable interest rate was then approximated using the corporate commercial interest rate. The non-tradable interest rate was approximated using the home building interest rate. These data are available from 2002:Q2 to 2013:Q2.

NOTES

- ¹ We define the country risk premium as the difference between the risk-free interest rate and the interest rate effectively paid by debtor countries for external debt.
- ² Evidence for Colombia indicates that imported goods prices are adjusted roughly every quarter; see Bonaldi, González, and Rodríguez (2011).
- ³ Since the oil firm is in a competitive international oil market, its revenues and costs are denominated in foreign currency.
- ⁴ We make this assumption as long as the share of the non-mining exports to GDP is around 5 percent.
- ⁵ See Pindyck (1981) for instance.
- ⁶ The British Petroleum crude oil price series is from the BP Statistical Review of World Energy 2014. This crude price is constructed with the Brent Crude price dated over the 1984-2013 period, the Arabian Light crude price posted at Ras Tanura in the 1945-1983 period, and the U.S. average crude price over the 1861-1944 period.
- ⁷ The data for the stock of reserves and oil production are from Colombia's National Hydrocarbons Agency.
- ⁸ To avoid stochastic singularity in the oil's block estimation, a preferences shock is included in the model.
- ⁹ This is a consequence of the preferences specification assumed.
- ¹⁰ To check the robustness of our results, we perform an experiment with alternative specifications of the policy rule that also includes the output gap. In the first experiment, we use an output gap defined as the difference between the sticky price GDP and the flexible price GDP. In the second experiment, we use a different definition of output gap: the difference between the sticky price non-tradable output and the flexible price non-tradable output.
- ¹¹ This is the estimated value of the persistence parameter of the oil price, as reported in Table 1.

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