Borradores de ECONOMÍA

Monetary policy implications for an oil-exporting economy of lower long-run international oil prices

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Abstract

The sudden collapse of oil prices poses a challenge to inflation targeting central banks in oil exporting economies. This paper illustrates that challenge and conducts a quantitative assessment of the impact of permanent changes in oil prices in a small and open economy, in which oil represents an important fraction of its exports. We calibrate and estimate a variety of real and monetary dynamic stochastic general equilibrium models using Colombian historical data. We find that, *in these artificial economies* the macroeconomic effects can be large but vary depending on the structure of the economy. The main channels through which the shock passes to the economy come from the increased country risk premium, the real exchange rate depreciation, the sectoral reallocation of resources from nontradables to tradables and the sluggish adjustment of prices. Contrary to the conventional findings in the literature of the financial accelerator mechanism for single-good closed economies, in multiple-goods small open economies the financial accelerator does not play a significant role in magnifying macroeconomic fluctuations. The sectoral reallocation from nontradable to tradables diminishes the financial amplification mechanism.

Keywords: oil prices, precautionary savings, monetary policy, credit, leverage, financial accelerator, Colombia

JEL Classifications: C61, E31, E37, E52, F41

"It's just the nature of the business. You're not going to go drill holes in the ground if you think prices are going down." Mike Corley, the founder of Mercatus Energy Advisors, a Houston-based firm that advises companies on hedging strategies. Source: Bloomberg News, December 18, 2014.

1 Introduction

Two global events shaped the economic outcomes during 2014: monetary policy normalization in the United States and the sudden collapse of world oil prices. Both have been a source of instability in global financial markets. The first event opens the possibility for higher world interest rates for a prolonged period, affecting all emerging economies. The second has already hit exchange and interest rates in oil exporting countries, like Russia, Venezuela, Ecuador and Colombia. These events have caught the attention of policy makers and academics as their macroeconomic consequences may be important, should low oil prices persist over the coming years.

An analysis of the implications for monetary policy in Colombia is needed for several reasons. First, the oil price shock is large and to some extent it occurred earlier than expected. Since 2009 oil price increased steadily to levels that surpassed US$100 per barrel from US$35. In the last quarter of 2014 oil prices fell by 38% and country risk spreads and interest rates in oil exporting economies jumped. Second, oil production in Colombia is significant. In the last decade, oil production increased from 5% of GDP to 11% in 2014; the share of oil exports in GDP jumped from 3% in 2002 to 8% in 2014. In turn, fiscal revenues from oil (as a share from total public revenues) increased from under 10% in 2002 to close to 20% in 2011. Foreign direct investment in oil sector represented 32% (as a share from the total FDI in Colombia) while FDI in mining represented 17% in 2014. Third, persistent oil price swings do impact oil activity in Colombia. Figures 1 and 2 show the linkage between international oil prices and the ratio of oil reserves to production. The data support the idea that as prices increase producers extract oil from the ground and reserves fall, *ceteris paribus*. On the contrary, when prices approach zero incentives point to leave those reserves forever in the ground.

In addition, oil price shocks are also related to country risk spreads, capital flows and other macroeconomic indicators at the business cycle frequency. Periods of high commodity prices have been associated with lower spreads, capital inflows and good macro performance, while the opposite happens during periods of low prices. Gonzalez et al. [2013] have documented some empirical regularities around *transitory* oil price shocks in Colombia. The study performs an oil price shock identification analysis, which analyzes how a key set of

2

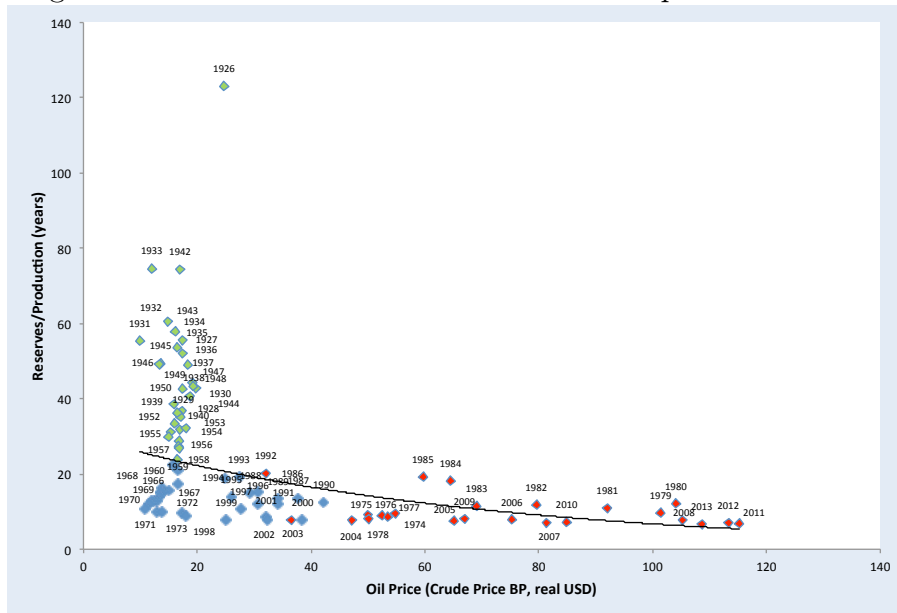Figure 1: Oil Price and Colombian reserves to production ratio

Figure 2: Colombian reserves to exhaustion (in years)
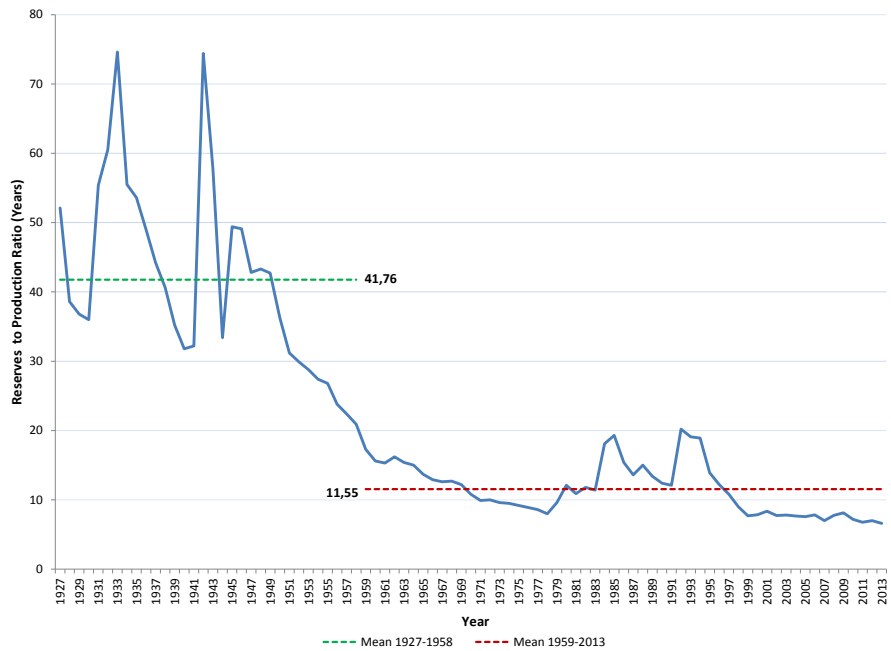
macroeconomic variables behave around such events. In that work the focus is to study large and temporary increases in international oil prices. The paper describes how country risk, output, private consumption, domestic credit, trade balance and the real exchange rate evolve during oil price surges as well as during the corrections. Their sample covered episodes from 1988 to 2012 and the event analysis was carried out at quarterly frequency. Following Hamilton [2003] the study finds the quarters during which there were oil price shocks, defined as large increases in oil prices. The paper documents that before the peak of a large and steady oil price hikes, country risk falls, output rises, private consumption increases, domestic credit booms, trade balance improves and the real exchange rate appreciates. In general, after the sudden oil price reversal all these patterns shift back in the opposite direction.

Figure 3: Macroeconomic effects of temporary oil shocks
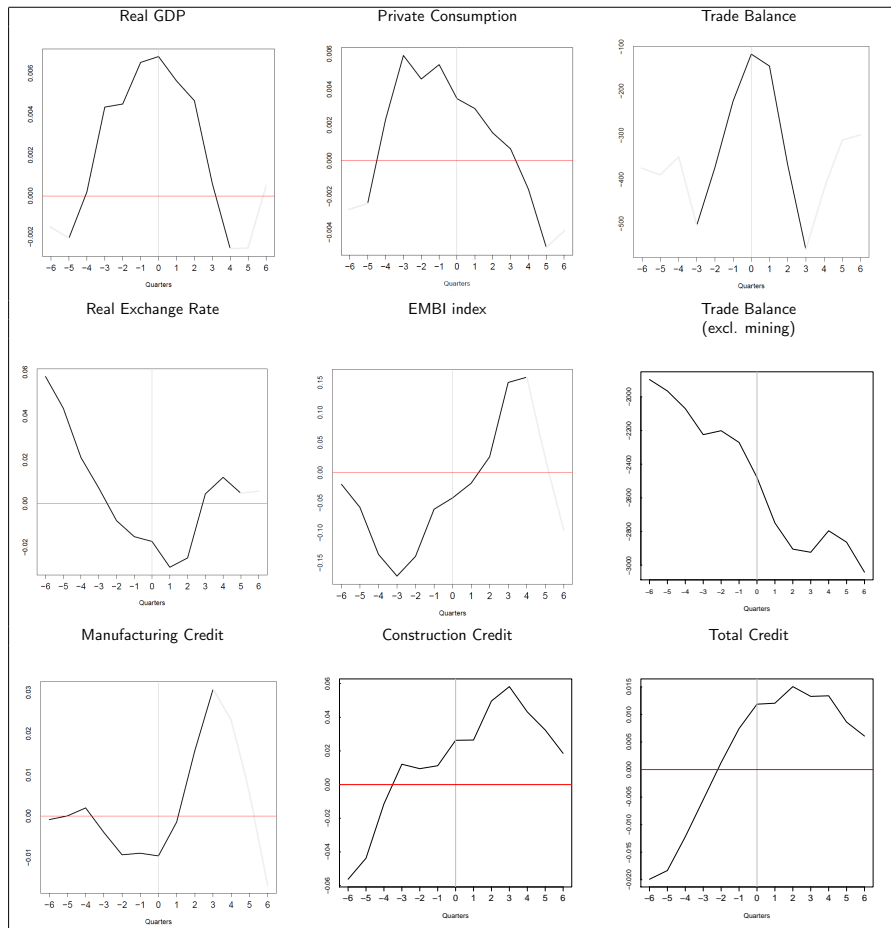
Source: Gonzalez et al. [2013] event-study analysis.

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 risk premium improving overall creditworthiness, creating a surge in demand for tradable and nontradable goods, inducing a real exchange rate appreciation and a shift of economic resources from the tradable sector to the nontradable 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 and a reallocation of resources happen together with a collapse in asset prices and the currency.

There is the possibility that this time around oil prices remain low not just for a few quarters, but for the next years. 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 nontradable sectors which show up in the real exchange rate, wages and the country's net foreign asset position in the long term. Usually monetary policy sets its goals looking forward at a policy horizon that reaches one to two years. These long term changes may have different macroeconomic consequences than temporary shocks, as stressed by Rebucci and Spatafora [2006], Kilian [2009] and Kilian et al. [2009]. The logic of monetary policy models of small open economies in which the long-term or steady state remains invariant to the occurrence of the shocks is also challenged.

Still, nominal adjustment may continue to be important because a flexible nominal exchange rate may compensate partially the fall in oil prices. The importance of the role of nominal stickiness in small open economy models has been emphasized by Gali and Monacelli [2005], Paoli [2009], Benigno and Paoli [2010], Auray et al. [2011],Gertler and Karadi [2011] and Schmitt-Grohe and Uribe [2013], to name a few. In the presence of nominal price and/or wage rigidities, quantities will likely accommodate further the adjustment. In addition, financial amplification mechanisms may also interact with the sectoral efficient reallocation of resources in nontrivial ways. For instance, gasoline and other oil derivatives are key inputs of production and by becoming relatively cheaper 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.

This paper conducts a quantitative assessment of the impact of permanent changes in

oil prices in a small and open economy, in which a commodity, like oil, represents an important share of economic activities. Our analysis takes into account the central bank's policy response to such changes. We proceed in two stages. In the first stage we use a set of canonical Bewley-type real dynamic models (without nominal rigidities and without a central bank) models to determine the long-run impact of permanent changes in oil prices.[1] The use of these family of quantitative models in the international economics literature has its roots in Mendoza [1991] whereas the dynamics of the real exchange rate adjustment has been quantified in Mendoza and Uribe [2001]. More recently, the macroeconomic interaction with financial frictions has been investigated in Mendoza [2006] and Mendoza [2010]. The main insights and lessons of this strand of the literature have been reviewed in Korinek and Mendoza [2014].

To understand the basic mechanisms at work in the long term adjustment, our departing point is a simple one-good endowment economy in which agents can borrow and lend to smooth fluctuations in income. Differences between interest and discount rates and precautionary saving motives drive the determination of net foreign assets in the long run. We then consider a two-good (tradable and non-tradable) endowment to assess the impact on the real exchange rate. Next we complement our analysis by introducing the oil sector into the model. Unlike the previous two cases, oil production is endogenous and responds to economic incentives. We model the oil sector as a resource extracting problem as in Sickles and Hartley [2001] and Pesaran [1990]. The economy owns a stock of oil, extracts the optimal portion of it to sell it in international competitive commodity markets. Thus optimal extraction rules depend on the stock of oil reserves, commodity prices, interest rates, marginal costs of oil operation and the uncertain nature of discoveries.

In the second stage we complement our long-run analysis with two large scale monetary policy models to study the implications for an inflation targeting central bank of permanent oil shocks. The model has the same three sectors as the previous one, but we add monopolistic competition and sticky prices in the nontradable sector. We also allow that sector to use labor and an imported intermediate good in the production of final non-tradable goods to assess the response of these components of real marginal costs. We close the nominal portion of the model assuming a *strict* inflation targeting central bank. The model also considers capital accumulation in both tradable and nontradable sectors and markets of capital goods are subject to financial frictions as in Bernanke et al. [1998].

Our quantitative analysis points to two main findings about the long-run adjustment of a small open oil-exporting economy in response to permanent changes of international oil

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[1]Permanent changes in interest rates are also important and in fact induce a different macroeconomic adjustment but for reasons of space, we focus on permanent oil shocks.

prices. First, the natural response to lower oil prices is to cut extraction and to increase oil reserves. More interestingly, the small scale models highlight that the real exchange rate and net foreign assets appear to be the key variables in the long-term adjustment process of the economy. The differences between the macroeconomic response of the one-good endowment model and the two-good model stresses that in an economy in which both the supply of tradable and nontradable is inelastic, the real exchange rate can be very volatile, absorbing a large portion of the oil price collapse. As these effects are of considerable magnitude, the financial and real structure of the economy are important when studying the long run determination of the net foreign position of the economy. An economy in which agents are limited to smooth consumption through a single financial non-state contingent asset can respond differently to an economy with an additional stock of a real asset, like oil reserves. This is so even if both oil accumulation decisions and borrowing decisions are taken by different private agents. Precautionary savings coupled with incomplete financial markets imply that uncertainty in the oil sector translates into the private agents income uncertainty affecting their motives to spend, save and borrow. Therefore, the structure of the economy and especially the contribution of the oil sector is important. The degree of openness of the economy, that is the share of the tradable sector relative to the nontradable, as well as the size of the resource sector within the tradable sector determine how the economy copes with international oil price fluctuations. The quantitative simulations of the three-sector model, calibrated to mimic a few facts of the Colombian economy, indicate that a permanent reduction equivalent to one standard deviation of the international oil price[2] reduces net foreign asset position from a 30% debt to GDP ratio to nearly 36%.

Second, once we feed this long term change in international oil prices into the monetary policy models used in this paper, we find that an strict inflation targeting central bank is confronted with a policy dilemma: the permanent fall of oil revenues causes a permanent fall in consumption and GDP but the nominal depreciation drives total inflation off the target, calling the bank for a tighter policy stance. We also show, however, that this dilemma arises because the tradable sector features flexible prices, while in the nontradable one prices are sticky. Therefore, the dilemma disappears if the central bank were able to identify exactly where the nominal rigidities reside (that is the nontradable sector) and would target non-tradable inflation.

Both the nominal and the real exchange rate adjustment are at the core of the adjustment mechanism. As in the small scale models, there is a reallocation from nontradable sectors to tradables, implying a large real exchange rate depreciation. Aside from the usual reallocation of inputs of production (capital and labor) credit also reallocates. Credit to tradable sectors

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[2]Our proxy for international oil prices is the yearly average international oil price from 1921 to 2014.

(other than oil) expands while credit to nontradable activities falls, balancing each other the financial accelerator mechanism.

Also, at the core of the adjustment mechanism lies the external interest rate that the economy faces in international financial markets. The estimated model predicts a protracted period of higher external interest rates because of higher risk premium. The effect of a higher risk premium induced by larger foreign financing needs and low oil prices dominate the effect of lower risk induced by the higher level of oil reserves that the economy accumulates endogenously. The interaction of these real adjustments with nominal rigidities is interesting because the model delivers a nominal exchange rate depreciation, which passes to total inflation. The pass-through of this change to inflation is significant. It raises temporally but persistently annual inflation well above target, calling the model's strict-inflation-targeting central bank to tighten monetary policy to keep inflation in control.

Our framework also contributes to the debate about the use of small open economy models in central banks. We highlight the importance of linking short-run monetary policy models with long-run real and financial models in small open economies. Conventional policy models often assume that most of the shocks are temporary and the steady state does not change when they hit the economy. More importantly, most small open economy models are solved around an arbitrary value of long run net foreign assets (or its ratio to GDP). Although this practice is convenient to perform quarter to quarter analysis, it limits the scope of the conclusions that can be obtained when a longer term perspective is needed.

The rest of the paper proceeds as follows. In Section 2 we present the set of Bewley models and analyze their quantitative implications. In Section 3 we present the monetary policy models and evaluate the quantitative predictions. We conclude with Section 4 examining the implications of our framework for monetary policy.

2   Small scale Bewley models

2.1   One-good economy

2.1.1   Structure of the model

Consider a small open economy with a representative agent, who every period consumes c units of a tradable non-storable good. The agent's preferences are given by

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

where $\beta \in (0,1)$ is the discount factor and σ is the discount factor. The agent chooses to maximize (1) subject to the resource constraint:

$$c_t = y_t - b_{t+1} + Rb_t + A \tag{2}$$

where y denotes the economy's income in units of the consumption good, which evolves over time as a first-order Markov chain. b is the net foreign asset (NFA) position of the economy, which consists of a one-period risk-free bond traded in competitive, frictionless international financial markets and whose gross rate of return is R. A key assumption is that the representative agent can credibly commit to repay its debts.[3] We restrict our attention to cases in which the country is a net foreign debtor, set $b \leq 0$. The model has a natural debt limit, which arises from the assumption of CRRA preferences. As consumption approaches zero, marginal utility goes to infinity and the consumer becomes extremely averse to bad outcomes and she self-imposes a limit to borrowing. Yet, this limit is too loose, so we impose a stricter limit on NFA, $b_{t+1} \geq \phi$, closer to the data.

2.1.2 Basic mechanisms at work

The backbone of these so-called "Bewley models" is the permanent income model. In a deterministic world, if $y_t \to y$ a constant and the stationary condition: $\beta R = 1$, the assumption that the economy is small (takes a fixed interest rate as given), commits credibly to repay and international financial markets are frictionless, implies that the current account acts as a vehicle for consumption smoothing and in the long-run the net foreign asset position is the annuity value of the steady state trade balance:

$$b = -\frac{y-c}{R-1}.$$

A permanent reduction in the tradable endowment stream would imply a higher level of NFA and a muted long term response of the current account.

In a stochastic environment, optimal consumption and saving decisions in this model are also influenced by precautionary motives and are analogous to those found in the heterogeneous-agent incomplete financial markets literature.[4] Therefore, the stationary condition becomes $\beta R < 1$, because otherwise the level of NFA would be either indeterminate or would grow without bound. Intuitively, when $\beta < R^{-1}$ the interest rate does not compensate

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[3] A is an auxiliary variable which captures the part of absorption which is not included in private consumption c and that it is not modeled, but it is present in the National Accounts data.

[4]See for instance Bewley [1986], Aiyagari [1993] and Huggett [1993].

enough consumers to postpone consumption providing them incentives to borrow. However, income is random and agents have only access to non-state contingent debt (incomplete financial markets) to smooth consumption, providing consumers an incentive to save. These two opposing forces tend to balance. The pro-borrowing incentive against the pro-saving incentive guarantees the existence of a stochastic steady state. Despite the added complexity, the model preserves the instinct of the permanent income hypothesis: consumption is proportional to financial and non-financial wealth and NFA and increases when a permanent shock hits the economy's income.

2.1.3 Calibration and baseline results

We calibrate this simple model to the Colombian economy. We model y_t as an exogenous Markov chain which mimics an autoregressive process with mean one and standard deviation 2.6%. The last value corresponds to the standard deviation of the Hodrick-Prescott filtered cyclical component of the Colombian GDP at the annual frequency. We set $\sigma = 4$ and $R = 1.035$, which correspond to the coefficient of relative risk aversion and the steady-state real interest rate used in several models in Colombia. We then calibrate the values of β and ϕ to match as closely as possible both the level of NFA to GDP observed in the data (30% of GDP) and the fraction of the years that Colombia has been excluded from financial markets.[5] Setting $\beta = 0.96$ and the borrowing limit at 40% of GDP ($\phi = .4$) we obtain a debt to GDP ratio of 31% and a frequency of international financial markets exclusion of 12% (vs. 16% in the data).

We solve this model by discrete dynamic programming, finding the solution to the Bellman equation:

$$v(y, b) = \max_{b' \in [-\phi, 0]} \frac{(y - b' + Rb + A)^{1-\sigma}}{1 - \sigma} + \beta E\left[v(y', b')\right], \tag{3}$$

using a discrete grid of 500 equidistant nodes for both b and b' on the interval $[-\phi, 0]$. We approximate the endowment's Markov chain using Rouwenhorst's method (with 9 nodes) as described in Cooley and Prescott [1995]. We find the optimal policy rules $b'(y, b)$ and $c(y, b)$ as well as the optimal Markov transition matrix P associated with the problem. This optimal transition matrix is key for our purposes because, as we will explain later we will use it to compute the optimal forecasting functions, which lie at the center of the analysis toolkit of the long-run models.

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[5]The definition of financial access to foreign borrowing is taken from Borensztein and Panizza [2008]

Table 1: Ratios (% of GDP) of the Endowment Small Open Economy Model vs. Data

	Data	Model	
	Colombia	Ergodic	Simulated
Output	1.00	1.00	1.00
Consumption	0.66	0.65	0.65
NFA to Output	-0.30	-0.32	-0.31
Borrow constr. (pct time)	0.16	0.12	0.12

The results of the model are in line with those well documented in the literature: first, consumption is procyclical and highly autocorrelated, as in the data, but is about one-third smoother. Second, the current account and the trade balance are also highly correlated in the model as in the data, however the model results are at odds with a well-documented fact which is that both are counter-cyclical in emerging economies.

Table 2: Statistical Moments: the Small Open Endowment Economy Model vs. the Data

Variable, x	Data			Model		
	σ_x	$\rho_{x,y}$	$\rho_x(-1)$	σ_x	$\rho_{x,y}$	$\rho_x(-1)$
Output	2.6	1.00	0.76	2.6	1.00	0.75
Consumption	2.7	0.89	0.75	1.9	0.82	0.89
Current Account	2.2	-0.34	0.70	1.45	0.81	0.67
Trade Balance	4.6	-0.39	0.92	1.5	0.70	0.69

2.1.4 Effects of permanent changes in income

Despite these anomalies, this model can be a starting point to gain some quantitative insight about the impact of unexpected permanent changes in the economic environment. Before describing the results of the effect of a permanent oil price shock, it is convenient to explain how these expected consequences were computed.

Let e denote the duple (y, b), which characterizes any given state of the economy. Associated with the solution to program (3) there is an optimal borrowing policy, $\tilde{b}(e)$, where e denotes the duple (y, b), the state of the economy. The controlled-state process of the representative agent's program with optimal policy function $\tilde{b}$, is a stationary Markov chain with transition probability matrix P whose typical element in the position (i, j) is the probability of jumping from state i in the current year to state j next year, conditioned on following the

optimal policy $\tilde{b}(i)$:

$$P_{ij} = \Pr\left(e_{t+1} = j | e_t = i, b_{t+1} = \tilde{b}(i)\right).$$

Recall that this probability transition matrix depends on the deep parameters of the model, among them the expected value of the endowment process, which we have set equal to one. Also, this probability transition matrix has a long run ergodic distribution, f.

The computational exercise can be thought as a sudden change in regime. Assume that under a high oil prices regime there is an optimal transition matrix $\bar{P}$, with ergodic distribution $\bar{f}$. Denote $\bar{e} = \left(\bar{y}, \bar{b}\right)$ the expected state of the economy under that regime. Oil prices fall unexpectedly, implying a fall in *expected* income to $\underline{y}$. Agents wake up, update their optimal plans by solving problem (3) under the new stochastic properties of income, find a new set of optimal rules, $\underline{P}$, with ergodic distribution, $\underline{f}$. The new long run value of expected debt is $E[b] = \underline{f} \times b = \underline{b}$. The economy falls from $\bar{e} = \left(\bar{y}, \bar{b}\right)$, previously, to wake up at $\underline{e} = \left(\underline{y}, \bar{b}\right)$ and eventually settle at $\underline{e} = \left(\underline{y}, \underline{b}\right)$. The evolution of the economy can be characterized by a sequence of probability functions, $\{f_t\}_{t=0}^{\infty}$ which can be computed iteratively $f \leftarrow f\underline{P}$ and starting from f_0. Since $\underline{P}$ is a well behaved Markov chain, the sequence of distributions eventually converges to $\underline{f}$. We use this sequence of distributions to compute the expected path of debt, $\{E_t[b] = f_t \times b\}_{t=0}^{\infty}$.

To compute the permanent reduction in oil prices as a lower expected value of the endowment process, we lower the mean of the Markov chain of the endowment process (keeping its variance constant). By simple accounting, a one standard deviation oil price negative shock, keeping oil extraction constant, maps into this model as a permanent 2.5 percentage points reduction in expected income. Theoretically, this would be equivalent to a one standard deviation of the permanent fall in the real value of oil exports (they account for about 8% of GDP).

The dynamics of the model is influenced by three factors. First, expected income has fallen permanently and consumption has to fall. How much? The deterministic version of the permanent income model predicts that, if $\beta R = 1$, the relative cut should be the same as the relative fall in income, 2.5 pp. In the stochastic version of the model and under our calibrated parameters, however, the fall in consumption is 2.1 pp on impact, to fall even further by 4 pp after several years, to increase later and exhibit a fall of 3.76 pp relative to the old steady state.

The dynamics of the model is also influenced by the two forces, which commonly drive Bewley models. First, income is still uncertain along the convergence path and there is a motive to save, because financial markets are incomplete. Moreover, with a lower expected value of income and the same uncertainty, the precautionary motive induces the representa-

12

Figure 4: Model response to a 2.5% permanent reduction in GDP
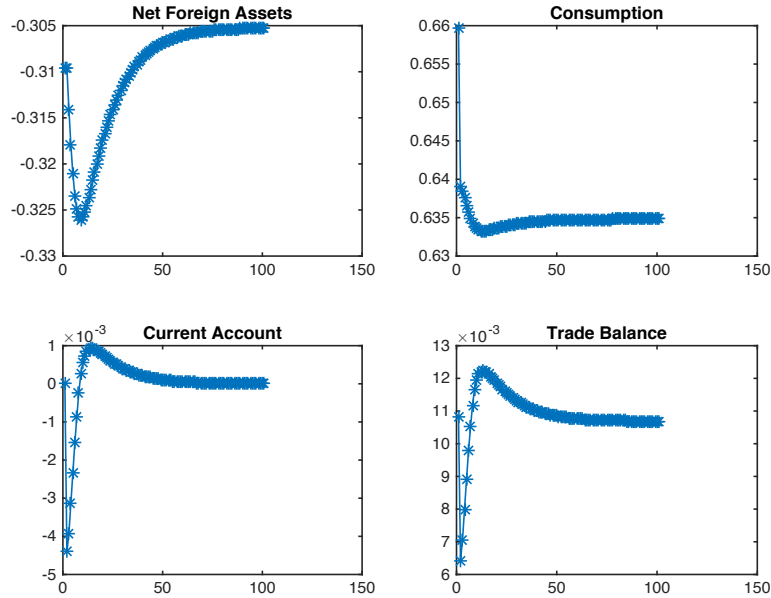
tive agent to increase her long-term level of net foreign assets by reducing her external reduce debt with respect to $\bar{b}$. To increase the long term level of NFA she has to cut consumption today. However, she does not cut consumption all at once, as in the deterministic case. It turns out that the condition $\beta R < 1$ gives her a motive to borrow. Since the borrowing constraint is not binding (because NFA are -0.3, a value higher than the ad-hoc debt limit, -0.4) she will happily do it. So the agent takes the borrowing opportunity, but at the same time cuts consumption because her permanent income is inevitably lower. Thus, trade balance and current account deteriorate on impact (during the first year) and external debt increases as the economy borrows on international financial markets.

2.2 Two-good economy and the real exchange rate

2.2.1 Structure of the model

We modify the model of the previous subsection to account for real exchange rate movements. The model is similar to Durdu et al. [2009], although ours is simpler because nontradable output is inelastic. Tradable output is stochastic and it is the source of uncertainty in the economy. Consumption now is a compound of tradables and nontradables according to:

$$c_t = \left[a \left(c_t^T \right)^{-\mu} + (1-a) \left(c_t^N \right)^{-\mu} \right]^{-\frac{1}{\mu}}, a > 0, \mu \geq -1. \tag{4}$$

Parameter μ determines the elasticity of substitution between tradable and nontradable goods, while a determines the CES weighting factor for tradables.

In this setting, the representative agent maximizes (1) subject to two resource constraints in this economy:

$$c_t^T = y_t^T + p_t^N y^N - b_{t+1} + Rb_t + A^T \tag{5}$$

and

$$c_t^N = y^N + A^N. \tag{6}$$

The first equation is the market clearing condition for tradable goods (that is, the balance of payments) and the second is the market clearing condition of nontradable goods market. As in the previous model, the constants A^T and A^N capture other components of aggregate demand not modeled.

2.2.2 Basic mechanisms at work

It can be shown that the relative price of nontradable goods in this economy is:

$$p_t^N = \frac{1-a}{a} \left(\frac{c_t^T}{c_t^N} \right)^{1+\mu}.$$

Since the supply of nontradable goods is fixed, $a \in (0,1)$ and $\mu \geq -1$, the price of nontradables is proportional to and increasing in tradable consumption. Shocks that reduce total consumption will contract the demand for both tradable and nontradable goods. Given the endowments, tradable goods can be exported away but nontradable goods can only be satisfied by the domestic supply and therefore the relative price of nontradable must fall and the real exchange rate depreciates. In this extreme case, of a two-good endowment economy, the depreciation is sharper than in a case in which production is endogenous because factors of production do not flow to the tradable sector.

Note also that despite the economy being an endowment economy, GDP in units of the tradable good is endogenous because the relative price of nontradables adjusts in response to exogenous shocks. For instance, a positive shock to tradable income would increase total GDP not only because tradable income is higher but also because the relative price of nontradable goods increases. Thus, the real exchange rate appreciates. If business cycles were driven mostly by these shocks, the model would predict that the real exchange rate should be counter-cyclical.

2.2.3 Calibration and baseline results

We also calibrate the two-good endowment model to match a few ratios of the Colombian data. Sectoral output and consumption in National Accounts Statistics in Colombia are only available since 2000, and at a quarterly frequency. Throughout the calibration, we assume that exports belong exclusively to the tradable output, while there are both tradable and nontradable imports, as the classification between tradable and nontradable is not perfect, and there are some nontradable sectors with imports in the data[6]. Note that we can normalize aggregate production in units of tradables and relative price of nontradables such that $p^{NT} = 1$ and $y^T + p^{NT}y^{NT} = 1$. This normalization allows us to interpret the steady-state allocations of y^T and y^{NT} as ratios relative to total GDP in units of tradables.

The first ratio is $p^{NT}y^{NT}/y^T = 1.5$, the 2000Q1-2012Q4 ratio of nontradable GDP to tradable GDP. Departing from this ratio and given $y^T + p^{NT}y^{NT} = 1$, we have $y^T = 1/(1 + 1.5) = 0.4$, and $y^{NT} = 1.5/(1 + 1.5) = 0.6$. The second ratio is c^T/y^T, the tradable consumption to output ratio, which yields an average of 0.83 for the same period. From this ratio, $c^T = 0.83y^T = 0.33$. Finally, $p^{NT}c^{NT}/p^{NT}y^{NT}$, the average nontradable consumption to output ratio is 0.54, from which follows that $c^{NT} = 0.54y^{NT} = 0.325$. The calibration of the two-good model is summarized in Table 3.

Table 3: Calibration of the two-good model

Notation	Variable	Value
$y^T + p^{NT}y^{NT}$	Output in units of tradables	1
p^{NT}	Relative price of nontradables	1
$p^{NT}y^{NT}/y^T$	Nontradable to tradable output ratio	1.50
c^T/y^T	Tradable consumption to output ratio	0.83
$p^{NT}c^{NT}/p^{NT}y^{NT}$	Nontradable consumption to output ratio	0.54

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[6]However, according to our classification, on average only 5% of imports are nontradable.

Table 4: Ratios (% of GDP) of Two-good Small Open Economy Model: the Model vs the Data

	Data	Model	
	Colombia	Ergodic	Simulated
Tradable Output	0.40	0.40	0.40
Tradable Consumption	0.83	0.83	0.83
Trade Balance		0.01	0.01
NFA to Output	-0.30	-0.296	-0.295
Borrow constr. (pct time)	16%	3%	3%

We model y_t^T as an exogenous Markov chain which mimics an autorregressive process with mean one, standard deviation of tradable output at 2.8% and autocorrelation coefficient equal to 0.1, which corresponds to the moments of the Hodrick-Prescott filtered cyclical component of our estimation of the Colombian tradable output at the annual frequency. As in the previous model, we set $\sigma = 4$ and $R = 1.035$. We do not have an estimation for the elasticity of substitution between tradables and nontradables so we take the value in Durdu et al. [2009] for Mexico, $\mu = 0.316$. We then calibrate the values of β and ϕ to match as closely as possible both the level of NFA to GDP observed in the data (30% of GDP) and the fraction of the years that Colombia has been excluded from financial markets. Setting $\beta = 0.96225$ and the borrowing limit at 40% of GDP ($\phi = 0.4$) we obtain a debt to GDP ratio of 30% and a frequency of international financial markets exclusion of 3% (vs. 16% in the data).

We solve this model by discrete dynamic programming, finding the solution to the Bellman equation:

$$v(y^T, b) = \max_{b' \in [-\phi, 0]} \frac{c^{1-\sigma}}{1-\sigma} + \beta E \left[v(y^{T'}, b') \right],\tag{7}$$

subject to (4), (5) and (6), using a discrete grid of 1000 equidistant nodes for both b and b' on the interval $[-\phi, 0]$. We approximate the tradable output Markov chain using Rouwenhorst's method (with 3 nodes) as described in Cooley and Prescott [1995]. We find the optimal policy rules $b'(y, b)$ and $c(y, b)$ as well as the optimal Markov transition matrix P associated with the problem. Using P we simulate the economy's path overtime and obtain the statistics shown on Tables 4 and 5.

Table 5: Statistical Moments: Two-good Model vs the Data

|	Colombian Data			Model		
	σ_x	$\rho_{x,y}$	$\rho_x(-1)$	σ_x	$\rho_{x,y}$	$\rho_x(-1)$
GDP	2.6	1.00	0.76	3.6	1.00	0.30
Tradable Output	2.8	0.75	0.10	2.8	0.95	0.10
Tradable Consumption	1.9	0.65	0.22	0.5	0.73	0.82
Current Account	2.2	-0.34	0.70	2.4	0.82	0.04
Trade Balance	4.6	-0.39	0.92	2.5	0.76	0.05
Real Exchange Rate	9.0	-0.71	0.68	4.3	-0.72	0.80

The model inherits most of the properties of the one-good model. Consumption is pro-cyclical and highly autocorrelated, but is about much smoother than in the data. The current account and the trade balance are also highly correlated in the model, however they are still at odds with the data. Nonetheless, the model is able to reproduce the countercyclical real exchange rate observed in the data. As we will see, the real exchange rate transmission mechanism turns out to be an important one.

2.2.4 Effects of permanent changes in tradable income

Analogously to the one-good endowment small open economy case, we model a permanent reduction in tradable income as a lower expected value of the stochastic process of the tradable endowment. We follow the same procedure described in subsection 2.1.4 to compute the forecasting functions and obtain the expected path of the economy after a shock. Tradable output is roughly 40% of GDP, thus we cut the mean of the Markov chain of the tradable endowment (keeping its variance constant) by 6.25 pp to match the permanent 2.5 pp reduction in expected income of the previous experiment.

The mechanisms at work in the two-good version of the model are similar to the one-good model. The trade balance and current account deteriorate on impact (during the first year) and net foreign assets decline for the first years a few basis points to 30% of GDP from 29.6% (external debt increases). Because of the lower expected income relative to tradable output volatility, the new long-run debt level cannot be higher than the initial one (before the permanent shock), implying that the new net foreign asset position must be lower in the long run than the initial one (29.1% vs. 29.6%). Thus, the model predicts a permanent fall in consumption. In the first year it falls by 3.6 pp, a sharper contraction than in the single-good model. It continues to fall by an additional 30 bp in the following years, to stabilize at a lower long-run average level. The permanent fall in consumption is 3.9 pp,

Figure 5: Model response to a 6.25% permanent reduction in tradable output
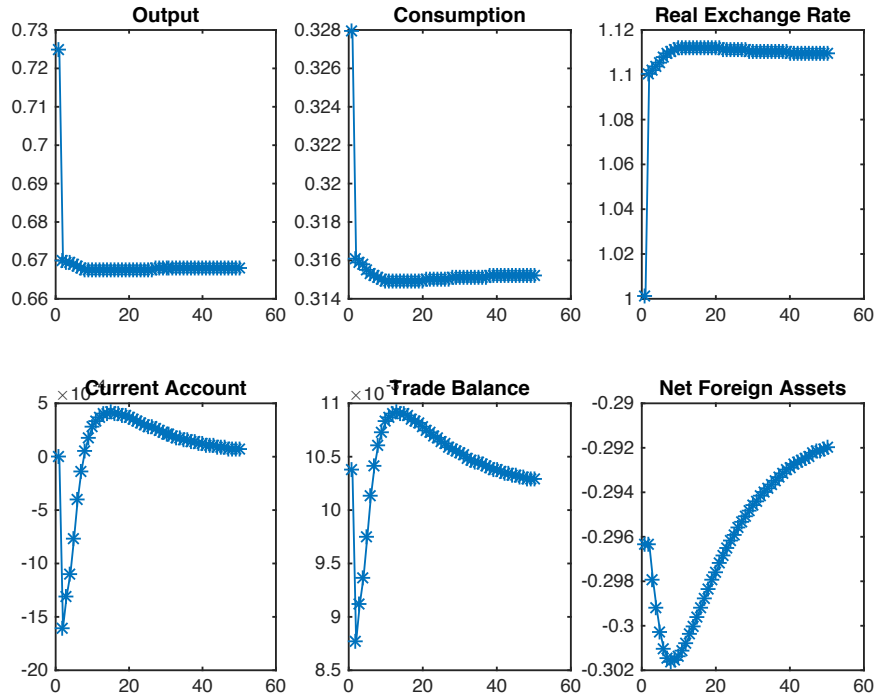
much higher than the two percentage points in the one-good economy. The difference lies on the real exchange rate adjustment. There is a 10% real depreciation on impact, which becomes a permanent real depreciation of 11%. Given the large share of nontradable output on GDP (60%) such large movement translates into a permanent fall in GDP of 7.6 pp (in units of tradable goods).

2.3 An oil-exporting small open economy

2.3.1 Structure of the model

We now expand the two-good endowment model to account for oil production. Oil activities are modeled as in Sickles and Hartley [2001]. There is a representative oil extracting firm, owned by agents, which decides how much of 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^x (in units of tradables). 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 total cost function has the following properties: $C_s < 0$, $C_x > 0$ and $C_s(s,0) = 0$. The cost function C is decreasing in s, total extraction cost falls the larger the oil reserves, and increasing in x, total cost

grows the higher the extraction rate. The marginal cost of an additional units of reserves, conditioned on not extracting oil, is zero: $C_s(s, 0) = 0$. The function we use in to perform the quantitative experiments is:

$$C(s, x) = \frac{\kappa}{2} \frac{x^2}{1 + s} \tag{8}$$

where κ determines the total cost elasticity to changes in the rate of extraction.

We assume that the country has a maximum level of $\bar{s}$ units of oil reserves and new oil can be discovered every year. Specifically, the stock of oil reserves is $s \in [0, \bar{s}]$ and d units of oil can be discovered. Oil discoveries are uncertain and follow a discrete i.i.d. random process, which we calibrate to the Colombian data. To keep things simple, this is the only source of uncertainty in the model. The oil firm can extract $x \in X = [0, s]$ units of oil from the available stock of reserves at the beginning of the year, and thus reserves evolve according to:

$$s' = s - x + d. \tag{9}$$

The value of the oil firm, given that the country has s units of oil reserves at the beginning of the year, satisfies the Bellman equation:

$$v(s) = \max_{x \in X} \{p^x x - C(s, x) + \delta E_d [v(s - x + d)]\} \tag{10}$$

where v is the value function of the oil company, $\delta \in (0, 1)$ is the discount factor of the oil company. We set the discount factor equal to $\delta = 1/R$, the international risk-free interest rate.

We solve the problem by discrete dynamic programming. Thus, associated with this program there is an optimal oil extraction policy, $\tilde{x}(s)$. The controlled-state process of the oil company's program with optimal policy function $\tilde{x}$, is a stationary Markov chain with transition probability matrix P whose typical element in the position (i, j) is the probability of jumping from state i in the current year to state j next year, conditioned on following the optimal policy $\tilde{x}(i)$:

$$P_{ij} = \Pr(s_{t+1} = j | s_t = i, x_t = \tilde{x}(i)).$$

In this setting, the economy has a new budget and resource constraint. The representative agent's budget constraint in the competitive equilibrium is:

$$c_t^T - p_t^N c_t^N = y_t^T + \pi_t + A^T + p_t^N y^N + p_t^N A^N - b_{t+1} + R b_t$$

where $\pi_t = p^x \tilde{x}(s) - C(s, \tilde{x}(s))$. We assume that agents take the oil extraction optimal policy function as given. Given this and the market clearing condition in the nontradables

19

sector, it follows that the representative agent maximizes (1) subject to (4) and two resource constraints:

$$c_t^T = y_t^T + p^x \tilde{x}(s) + p_t^N y^N - b_{t+1} + R b_t + A^T \tag{11}$$

and

$$c_t^N = y^N + A^N. \tag{12}$$

The first equation is the market clearing condition for tradable goods, which now assumes that all oil production is exported (this is the new balance of payments equation) and the second is the market clearing condition of nontradable goods market. As in the previous two models, the constants A^T and A^N capture other components of aggregate demand not modeled.

2.3.2 Basic mechanisms at work

Given the international oil price, the stock of oil reserves and the random pattern of discoveries, the oil company decides how much oil to extract from the available oil reserves to maximize current and future expected profits. The oil firm transfers its optimal profits to agents, and are an additional source of income to finance their expenditures. Assuming that $\bar{s}$ is sufficiently large, the constraints will not be binding at the optimal solution, and the shadow price of oil, λ, the derivative of the value function with respect to the stock of reserves (i.e. the marginal lifetime profits), will satisfy the Euler equations:

$$p^x = C_x(s, x) + \delta E_d [\lambda (s - x + d)]$$

$$\lambda(s) = C_s(s, x) + \delta E_d [\lambda (s - x + d)].$$

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 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. 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. Permanently lower oil prices induce oil firms to extract less oil from the ground and reserves should increase over time. The impact on profits depend on the cost structure, but notice that the lowest possible value of profits is zero as oil firms can choose to leave oil in the ground, instead of extracting it at a loss.

Now the economy has two assets: a real asset (the stock of oil) and a financial asset (the stock of debt). Discovery shocks are likely to be adjusted mostly by extraction decisions, showing up on the trade balance adjustment. However, by relaxing or constraining the agents budget constraint they will also impact consumption and saving. Borrowing decisions, formally seen on the optimal decision rule $b'(s, b)$ now depend not only on the NFA, but also on the stock of oil reserves. Despite that, by assumption, private agents external debt does not impact the oil industry, borrowing decisions are influenced by the stock of reserves (through the optimal extraction policy, $\tilde{x}(s)$). Thus, at any given point in time, the outstanding level of debt is not only the summary of past debt history but also of the oil reserves history.

How would a permanent fall in oil prices affect this artificial economy? Intuitively, a permanent reduction in oil prices induces oil firms to cut extraction an keep oil in the ground. Since the model assumes that all oil extracted is produced and exported, the value of oil exports falls not only due to the international price reduction but also because of the cut in production. Oil profits would fall, to later recover as extraction normalizes (meaning the should eventually be equal to average discoveries) and reserves return to a new higher steady state value. Since oil profits are a source of income to private agents, a permanent fall in profits acts like a permanent income reduction. Agents would borrow more trying to keep consumption as smooth as possible. However, since the fall in income is permanent, consumption needs to be permanently reduced if debts are going to be eventually repaid. The cut in consumption should be front-loaded because in order to repay the newly-acquired external obligations (current account deficit widens initially) they should generate current account surpluses in the future. However, the permanent cut in consumption is likely to be smaller than in the previous two models. In this case, instead of hitting directly the endowments, which are both demanded by households, the oil shock affects the value of exports and it hits only the disposable income. Still, this fall in income tightens the consumers budget constraint and motivates them to reduce both tradable and nontradable consumption. Since the supply of both tradable and nontradable goods is invariant to the collapse in oil prices, the excess of supply in tradable goods market adjusts through the trade balance but the excess of nontradable goods supply has to adjust through a permanent fall in the relative price. Therefore there should be a permanent real exchange rate depreciation.

2.3.3 Calibration. solution method and baseline results

The three-good calibration shares some similarities to the two previous calibrations. As in the previous two models, we set $\mu = 0.316$, $\sigma = 4$, $R = 1.035$. We then calibrate the values

of β and ϕ to match as closely as possible both the level of NFA to GDP observed in the data (30% of GDP) and the fraction of the years that Colombia has been excluded from financial markets. Setting $\beta = 0.9645$ and the borrowing limit at 40% of GDP ($\phi = .4$) we obtain a debt to GDP ratio of 30% and a frequency of international financial markets exclusion of 6% (vs. 16% in the data).

As in the previous models, we work with units of tradables in the model and we follow the procedure described Durdu et al. [2009] for the case of Mexico and normalize the steady-state relative price of nontradables, and gross production in units of tradables. We set $p^N = 1$ and $y^T + p^x y^x + p^N y^N = 1$, where y^x is the production of oil in the economy, and p^x the world price of oil. One difference of this paper relative to Durdu et al. [2009] is that we do not have intermediate goods as an input of the nontradable sector. Instead, we have the oil sector. The model is calibrated to match some ratios of the two-sector economy, using aggregate and sectoral data from Colombian national accounts. All the information is available from DANE (National Administrative Department of Statistics of Colombia).

The ratio of nontradable GDP to tradable GDP is $p^N y^N / y^T$, which yields an average of 1.74 for the 2000Q1-2012Q4 period. This ratio can be calculated using the GDP from the supply side, that decomposes gross production in ten main economic activities. The tradable sector does not include the oil sector, the last encompassing the industry of oil, natural gas, and uranium and thorium minerals. Thereby, the tradable sector includes the following: manufacturing industries, mining sector (expect for the oil sector), agriculture, animal agriculture, forestry, and hunting. Some services can also be classified as tradable (as they have a large share of either exports or imports in gross production), such as air transportation, complementary services to transportation, and services to businesses different from financial and real estate services. The sectors that are classified as nontradable are personal, social, and community services, construction, electricity, water and gas, financial services, commercial services, terrestrial transportation, mailing, and telecommunications. We further assume that total taxes are proportionally distributed between the two sectors.

From $p^N y^N / y^T = 1.74$ and $y^T + p^x y^x + p^N y^N = 1$, $y^T = 1/\left(1 + 1.74 + p^x y^x / y^T\right)$. The ratio $p^x y^x / y^T$ can also be retrieved from the data, yielding an average of 0.16 for the same sample period. Therefore, y^T is 0.34, which implies $p^N y^N = \left(\left[1/y^T\right] - 1 - 0.16\right) y^T = 0.6$. In addition, after solving the problem of the oil firm we get E_x, the steady state level of extraction of crude oil from the solution to problem (10), which has a direct mapping to y^x. Thus, $p^x = 0.16 y^T / E_x$.

22

Table 6: Calibration for the three-sector model

| Notation	Variable	Value
$y^T + p^x x + p^{NT} y^{NT}$	Output in units of non-oil tradables	1.0000
p^{NT}	Relative price of nontradables	1.0000
$p^{NT} y^{NT} / y^T$	Nontradable to tradable output ratio	1.7440
$p^x x / y^T$	Oil to Tradable output ratio	0.1624
c^T / y^T	Consumption to output ratio in the tradable sector	0.9185
$p^{NT} c^{NT} / p^{NT} y^{NT}$	Consumption to output ratio in the nontradable sector	0.5416

The other two ratios that are calibrated are the shares of sectoral consumption in each sector's GDP. The 2000Q1-2012Q4 average of c^T/y^T is 0.92, while the $p^N c^N / p^N y^N$ average for the same period is 0.54. To construct these numbers, we can use the annual matrices of utilization at current prices from DANE, which are only available until 2012. These matrices divide consumption, gross capital formation, exports and government expenditures between 61 sectors, that can be classified between tradable, nontradable, and oil sector. We assume that exports belong completely to the tradable sector (except for oil), and thus we have $y^T = c^T + g^T + i^T + x - m^T$ and $y^N = c^N + g^N + i^N - m^N$. Departing from these macroeconomic identities, we can construct the ratios mentioned above. It is worth mentioning that there is no consumption of oil, so $p^x y^x$ does not enter in c^T. From these numbers, and using the normalization, we get $c^T = 0.3165$ and $c^N = 0.3240$. Finally, we introduce constant levels of absorption A^T and A^N that capture investment and government expenditures in both sectors, and are compatible with the budget constraint of households. Thus, we have $A^T = y^T + p^x y^x + b(R-1) - c^T$ and $A^N = y^N - c^N$. The full calibration is summarized in Table 6.

There are some differences, though. In particular, the calibration of the model's oil block. Here the only source of uncertainty is oil discoveries. In Colombia there is no official data on "discoveries". There are however annual data of the stock of reserves and production since 1921, whose source is the National Hydrocarbons Agency. Using the dynamics of stock accumulation, equation (9), we can infer annual data on "discoveries" from 1922 to 2013 in Thousands BPDC (biphenyldicarboxylate). We assume (and estimate) by maximum likelihood method a two parameters gamma distribution assuming independent data, see Hogg and Craig [1978] section 3.3 for details[7]. The resulting estimated parameters are 1.19 and 148537, with an estimated expected value of 176.86 million of barrels and a mode value of 28.328 million barrels, highlighting the asymmetry in the distribution. In order to use the

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[7]Given the few negative values in the variable, a small positive constant was added to each data point in order to assure positiveness.

Gauss-Laguerre quadrature algorithm (see W.H. Press and Flannery [1992]) to discretize the states we use the probabilistic result that a Gamma(α, β) random variable divided by β (scale parameter) is distributed as Gamma$(\alpha, 1)$ which is the representation used for discretization. Figure 6 shows the histogram (relative frequencies) of our proxy for discoveries and the fitted gamma distribution. We use $\alpha = 1.19$ and $\beta = 0.8$ for the discretized gamma distribution.

Figure 6: Histogram and fitted density.
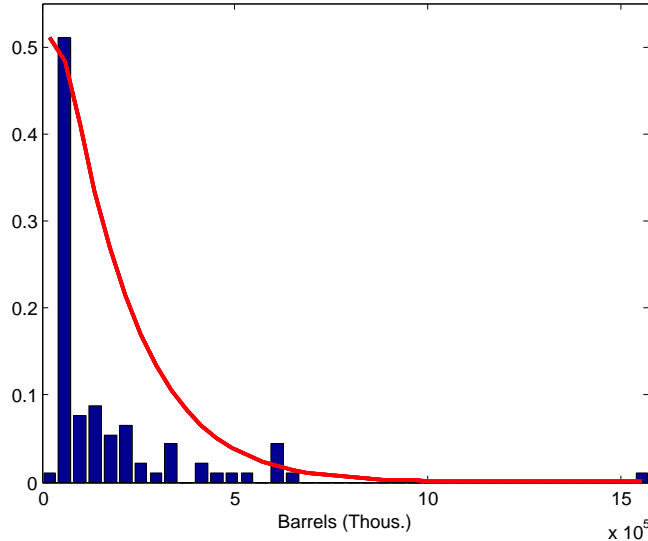
We also need to calibrate the parameter that determines the cost sensitivity of oil firms to the extraction rate, χ, in equation (8). Given that we assume that the representative oil firm's discount factor is $\delta = R^{-1}$, we fix $\kappa = 2.45$ to match the years of reserves to exhaustion (s/x) of Colombia (6.3 years) at a price of oil barrel of US\$100. We set the price at high levels to later simulate a collapse of one standard deviation in oil prices. At this price, observed over the last few years, reserves hovered around 2 billion barrels and production reached one million barrels per day.

We solve the model in two stages. In the first stage we solve the oil block by discrete dynamic programming using using a discrete grid of 81 equidistant nodes for both s on the interval $[0, 20]$. We approximate the discovery distribution with a 7-node discretization as we just described. We find the optimal policy rule $\tilde{x}(s)$ as well as the optimal Markov transition matrix P_x associated with the problem. This matrix P_x will be determine the optimal evolution of the oil sector in the economy. Taking it as given, we solve the problem of the rest of the economy:

$$v(s, b) = \max_{b' \in [-\phi, 0]} \frac{c^{1-\sigma}}{1 - \sigma} + \beta E\left[v(s - \tilde{x}(s) + d, b')\right],\qquad(13)$$

24

Figure 7: Ergodic joint density of NFA and oil reserves of the calibrated model
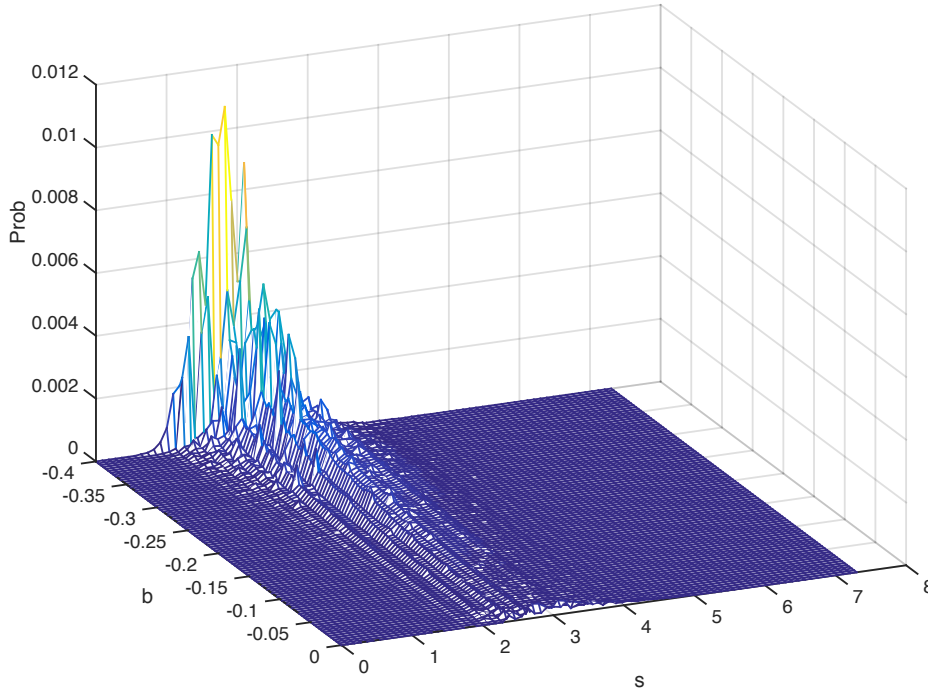
subject to (4), (11) and (12), using a discrete grid of 100 equidistant nodes for both b and b' on the interval $[-\phi, 0]$. We find the optimal policy rules $b'(y, b)$ and $c(y, b)$ as well as the optimal Markov transition matrix P associated with this problem. Figure 7 shows the ergodic optimal distribution of stock and debt for the calibrated model.

Using the optimal transition matrix P of this model we simulate the economy's path overtime and obtain the statistics shown on Tables 7 and 8. The model matches quite closely the oil sector statistics. It matches not only the targeted statistic: years of reserves, but also matches (after rescaling the probability distribution of discoveries) the stock of reserves at 2.4 billion barrels and annual production at one million barrels per day.

Table 7: Ratios (% of GDP) of the Three-good Small Open Economy Model: the Model vs the Data

	Data	Model
	Colombia	Steady State
Tradable Output	0.40	0.40
Consumption (% of y^T)	0.92	0.92
Net Foreign Assets	-0.30	-0.30
Borrow constr. (pct time)	16%	10%
	Oil Sector	
	Data	Model
Years of Reserves	6.3	6.3
Extraction (TBPD)	1028	1054
Oil Stock (billion bl.)	2.38	2.44

Note: Oil extraction is expressed in thousand barrels per day, Oil Stock in billions of barrels.

Since the only source of uncertainty in the model is oil discoveries and oil accounts for a smaller fraction of total activity, the performance of the model to replicate the macroeconomic time series is more limited than the previous two models. Yet oil discoveries is able to closely match GDP's volatility. The simulated model generates a cyclical volatility of 2.9% vs 2.6% in the data. Persistence is higher than in the data because of the extraction dynamics, which tends to take longer to converge to the steady state after the realization of a new oil discovery. This result is a remarkable, considering that unlike the previous two models, the calibration of the exogenous shocks are not targeting GDP but oil sector statistics. The model also performs quite well by explaining about one third of the volatility of the current account and the real exchange rate. It is also able to generate a countercyclical trade balance and to capture the high degree of persistence observed in the majority of the macroeconomic data.

Table 8: Statistical Moments: the Three-good model vs data

|	Colombian Data			Model		
	σ_x	$\rho_{x,y}$	$\rho_x(-1)$	σ_x	$\rho_{x,y}$	$\rho_x(-1)$
Output	2.6	1.0	0.76	2.87	1.00	0.86
Consumption	2.7	0.89	0.75	0.38	0.96	0.92
Current Account	2.2	-0.34	0.70	0.74	0.58	0.53
Trade Balance	4.6	-0.39	0.92	0.76	-0.96	0.92
Real Exchange Rate	9.0	-0.71	0.68	3.27	-0.96	0.92

The model falls short in several dimensions. As in the previous two models, the model cannot generate a counter-cyclical current account, a well known fact not only in Colombia but also in many emerging economies. The model also predicts a much smoother total consumption and trade balance than in the data. In the case of consumption the model delivers a standard deviation of 0.38% vs 2.7% in the data. This excess volatility of consumption is also a well documented fact in emerging economies. In the case of the trade balance, the model predicts a standard deviation of 0.76% against a 4.6% standard deviation of the Colombian trade balance. Despite all this shortcomings, our judgment is that considering that the model is still a small scale model and has only one source of uncertainty, it seems to do a good job replicating some macroeconomic properties of the Colombian economy and its oil sector. We now proceed to analyze the impact of a permanent reduction of international oil prices.

2.3.4 Effects of permanent changes in oil prices

As in the previous models, we simulate a permanent oil price fall of one standard deviation. At lower oil prices it becomes less attractive to extract oil and incentives point to leave a larger stock of oil reserves in the ground. The model predicts that after the first year, a permanent collapse in oil prices induces a cut in oil extraction to 775 thousand barrels per day down from one million barrels per day. Since the model assumes that all oil extracted is produced and exported, the value of oil exports falls not only due to the international price reduction but also because of the cut in production. Oil profits collapse 49% initially, to later recover some lost ground, but suffer a permanent hit of 31%. Oil profits are a source of income to private agents. A permanent fall in profits acts like a permanent income reduction. Therefore consumption also falls. The initial impact is a 0.6% reduction in consumption after the first few years to stabilize later at a permanent consumption cut of 0.1%.

Despite the large impact on income, the effect on aggregate consumption is much smaller than in the previous two models. Recall than in the previous models shocks were directly on the endowments, which were consumed and demanded domestically. Here, all oil is exported and the permanent shock hits only the disposable income. Still, this fall in income tightens agents budget constraint and motivates them to reduce both tradable and nontradable consumption. Since the supply of both tradable and nontradable goods is invariant to the collapse in oil prices, the excess supply in tradable goods market adjusts through the trade balance but the excess of nontradable goods supply has to adjust through a fall in the relative price. Therefore there should be a permanent real exchange rate depreciation. The model predicts an immediate fall of 1.15% in nontradable prices and a permanent real

Figure 8: Model response to a 30% permanent oil price reduction
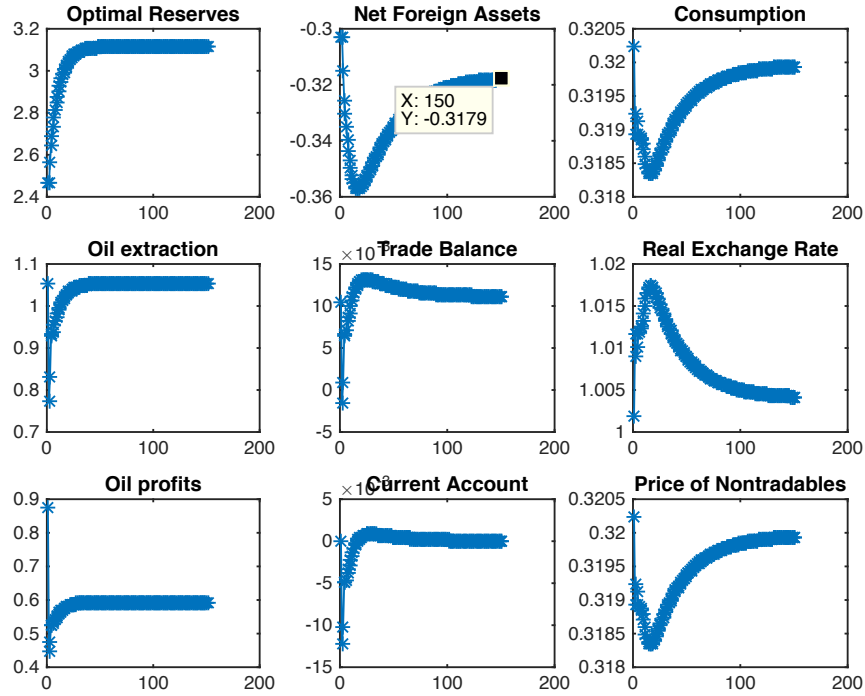
depreciation of 25 basis points.

How to reconcile the large impact on income and the small effects on consumption, the price of nontradables and the real exchange rate? The answer lies on the net foreign financial asset position and its relationship to the stock of oil reserves. The collapse in oil prices has a large impact on the oil sector. Oil profitability tanks, oil extraction is cut significantly and incentives to keep oil in the ground are large. Therefore, most of the adjustment in reaction to the change in oil prices happens in the oil sector. Aside from this endogenous adjustment, the current account is still the vehicle to smooth out the effects of the permanent change in oil prices. The model predicts an initial deterioration of the current account of one 1.2 percentage points on impact, it remains in deficit for a few years and then it moves into positive territory to later converge to its steady state value of zero. As in the previous models, private agents borrow initially because they are impatient. External debt increases to levels close to 36% of GDP from 30% in the following years. Unlike those models, which predict a long run increase in NFA, this model delivers a higher permanent level of indebtedness after a permanent fall income. Net external debt increases permanently to 32% from 30% of GDP.

A higher level of indebtedness in this model is possible because the country has now a higher stock of oil reserves. Given the calibrated expected discovery rate, the model

predicts that oil reserves increase 27% in the long run, from 2.4 billion barrels to 3.1 billion barrels. In this model, the long run distribution of NFA is not independent from the long run distribution oil reserves. In other words, the total net foreign asset position of the country is composed of both: the stock of financial assets and the stock of real assets. A larger stock of a tradable real asset, like oil reserves or any other stock of a storable commodity, may help a country to borrow more when hit by negative shocks. In the case studied in this paper, the negative shock is a permanent fall in oil prices.

The small scale models presented here give us key insights about the long-run adjustment of a small open oil-exporting economy in response to permanent changes of international oil prices. First, the real exchange rate appears to be a key variable in the adjustment process. The differences between the macroeconomic response of the one-good endowment model and the two-good model highlights that in an economy in which both the supply of tradable and nontradable is inelastic, the real exchange rate can be volatile, absorbing a large portion of the adjustment.

Second, the financial and real structure of the economy are important when studying the net foreign position of the economy. An economy restricted to smooth consumption through a single financial non-state contingent asset can respond differently to an economy with an additional stock of a real asset. This is so even if the extraction or accumulation decisions of such asset and the decisions to borrow and lend are taken by different private agents. Yet uncertainty in the oil sector translates into the private agents income uncertainty and changes their precautionary motives to spend, save and borrow.

Therefore structure of the economy and especially the contribution of the oil sector is important. The degree of openness of the economy, that is the share of the tradable sector relative to the nontradable, as well as the size of the resource sector within the tradable sector determine how the economy copes with international oil price fluctuations.

Despite the insights provided by these family of models, they leave aside many features that are of interest to policy makers and particularly central banks. A first key aspect is that small scale models used so far feature endowment economies, keeping the supply of tradable and nontradable goods fixed. Endogenous production with factors of production is needed to determine the reallocation of resources in the economy and helping to mitigate the real exchange rate adjustment.

In addition, all the models presented so far abstract from the role of country risk. Recent experience shows that country risk indicators and interest rate spreads may respond to changes in oil prices. In the recent past, in Colombia, EMBI spreads, credit default swaps and government bond interest rates have increased in response to the collapse of oil prices. Figure 9 presents a scatter plot between the real price of oil and a measure of country risk,

Figure 9: Oil price and Colombia's country risk
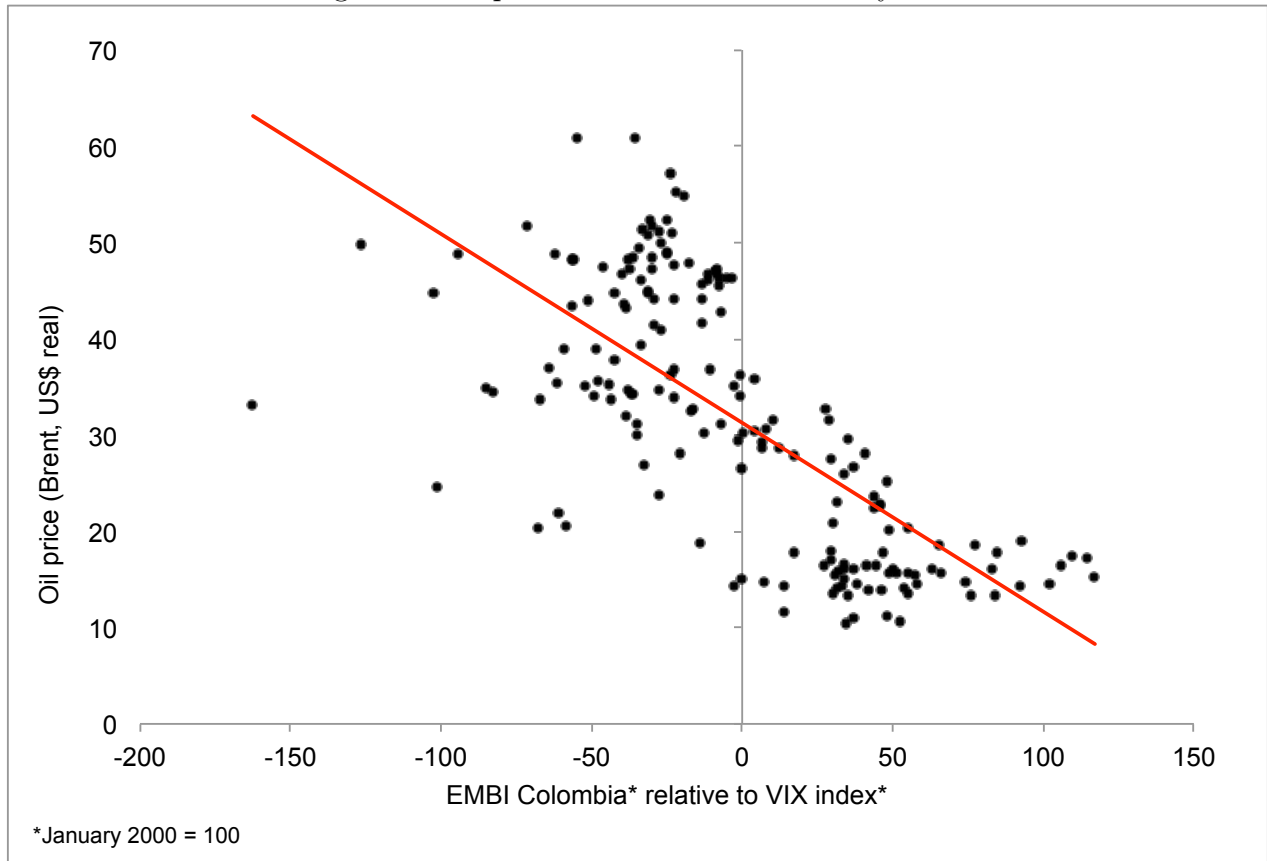
which controls for movements on aggregate risk. The proxy is the difference (in basis points) between the EMBI Colombia and the VIX index. The Colombian risk spread widens during phases of low oil prices and narrows during oil booms. Risk spreads affect real interest rates suggesting that there is room for an additional channel through which consumption, saving and borrowing may be affected. The channel is far from trivial: higher net external debt increases the risk premium, while a larger future value of the stock of oil may help to mitigate it. The balance between these two opposing forces may be important.

In a monetary economy, nominal adjustment may be important, especially if the quantitative impact of nominal rigidities is significant. Nominal exchange rate in oil exporting countries has reacted significantly in Colombia and dramatically in other oil exporting economies, like Russia. If most of the oil export revenue is transferred to local agents in domestic currency, the nominal exchange rate depreciation may compensate, at least partially, the fall in exports denominated in foreign currency. However, the presence of nominal price and wage rigidities may play an important role in the adjustment process of real variables.

Our small models also leave aside the possibility that part of the inputs of the production

30

process are influenced by oil prices. For instance, gasoline and energy are intermediate goods used in the production of final goods and therefore are also part of real marginal costs of firms. Lower oil prices may also mean lower input costs and may help to alleviate even further the negative impact of lower international oil prices.

Finally, monetary and macro-prudential policy responses are also not considered in our small scale models. An inflation targeting central bank may try to stabilize inflation and its actions may feed back into the economy. In the following sections we present two larger scale models that intend to capture some of these features.

3 Monetary policy models

In this section we describe two monetary policy models to analyze the dynamic adjustment to permanent changes in oil prices. Both models consider a small open economy, in which the oil sector is also part of the economy along with a tradable and a nontradable sectors. Also, both feature monopolistic competition and sticky price adjustment to give a role to monetary policy, modeled as a central bank which is assumed to target exclusively total inflation. Once again, we analyze the response of the economy to a permanent fall of international oil prices. The second model also considers the importance of a market for capital goods and the presence of financial frictions in both tradable and nontradable sectors, in the spirit of Bernanke et al. [1998]. In essence both model setups correspond to a commodity-driven transfer problem, in which low oil prices reduce export revenues and cause lower demand for tradable and nontradable goods and implying a real exchange rate depreciation. The models allow us to show that the dynamics of the proposed transfer problem can be the efficient response of the economy to exogenous terms-of-trade shocks. We derive the implications for inflation and monetary policy.

3.1 A monetary policy model with an oil sector

In this subsection we describe a monetary policy model to study the transitional dynamics of a small open commodity-exporting economy to a lower permanent international oil price.

3.1.1 Structure of the model

The model is a three-sector economy (oil, tradable and nontradable sectors) populated by households, producers, the government and the central bank. Households supply labor to firms and consume final goods, save in the form of foreign debt and receive the revenues from the oil sector, which decides how to extract oil optimally (as in the long run model).

Tradable output is still an endowment, but nontradable output is produced in several stages in a monopolistic competitive environment with nominal rigidities. In addition to this, nontradable output production needs an imported input of production.

Households

More formally, there is a representative household which 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:

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

where c_t is the consumption basket, h_t are the worked hours, b_t^* is the real external debt expressed in terms of the foreign consumption basket, b_t is a real state-contingent domestic bond, w_t is the real wage, 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 nontradable goods producers, y^T is a constant stream of income of an endowment of tradable goods (which can be consumed or exported) and ξ_t^X are the profits from the oil firms and r_t^* is the real interest rate that this economy faces in international financial markets.

We model this external real interest rate as having two components: one, the risk-free real interest rate and second, a risk component, which we assume it is a positive function of the deviations of the external debt to oil reserves with respect to its steady state value. That is,

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

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.

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

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

where c_t^T is the consumption of tradable goods and c_t^N is the basket of differentiated non-tradable goods. Here, unlike the models of the previous section, this basket 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, worked hours, domestic bonds and external debt are:

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

$$\left[c_t - \frac{h_t^\omega}{\omega}\right]^{-\sigma} h_t^{\omega-1} = w_t \lambda_t$$

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

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

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

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

Since preferences are separable across periods, intra-temporal optimal choice can be made independently form the inter-temporal optimal choice, therefore optimal choices of nontradable and tradable consumption are:

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

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

and the consumer price index is:

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

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

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

where p_t^N and p_t^T are the nontradable and tradable prices relative to the consumer price index.

Since we assume a Dixit-Stiglitz aggregator, optimal choice of non traded good variety j is independent of the optimal aggregate nontradable choice, hence the optimal choice of the j-th nontradable variety is

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

and the nontradable goods price level aggregator is:

$$p_t^N = \left[\int_0^1 p_t^N(j)^{1-\theta} dj\right]^{\frac{1}{1-\theta}}. \tag{14}$$

Oil extraction

Oil production in this model is the same as in the three-good model, described in subsection 2.3.1. However, unlike in the three-good model which had oil discoveries as the only source of uncertainty, we now assume that the international price of oil is also stochastic and may influence the rate of discoveries in Colombia. We also need to use an alternative representation of the oil block because our solution method will now work with the Euler equations of the model instead of the Bellman equation. Thus, in this alternative representation, 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}. The problem of the representative oil firm is:

$$\max_{\{x_t, s_{t+1}\}} \mathrm{E}_t \left\{ \sum_{i=0}^{\infty} \beta^i \frac{\lambda_{t+i}}{\lambda_t} [\Pi_t] \right\} \tag{15}$$

subject to

$$s_{t+1} = s_t + d_t - x_t \tag{16}$$

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

$$\Pi_t = p_t^x x_t - C(x_t, s_t) \tag{17}$$

where p_t^x is the relative (to foreign prices) price of oil and the cost of extraction, $C(x_t, s_t)$, is assumed to be a convex function which varies positively with extraction, x_t, and negatively with the level of remaining reserves, s_t.

Optimal extraction satisfies the following conditions:

$$[x_t] : \mathrm{E}_t \left\{ p_t^x - \frac{\partial C}{\partial x_t} - \beta \Upsilon_{t+1} \right\} = 0$$

$$[s_{t+1}] : \mathrm{E}_t \left\{ -\frac{\partial C}{\partial s_{t+1}} + \Upsilon_{t+1} - \beta \Upsilon_{t+2} \right\} = 0$$

where Υ_t is the Lagrange multiplier associated to the oil reserves accumulation equation. The intuition of these Euler equations is similar to the optimality conditions of the three-good model.

We use the same functional forms used in the three-good model for the cost and revenue functions :

$$C = \frac{\kappa}{2} \frac{x_t^2}{1 + s_t} \tag{18}$$

Both oil prices and discoveries follow autoregressive processes:

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

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

Note that discoveries are not independent of oil prices. If discoveries depended positively on oil prices, a permanent price reduction would increase long run oil reserves even further. Discoveries would fall implying a lower oil extraction in the steady state, increasing the long run stock of oil reserves.

Nontradable goods production

There is a representative firm producing a homogeneous nontradable good in a perfectly competitive environment. The firm chooses two inputs, labor and oil, to produce the non-tradable good, which are 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 represents a constant total factor productivity, m_t is the demand of oil from producers of nontradable goods. Note that we have implicitly assumed that capital is fixed and equal to one unit for all t.

We assume that the the Law of One Price holds for oil:

$$p_t^x = q_t p_t^{x,\star}$$

where p_t^x is the real price of oil and $p_t^{x,*}$ is the real price of oil in terms of foreign consumer price index.[8] The latter evolves according to an exogenous AR(1) process:

$$log\left(p_t^{x,\star}\right) = \rho^{p^{x,\star}} log\left(p_{t-1}^{x,\star}\right) + (1 - \rho^{p^{x,\star}})log(p^{\bar{x},\star}) + \varepsilon_t^{p^{x,\star}}.$$

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

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

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

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

And the homogeneous nontradable good's price is $p_t^N = \varphi_t$ since the homogeneous good is produced in a perfect competitive environment.

Price-Setting

There is a continuum of retailer firms which buy the homogeneous good from the perfectly competitive firms and transform this homogeneous good in a differentiated variety j. Therefore, each of these firms has monopoly power in their respective variety. We assume that

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[8]Note that we have slightly changed our notation and now the international real price of oil is $p_t^{x,\star}$.

there is Calvo price-stickiness: each retailer receives a random signal to adjust their prices with a probability $1 - \epsilon$, setting a price $\tilde{p}_t^N(j)$ to maximize:

$$E_t \sum_{i=0}^{\infty} \epsilon^i \Lambda_{t,t+i}[p_t^N(j)y_{,t+i}^N(j) - \varphi_{t+i}y_{,t+i}^N(j)] \tag{19}$$

subject to:

$$y_t^N(j) = \left(\frac{p_t^N(j)}{p_t^N}\right)^{-\theta} y_t^N \tag{20}$$

as long as the market clearing condition for each nontradable 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 household's stochastic discount factor since they own the firm.

Therefore, retailers optimal price setting is represented by the first order condition of solving (19) subject to (20), which is:

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

and can be written as:

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

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 retailer that keep their prices fixed and $1 - \epsilon$ the fraction of retailer that re-optimize their price by choosing $\tilde{p}_t^N$, then by using (14) , the nontradable good price index can be expressed as:

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

which is the conventional Calvo-pricing equation for the determination of prices, in this case the nontradable 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:

$$i_t = r_t^{\star} + \bar{\pi} + \phi_\pi \left(\pi_t - \bar{\pi}\right)$$

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.

Market clearing conditions

From the household's budget constraint, it can be shown that, by using the clearing market 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 this economy is:

$$p_t^x m_t + p_t^T c_t^T + q_t b_t^\star(1 + r_t^\star)+ = p_t^T y_t^T + p_t^x x_t + q_t b_{t+1}^\star. \tag{21}$$

3.1.2 Basic mechanisms at work

This model shares the core mechanism of the three-good model presented in the previous section: a negative and permanent oil shock reduces disposable income permanently and causes a permanent reallocation of resources between tradable and nontradable sectors. Since the excess of supply of tradable goods can be exported away, but the fall in demand of non-tradable goods is permanent, there should be a permanent real exchange rate depreciation. Since in this model only the nontradable sector produces goods using labor and imported intermediate inputs (gasoline) and nontradable demand falls, the demand of these inputs also falls. Thus employment falls and imports fall. Part of these imports are intermediate inputs, used in the production of nontradable goods. Since the price of intermediate inputs is also the price of oil, there is a reduction on its real marginal cost, which increases the quantity demanded of that input, acting in the opposite direction to the fall in nontradable goods demand. On balance, one can expect that the fall in the derived demand to be larger than the increase in the quantity demanded by nontradable producers of the imported input.

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 oil. On one hand long run external debt will be higher, pushing the risk premium up. On the other country risk falls with the *value* of the stock of oil reserves, $p^x s$. A collapse in oil prices lowers 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 like consumption, employment and output adjust even further when compared to a flexible price economy. Therefore, real variables in the economy with stickiness are likely to be more volatile than their flexible price counterparts. 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 compensates partially the fall in the value exports denominated in foreign currency. The nominal exchange rate eases pressure on the households budget constraint. Second, there is pass-through from the nominal depreciation to inflation. Total inflation shoots away 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 nontradable sector, amplifies the fall in economic activity.

3.1.3 Calibration, estimation and baseline results

In this section we report the parameter values of the model. The parameters of the oil block of model are estimated, while the parameters of the macro block of the model are calibrated. For the estimation of the oil's sector block, we use the same data set used for the calibration of the three-good model of the previous section. Data frequency is annual for the period of 1921-2013. It includes the following time series: crude oil British Petroleum price[9], change in oil reserves relative to total oil reserves and ratio between oil production and oil reserves. Since variables such as discovery of new oil reserves and exogenous shock process are not observed, we use Kalman filter and Bayesian methods to estimate non-observable variables, parameter values and exogenous shocks' standard deviations. These estimation results are presented in Table (9). The table reports prior and posterior distributions (of both parameters and shock's standard deviations). These posterior distributions were computed using two Markov Chains (MCMC) with 100.000 draws each.

Table 9: Estimation

Parameter/Std	Prior			Posterior				
	Distribution	mean	std	mode	std	mean	HPD inf	HPD sup
ρ_{diss}	β	0.5	0.15	0.3471	0.0774	0.3613	0.2243	0.4949
$\rho_{p^{oil\star}}$	β	0.8	0.015	0.8633	0.0115	0.8618	0.8449	0.8812
$\rho_{p^{oil\star},diss}$	$\mathbb{N}$	0.0	0.15	0.2023	0.1112	0.2085	0.0204	0.3959
κ	Γ	2.0	0.25	3.7889	0.1456	3.7717	3.5778	4.0213
$\varepsilon_{p^{oil\star}}$	inv Γ	0.125	inf	0.7531	0.0754	0.7608	0.6315	0.8862
ε_{diss}	inv Γ	0.125	inf	1.0416	0.1690	1.1025	0.8193	1.3690
ε_{β}	inv Γ	0.125	inf	0.1169	0.0102	0.1190	0.1022	0.1352

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[9] The crude oil British Petroleum price series is taken from the BP Statistical Review of World Energy 2014. This crude price is constructed with the Brent dated over the 1984-2013 period, Arabian Light posted at Ras Tanura in the 1945-1983 period and US Average over the 1861-1944 period.

Table (10) shows the long-run ratios of key macro variables of the model and the Colombian economy. We use annual frequency data from the Colombian national statistics department, *DANE*. Since the model has only labor in the non-tradable sector, we need to guess the labor income share in the nontradable sector. Labor income in total output is about 60% and nontradable production weights 60% of total production. Therefore, we set the labor income share of the nontradable sector at 0.36. Other values of the parameters of the model are reported in Table (10).

Table 10: Long run ratios: model vs data

Relation		Model	Data
$\dfrac{\text{external debt}}{\text{GDP}}$	$\dfrac{qb^\star}{y}$	-0.3	-0.3
$\dfrac{\text{labor income}}{\text{GDP}}$	$\dfrac{wh}{y}$	0.36	0.36
$\dfrac{\text{non tradable output}}{\text{tradable output}}$	$\dfrac{p^N y^N}{p^T y^T}$	1.74	1.74
$\dfrac{\text{oil reserves}}{\text{oil production}}$	$\dfrac{s}{x}$	6.3	6.3

To obtain these values, we use the analytical steady state solution of the model. The rest of the parameters were taken from previous studies of the Colombian economy, and are reported in Table 12.

Table 11: Key calibrated parameters of the model

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

40

Table 12: Other parameters of the model

| Parameter		Value	Source
Nontradable consumption share	γ	0.6	DANE
Labor participation in nontradable production function	α	0.9	Gonzalez et al. [2011]
Inter-temporal elasticity of substitution	σ	4	Gonzalez et al. [2011]
Estimated parameter of oil extraction cost	κ	3.7889	Estimated
Oil discount factor	β^{oil}	0.9661	Gonzalez et al. [2011]
Correlation between oil price and discoveries	ρ^{d,p^x}	0.2023	Estimated
Interest rate to debt elasticity	Ψ	0.0544	Estimated
Long run foreign real interest rate	$\bar{r^f}$	0.035	Gonzalez et al. [2011]

3.1.4 Estimated effects of permanent lower oil prices

To assess the monetary policy implications of permanent changes in oil prices we perform a transitional dynamics exercise using the estimated model as our baseline. The initial state of economy corresponds to a high oil prices environment: oil price is US$100 per barrel, Colombian oil reserves are close to six years and external debt is 30% of GDP. The final state of the economy corresponds to the expected path of the three-good model, ten years after the sudden and permanent fall in oil prices. That is, oil prices fall by one standard deviation and external debt increases to 36% of GDP from 30%, ten years later. We let oil reserves to adjust endogenously. We choose ten years arbitrarily but we feel this may be a reasonable time-span for the monetary policy authority to fix as a "long-run period". The quantitative results of the transitional dynamics exercise are reported in Figure 10. We report two cases: one in which there are flexible prices and another in which prices are sticky.

The collapse in oil prices has a large impact on the oil sector. Oil extraction is cut by nearly 20% (to 800 thousand barrels a day from one million barrels a day), oil profits tank, and oil reserves increase by nearly 20% in the long run, to 2.9 billion barrels from 2.4 billion barrels. As in the small scale model, most of the adjustment in reaction to the permanent change in oil prices happens in the oil sector.[10] As in the previous model, the current account is still another vehicle to smooth out the permanent change in oil prices. The model predicts an initial deterioration of the current account of 1/3 of a percentage point on impact, it remains in deficit for a few years and then it moves into positive territory to later converge to its steady state value of zero. In this model there is no impatience imposed on agents, thus

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[10]These quantitative results are different from those obtained with the small scale model because in the latter case the oil block model is estimated, instead of calibrated, and there are two sources of uncertainty.

Figure 10: Short-run macro adjustment to a permanent fall in oil prices
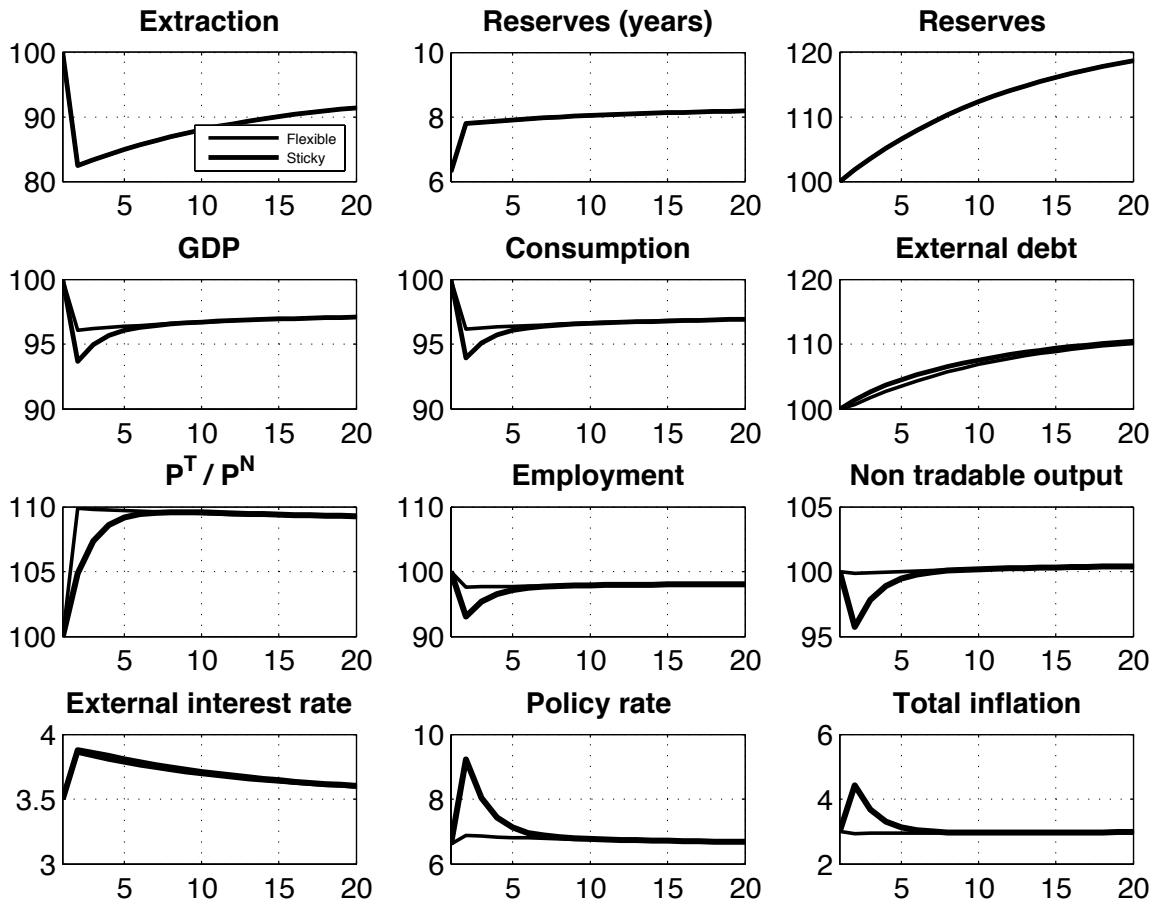
private agents borrow to mitigate the adjustment in consumption. External debt increases gradually to 36% of GDP from 30% in the following years. This last result is obviously tied to the design of the transitional dynamics experiment, which fixes the initial and final level of external debt to be equivalent to the previous model. Note however that, along the transition path, the external debt is higher in the sticky-price economy than in the flexible price one.

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

Aside from the large impact on the oil and external sectors, the effect on aggregate consumption is now larger than in the model without monetary policy. Consumption falls, on impact, by 4 pp in the flexible price economy and by 6 pp in the sticky prices economy. GDP also falls by similar magnitudes. The permanent fall in consumption and GDP is about 3 pp. The collapse in total consumption triggers a real depreciation by similar mechanisms as the previous models: tradable consumption adjustment happens through the trade balance, while nontradable consumption and activity tank. The result is a 6% RER depreciation on impact in the flexible price economy, and a steady real depreciation in the sticky prices one. Both models predict a permanent real depreciation of more than 5%.

The real depreciation dynamics implies that tradable inflation is higher than nontradable, implying that there has been a nominal depreciation passing through to total inflation. In the sticky price economy, total inflation jumps 1.5 pp away from the inflation target, triggering a central bank response of a 2.5 pp increase of its policy rate. In the flexible price economy these effects are of smaller magnitude.

The model also highlights a monetary policy dilemma. In this artificial economy 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 manages to drive inflation back to target eventually, but it does so at a time in which oil exports and nontradable sectors are adjusting to the new condition. A key insight from this model is that there is part of the adjustment that monetary policy simply cannot accommodate: the economy is permanently poorer and this happens in both economies with and without sticky prices.

A possible criticism to our results may be that we are ignoring investment, overlooking the role of the price of capital goods (specially the imported capital goods) credit and financial markets, missing an endogenous tradable sector and lacking capital accumulation

in both tradable and nontradable sectors. To address these issues we consider an even larger monetary policy model.

3.2 A monetary policy model with financial frictions and oil sector

In this subsection we describe a larger scale monetary policy model to study the transitional dynamics of a small open commodity-exporting economy subject to financial frictions to a lower permanent international oil price. The model is based on Gonzalez et al. [2013] and features endogenous production in both sectors, using capital and labor as inputs, investment as well as a monetary policy toolkit which includes exchange rate and credit policy instruments. In that paper the oil sector is modeled as an exogenous endowment. Here the oil sector is endogenous and behaves as described in the previous model. The complete set of equations are reported in appendix 4.

3.2.1 Structure of the model

The model is a three sector economy (oil, tradable and nontradable sectors) populated by households, entrepreneurs, retailers, capital producers, private banks, the government and the central bank. Households supply labor to firms and consume final goods, save in the form of bank deposits and receive the revenues from the oil sector, which decides how to extract oil optimally (as in the long run model). Output is produced in several stages, including a monopolistic competitive nontradable sector with nominal rigidities. Entrepreneurs, both in the tradable and nontradable sector face financial frictions and their external financing cost is decreasing in their net worth, as in Bernanke et al. [1998].

As in the previous monetary model, in the baseline specification of this model, the central bank sets the nominal interest rate using a monetary policy rule. The model also considers exchange rate and credit policies. Exchange rate policy is modeled as the sales/purchases of international reserves, which adjusts in response to real exchange rate misalignment. Credit policy is modeled as any financial regulation instrument, which respond to aggregate credit dynamics by enlarging or compressing the external financing premium in the economy. In the experiments performed in this paper we shut down both exchange rate and credit policies.

3.2.2 Basic mechanisms at work

The mechanism that we have in mind to explain the response of the economy to oil price shocks, approximated by the model's transitional dynamics, is similar to the previous model: besides the standard channels in the tradable and nontradable small open economy mod-

els, a key mechanism works through the external interest rate risk-premium. The role of this premium may be even more important here because of the presence of the financial accelerator mechanism. However, the financial accelerator in a multiple-good small open economy model may be substantially different than the financial accelerator in a single-good closed economy model. The transfer problem (from nontradable to tradable) coupled with the financial accelerator at the sector level may in fact weaken the overall aggregate financial accelerator. The depreciation of the exchange rate leads to a fall in the value of the assets of the nontradable sector, lowering the value of its collateral and consequently, rising the external financing premium that those firms pay to commercial banks. This increase in financing costs coupled with the lower demand of nontradable goods drives further down employment in this sector. In contrast, the tradable sectors benefit from an exchange rate appreciation. This channel is present in the model and highlights an apparent trivial result: in a small open economy with tradable and nontradable sectors, the financial accelerator may help to stabilize aggregate economic activity.

However, the sectoral transfer adjustment is inefficient because the equilibrium is distorted by financial frictions. Prior to the oil price collapse, in the oil boom phase, credit growth and real appreciation transfer net worth from the tradable to the nontradable sector, which enhances borrowing capacity in the latter, and then a sudden reversal in commodity prices causes a reallocation back to the tradable sector and causes the nontradable sector to experience a credit crunch. Moreover, a pecuniary externality is also at work in this process, because in the Bernanke et al. [1998] financing premium the value of net worth depends on equilibrium sectoral relative price movements that individual agents do not internalize when they make borrowing decisions.

3.2.3 Estimated effects of permanent lower oil prices

To quantify these mechanisms we perform a transitional dynamics exercise, identical to the one performed with the previous model. The quantitative results of the transitional dynamics exercise are reported in Figures 11 and 12. The first presents the response of some of the main macro variables while the second shows the response of some financial variables. We report both economies one with the financial accelerator mechanism and another without it. The sensitivity analysis to our results, in particular coming from the relative elasticity of country risk to external debt and the value of the stock of oil, is presented in Appendix 4.

Figure 11: Transitional dynamics of macro variables after a permanent fall in oil price
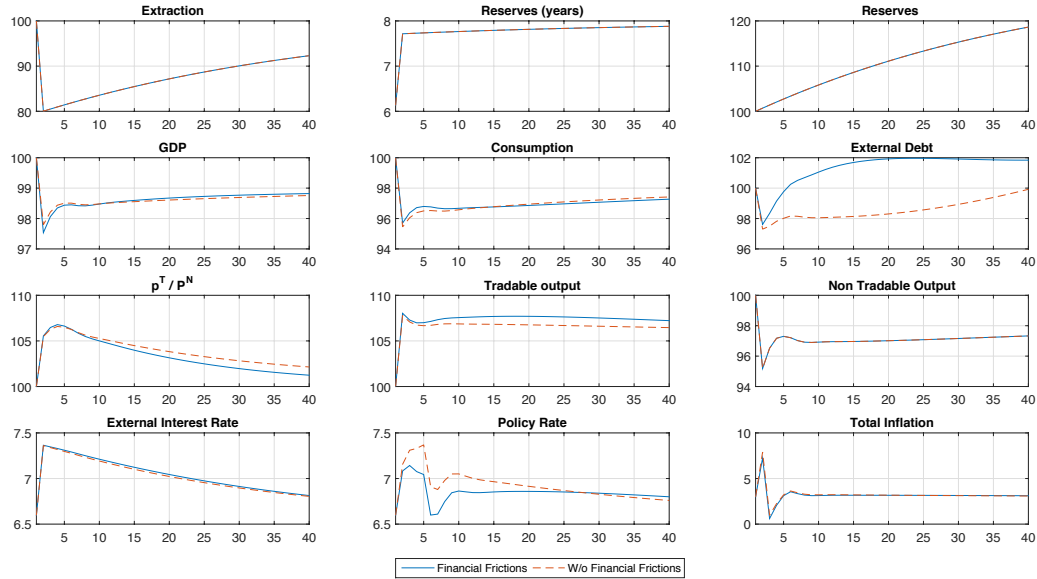
Figure 12: Transitional dynamics of financial variables after a permanent fall in oil price
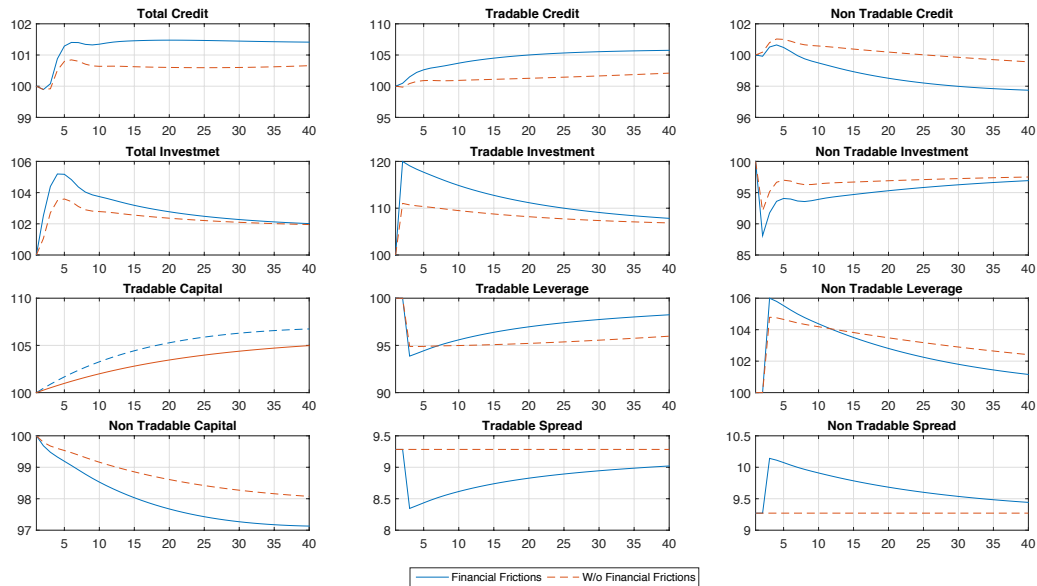
Like the previous model and by construction, a one standard deviation permanent fall in oil prices has a large impact on the oil sector. Oil extraction is cut by nearly 20% (to 800 thousand barrels a day from one million barrels a day), oil profits tank, and oil reserves increase by nearly 20% in the long run, to 2.9 billion barrels from 2.4 billion barrels. As in

the previous model, households borrow to mitigate the adjustment in consumption. External debt increases to 36% of GDP from 30% in the following years. Once again, this last result is also tied to the design of the transitional dynamics experiment, which fixes the initial and final level of external debt. Note however that, along the transition path, the external debt is higher in the financial frictions economy than in the flexible price one.

Country risk increases by nearly 80 bps on impact, like in the previous model, a relatively small jump, to later recede as oil reserves increase. Here, the two determinants of country risk are also present. On one hand long run external debt will be higher and lower oil prices push the risk premium up, but on another reserves increase in the future, lowering the country risk premium. It turns out that on our estimation of the impact on country risk is small, especially in the long run.

The effect of the permanent oil price shock on aggregate consumption is very similar to that one of the previous monetary policy model. Consumption falls, on impact, by 4 pp in both economies (with and without financial accelerator). GDP also falls by similar magnitudes in both economies but the contraction is smaller in this model by 2 pp, in comparison to the previous model. The permanent fall in consumption and GDP is about 1 pp. The collapse in total consumption triggers a real depreciation by similar mechanisms as the previous models: tradable consumption adjustment happens through the trade balance, while nontradable consumption and activity tank. The result is a steady 7% RER depreciation during the first years in both (with and without financial frictions) economies, close to the 6% depreciation of the previous monetary policy model. Both models predict a smaller permanent real depreciation (less than one percent).

Just like in the previous model, the real depreciation dynamics implies that tradable inflation is higher than nontradable, implying that there has been a nominal depreciation passing through to total inflation. In both economies, total inflation jumps by about than 4 pp away from the inflation target, triggering a central bank response of nearly one percentage point increase of its policy rate. In the economy without financial frictions the monetary policy response is smaller. Unlike the previous model, here the response of inflation is short-lived. It increases during the first quarters but then falls rapidly, close to zero, to stabilize later around the central bank's target.

It is also interesting to analyze the model's response of investment and financial variables. Again there is a sectoral reallocation of credit and investment from nontradables to tradables, but overall credit and investment increase. Both are possible through a larger net foreign debtor position of the economy. It is worth noting that financial frictions indeed amplify fluctuations of financial variables, like leverage, spreads and investment. Yet, as noted above, these sharper financial fluctuations do not show up in the main macroeconomic aggregates.

Figure 13: Transitional dynamics of macro variables after a permanent fall in oil price -
Nontradable inflation target
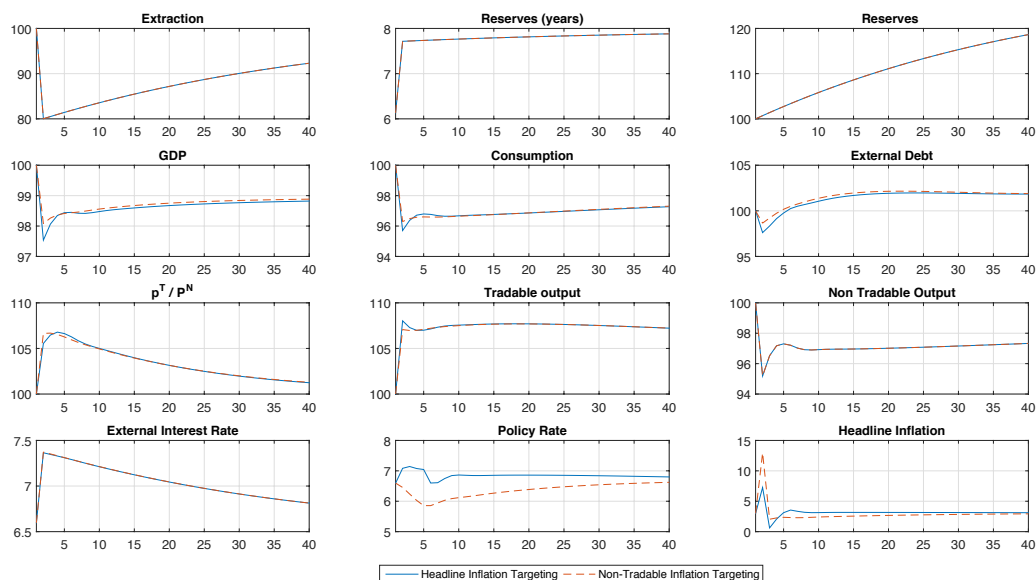

Of course, a central banker would be reluctant to raise interest rates in light of a per-
manent real shock with potentially large negative effects to the economy. The root of the
problem is that in this artificial economy, nominal depreciation is passing through to trad-
able inflation and thus driving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

We perform a counterfactual experiment in which, having the same shock, we simulate
what would have happened if the central bank targeted nontradable inflation instead of total
inflation. Figures 13 and 14 report the results of this transitional dynamics experiment for
the macro and financial variables.

In this alternative artificial economy the central bank instead of hiking the policy rate,
cuts it. Consumption, GDP and external debt fall less initially and tradable output does
not expand as much as in the total inflation targeting central bank. The long run effects
in both total inflation and nontradable inflation targeting regimes are identical. Obviously,
total inflation skyrockets to double digits. Once again, this intuitive result highlights the
short to medium-term policy dilemma for inflation targeting central banks in oil exporting

Figure 14: Transitional dynamics of financial variables after a permanent fall in oil price - Nontradable inflation target
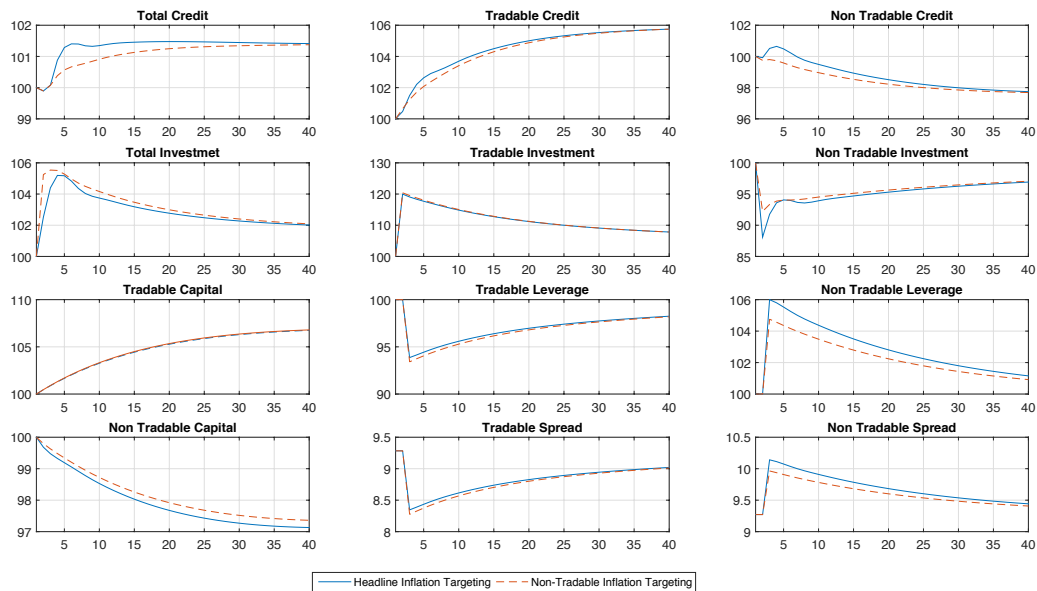
economies.

4 Conclusions

This paper analyzed the macroeconomic consequences and the monetary policy implications of permanent changes of oil prices on a small open economy from the perspective of dynamic stochastic general equilibrium framework. We proposed a complementary approach with two blocks: one in which optimal precautionary demand for foreign assets results from the presence of uncertainty and incomplete financial markets. For this block, we employed a set of precautionary savings models (Bewley models) without nominal rigidities and without a central bank to determine the macroeconomic impact of permanent changes in oil prices in the long-run. A second block in which nominal rigidities, real imperfections and financial frictions was used for the shorter term analysis. For this latter block we used two larger scale monetary policy models for small open economies.

The approach was to start with the long term adjustment, departing point from a simple one-good endowment economy in which agents can borrow and lend to smooth fluctuations in income. Differences between interest and discount rates and precautionary saving motives drive the determination of net foreign assets in the long run. We then considered a tradable and non-tradable endowment to assess the impact on the real exchange rate. Later we

moved on and introduced the oil sector as a resource extracting problem to find that, in an oil exporting economy, agents deal with uncertainty not only through external debt and the natural hedge that provides the real exchange rate but also through optimal management of oil reserves. The next step was to complement the latter model with a monetary policy model to derive some policy implications. The model had the same three sectors as the previous one, but we added monopolistic competition and sticky prices in the nontradable sector and allowed that sector to use labor and an imported intermediate good in the production of final non-tradable goods to assess the response of these components of real marginal costs. We closed the nominal portion of the model assuming a strict inflation targeting central bank. We closed our set of models with an even larger model in which sector-specific capital accumulation was possible for both tradable and nontradable sectors and markets of capital goods were subject to financial frictions. In each case, we performed a transitional dynamics experiment in which these artificial economies moved from a high international oil price environment to one in which these prices fell permanently by one standard deviation.

We found that the optimal response of the oil sector in these economies was to cut extraction significantly and to increase prospective long-term oil reserves. More interestingly, the small scale models highlighted that the real exchange rate and net foreign assets appear to be the key variables in the adjustment process of the economy, absorbing a considerable portion of the oil price collapse, specially during the transition phase. We also found that the financial and *real* structure of the economy are important for the long run determination of the net foreign position of the economy. An oil exporting economy uses its oil reserves as an additional instrument to deal with uncertain events. Precautionary savings coupled with incomplete financial markets imply that uncertainty in the oil sector translates into the private agents income uncertainty affecting their motives to spend, save and borrow. Therefore, the structure of the economy and especially the contribution of the oil sector is important. The degree of openness of the economy, that is the share of the tradable sector relative to the nontradable, as well as the size of the resource sector within the tradable sector determine how the economy copes with international oil price fluctuations. The quantitative simulations of the three-sector model calibrated for the Colombian economy indicate that a one standard deviation permanent cut of the oil price increases the economy's financing. Net foreign asset position falls from a 30% debt to GDP ratio to nearly 36% in the following years.

We encountered that, once we feed this long term adjustment to permanently lower oil prices into the larger scale monetary policy models, the efficient sectoral adjustment of the economy implies a challenge for an inflation targeting central bank. On one hand the permanent fall of oil revenues causes a significant and permanent fall in consumption and

GDP but the nominal depreciation of the exchange rate drives total inflation off the target, calling the bank for a tighter policy stance. Thus, both the nominal and the real exchange rate adjustment are at the core of the adjustment mechanism. There is a reallocation from nontradable sectors to tradables, implying a large real exchange rate depreciation, capital, labor and credit reallocate to tradable sectors (other than oil) from nontradable activities. Part of this adjustment is efficient, while another is inefficient due to the presence of financial frictions. However, the sectoral reallocation of credit "decelerates" the financial accelerator mechanism.

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

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Appendix 1: Equations of monetary policy model with oil sector

1.

$$tb_t + q_t b_t^\star = (1 + r_{t-1}^\star) q_t b_{t-1}^\star$$

2.

$$tb_t = p_t^T y_t^T + p_t^x x_t - p_t^x m_t - p_t^T c_t^T$$

3.

$$y_t^N = A_t h_t^\alpha \left(x_t^{IN} \right)^{1-\alpha}$$

4.

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

5.

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

6.

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

7.

$$r_t^\star = r_t^f + \Psi \left[exp \left(\frac{q_t b_t^\star}{p_t^X S_t} - \frac{q b^\star}{p^X S} \right) - 1 \right]$$

8.

$$\left[c_t - \frac{h_t^\omega}{\omega} \right]^{-\sigma} h_t^{\omega-1} = w_t^h \lambda_t$$

9.

$$log\,(A_t) = \rho^A log\,(A_{t-1}) + (1 - \rho^A) log\,(\bar{A}) + \varepsilon_t^A$$

10.

$$tb_{share,t} = \frac{tb_t}{y_t}$$

11.

$$ca_{share_t} = tb_{share,t} - \frac{r_t^\star b_t^\star}{y_t}$$

12.

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

13.
$$y_t^N = c_t^N$$

14.
$$p_t^T = q_t p_t^{T,\star}$$

15.
$$log\left(p_t^{T,\star}\right) = \rho^{p^{T,\star}} log\left(p_{t-1}^{T,\star}\right) + (1 - \rho^{p^{T,\star}})log(p^{\bar{T},\star}) + \varepsilon_t^{p^{T,\star}}$$

16.
$$q_t = \frac{q_{t+1} r_t^{\star}}{r_t}$$

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

18.
$$\tilde{p}_t^N = \frac{num_t}{den_t}$$

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

20.
$$den_t = (\theta - 1) \lambda_t y_t^N + \epsilon \beta_{t+1} den_{t+1} \left(1 + \pi_{t+1}^N\right)^{\theta - 1}$$

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

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

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

24.
$$y_t = p_t^N y_t^N + p_t^T y_t^T + p_t^x x_t$$

25.
$$i_t = r_t^{\star} + \bar{\pi} + \phi_{\pi} \left(\pi_t - \bar{\pi}\right) + z_t^i$$

26.

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

27.

$$z_t^i = \rho^{z^i} z_{t-1}^i + (1 - \rho^A)\bar{z}^i + \varepsilon_t^{z^i}$$

28.

$$(1 + r_t) = \frac{(1 + i_t)}{(1 + \pi_{t+1})}$$

29.

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

30.

$$\beta_t = \frac{1}{\left(1 + r_t^f\right)}$$

31.

$$p_t^{x,\star} = \frac{2\kappa x_t}{1 + s_{t-1}} - \beta_t \left(2\kappa \frac{x_{t+1}}{1 + s_t} - p_{t+1}^{x,\star} - \kappa \left(\frac{x_{t+1}}{1 + s_t}\right)^2\right)$$

32.

$$s_t = s_{t-1} - x_t + d_t$$

33.

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

34.

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

35.

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

36.

$$p_t^x = q_t p_t^{x,\star}$$

37.

$$x_t = x_t^{IN} + x_t^{OUT}$$

38.

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

Appendix 2: Monetary policy model with financial frictions and oil sector

We document the main equations of the monetary policy model with financial frictions and an oil sector.

Households

The economy is populated by households who discount the future at the factor $\beta \in (0,1)$ and choose consumption, c_t, labor supply, h_t, and deposits, d_t, to maximize expected lifetime utility

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[z_t^u \frac{c_t^{1-\sigma}}{1-\sigma} - \chi \frac{h_t^{1+\eta}}{1+\eta} \right]$$

where z_t^u is an exogenous preference shock, which evolves according to

$$z_t^u = \rho_{z^u} z_{t-1}^u + (1 - \rho_{z^u}) \log(\bar{z}^u) + \varepsilon_t^{z^u}. \tag{22}$$

The representative household budget constraint is

$$c_t + d_t = (1 - \zeta) q_t oil_t + \tau_t + \xi_t^N + w_t^h h_t + (1 + r_{t-1}) d_{t-1} \tag{23}$$

where w_t^h is the real wage, r_t denote the real deposit interest rate, q_t is the real exchange rate, ξ_t^N are the profits of the producers of nontradable goods, τ_t are lump-sum transfers from the government to households and $(1 - \zeta) oil_t$ is the fraction of oil revenues earned by households. Households also allocate labor between tradable and nontradable sector, thus the time constraint is $h_t = h_t^{Nh} + h_t^{Th}$. The consumption bundle for household is defined as

$$c_t = \left(\gamma^{\frac{1}{\omega}} \left(c_t^N \right)^{\frac{\omega-1}{\omega}} + (1-\gamma)^{\frac{1}{\omega}} \left(c_t^T \right)^{\frac{\omega-1}{\omega}} \right)^{\frac{\omega}{\omega-1}} \tag{24}$$

where c_t^T and c_t^N is the consumption of tradable and nontradables, ω is a parameter that determines the elasticity of substitution between tradable and nontradable goods and γ determines the household's importance of nontradable goods. Under these assumptions, the optimal household choices of consumption, labor supply and deposits are:

$$z_t^u c_t^{-\sigma} = \lambda_t \tag{25}$$

$$\chi h_t^\eta = w_t^h \lambda_t \tag{26}$$

$$\lambda_t = \beta \mathbb{E}_t \left[\lambda_{t+1} \left(1 + r_t \right) \right] \tag{27}$$

$$c_t^N = \gamma \left(p_t^N \right)^{-\omega} c_t \tag{28}$$

$$c_t^T = (1 - \gamma) \left(p_t^T \right)^{-\omega} c_t \tag{29}$$

where λ_t is the lagrange multiplier of the budget constraint and p_t^T and p_t^N are the relative prices of tradable and nontradable goods.

The relationship between the real and nominal rates in the economy is determined by the Fisher equation, $(1 + r_t) = \frac{(1+i_t)}{(1+\pi_{t+1}^C)}$, and by $\frac{(1+\partial_t)}{(1+\pi_t^C)} = \frac{q_t}{q_{t-1}}$ in the case of the exchange rates, where ∂_t is the nominal depreciation rate. Also, as there are two goods their inflation rates are:

$$\frac{\left(1 + \pi_t^N \right)}{\left(1 + \pi_t^C \right)} = \frac{p_t^N}{p_{t-1}^N} \tag{30}$$

and

$$\frac{\left(1 + \pi_t^T \right)}{\left(1 + \pi_t^C \right)} = \frac{p_t^T}{p_{t-1}^T}. \tag{31}$$

Capital Good Producers

In both tradable and nontradable sectors, there is a representative capital good producer acting in a perfectly competitive environment. Every period both producers buy x_t^T and x_t^N of final goods and old capital net of depreciation, $(1 - \delta) k_{t-1}^T$ and $(1 - \delta) k_{t-1}^N$, and transform these into new capital at a quadratic cost. Thus, the technology to produce each type of capital is

$$k_t^T = z_t^{xT} x_t^T + (1 - \delta_T) k_{t-1}^T - \frac{\psi_T}{2} \left(\frac{x_t^T}{k_{t-1}^T} - \delta_T \right)^2 k_{t-1}^T \tag{32}$$

$$k_t^N = z_t^{xN} x_t^N + (1 - \delta_N) k_{t-1}^N - \frac{\psi_N}{2} \left(\frac{x_t^N}{k_{t-1}^N} - \delta_N \right)^2 k_{t-1}^N. \tag{33}$$

Both z_t^{xT} and z_t^{xN} are exogenous investment effciency shocks which evolve according to

$$z_t^{xT} = \rho_{z^{xT}} z_{t-1}^{xT} + (1 - \rho_{z^{xT}}) \log\left(\bar{z}^{xT}\right) + \varepsilon_t^{z^{xT}} \tag{34}$$

$$z_t^{xN} = \rho_{z^{xN}} z_{t-1}^{xN} + (1 - \rho_{z^{xN}}) \log\left(\bar{z}^{xN}\right) + \varepsilon_t^{z^{xN}} \tag{35}$$

Under these assumptions the tradable and nontradable capital prices are:

$$p_t^{kT}\left(z_t^{xT} - \psi_T\left(\frac{x_t^T}{k_{t-1}^T} - \delta_T\right)\right) = p_t^T \tag{36}$$

$$p_t^{kN}\left(z_t^{xN} - \psi_N\left(\frac{x_t^N}{k_{t-1}^N} - \delta_N\right)\right) = p_t^N. \tag{37}$$

Entrepreneurs

Entrepreneurs produce an homogeneous good in both tradable and nontradable sectors. In the production process, the entrepreneurs buy capital from the capital producer firm and finance these payments by their own funds and taking loans from banks. Additionally, they work for the firm and hire labor from households. Once the production is made, entrepreneurs sell back the (depreciated) capital to the capital producer firm. During the production process, each entrepreneur is subject to an idiosyncratic shock that affects the productivity of its capital. While the tradable good is sold at international (given) prices, the non tradable homogeneous output is sold to a retail firm that differentiates the product and sells it to households. Thus, during the period t, this process can be characterized by the following technologies

$$y_t^N = z_t^N \left(\alpha_N^{\frac{1}{\omega_N}} \left(h_t^N\right)^{\frac{\omega_N - 1}{\omega_N}} + (1 - \alpha_N)^{\frac{1}{\omega_N}} \left(k_{t-1}^N\right)^{\frac{\omega_N - 1}{\omega_N}}\right)^{\frac{\omega_N}{\omega_N - 1}} \tag{38}$$

$$y_t^T = z_t^T \left(\alpha_T^{\frac{1}{\omega_T}} \left(h_t^T\right)^{\frac{\omega_T - 1}{\omega_T}} + (1 - \alpha_T)^{\frac{1}{\omega_T}} \left(k_{t-1}^T\right)^{\frac{\omega_T - 1}{\omega_T}}\right)^{\frac{\omega_T}{\omega_T - 1}} \tag{39}$$

where $h_t^N = \left(h_t^{Nh}\right)^{\Omega_N} \left(h^{Ne}\right)^{1-\Omega_N}$ and $h_t^T = \left(h_t^{Th}\right)^{\Omega_T} \left(h^{Te}\right)^{1-\Omega_T}$. Both z_t^T and z_t^N are exogenous technology shocks which evolve according to

$$z_t^T = \rho_{z^T} z_{t-1}^T + (1 - \rho_{z^T}) \log\left(\bar{z}^T\right) + \varepsilon_t^{z^T} \tag{40}$$

$$z_t^N = \rho_{z^T} z_{t-1}^N + (1 - \rho_{z^T}) \log\left(\bar{z}^N\right) + \varepsilon_t^{z^N} \tag{41}$$

The optimal allocation of labor services implies that in the nontradable sector

$$w_t^h = p_t^W \Omega_N z_t^N \left(\alpha_N \frac{y_t^N}{z_t^N h_t^N}\right)^{\frac{1}{\omega_N}} \frac{h_t^N}{h_t^{Nh}} \tag{42}$$

$$w_t^{Ne} = p_t^W (1 - \Omega_N) z_t^N \left(\alpha_N \frac{y_t^N}{z_t^N h_t^N}\right)^{\frac{1}{\omega_N}} \frac{h_t^N}{h^{Ne}} \tag{43}$$

and in the tradable sector

$$w_t^h = p_t^T \Omega_T z_t^T \left(\alpha_T \frac{y_t^T}{z_t^T h_t^T}\right)^{\frac{1}{\omega_T}} \frac{h_t^T}{h_t^{Th}} \tag{44}$$

$$w_t^{Te} = p_t^T (1 - \Omega_T) z_t^T \left(\alpha_T \frac{y_t^T}{z_t^T h_t^T}\right)^{\frac{1}{\omega_T}} \frac{h_t^T}{h^{Te}}. \tag{45}$$

The optimal allocation of capital depends on the expected return of one unit of capital.

$$\mathbb{E}_t r_{t+1}^{kN} = \mathbb{E}_t \left[\frac{p_{t+1}^W z_{t+1}^N \left((1 - \alpha_N) \frac{y_{t+1}^N}{z_{t+1}^N k_t^N}\right)^{\frac{1}{\omega_N}} + (1 - \delta_N) p_{t+1}^{kN}}{p_t^{kN}}\right] \tag{46}$$

$$\mathbb{E}_t r_{t+1}^{kT} = \mathbb{E}_t \left[\frac{p_{t+1}^T z_{t+1}^T \left((1 - \alpha_T) \frac{y_{t+1}^T}{z_{t+1}^T k_t^T}\right)^{\frac{1}{\omega_T}} + (1 - \delta_T) p_{t+1}^{kT}}{p_t^{kT}}\right]. \tag{47}$$

Given that entrepreneurs do not have enough resources to finance their total capital expenses, then their borrowing, b_t^N and b_t^T, is given by:

$$b_t^N = p_t^{kN} k_t^N - n_t^N \tag{48}$$

$$b_t^T = p_t^{kT} k_t^T - n_t^T. \tag{49}$$

which in turn depends on the net worth of the firm, n_t^N and n_t^T, which evolves in time according to:

$$n_t^N = \phi_N v_t^N + w_t^{Ne} h^{Ne} \tag{50}$$

$$n_t^T = \phi_T v_t^T + w_t^{Te} h^{Te}. \tag{51}$$

where

$$v_t^N = r_t^{kN} p_{t-1}^{kN} k_{t-1}^N - \mathbb{E}_{t-1}\left[r_t^{kN}\right] b_{t-1}^N \tag{52}$$

$$v_t^T = r_t^{kT} p_{t-1}^{kT} k_{t-1}^T - \mathbb{E}_{t-1}\left[r_t^{kT}\right] b_{t-1}^T, \tag{53}$$

are the proceeds per unit of capital acquired, net of the financing cost. Finally, entrepreneurs consume $p_t^N c_t^{Ne} = (1 - \phi_N) v_t^N$ and $p_t^T c_t^{Te} = (1 - \phi_T) v_t^T$.

Retailers

Retailers operate in a monopolistic competition environment, buy the homogeneous non-tradable goods from the nontradable entrepreneurs at a wholesale price, p_t^W, differentiate it at no cost and sell it to households and to the capital producer firms at the retail price, p_t^N. There are nominal price rigidities in the nontradable sector, as each firm maximizes profits under costly price changes as in Rotemberg [1982]. Thus, the optimal price set is

$$
\begin{aligned}
0 = {}& (1 - \theta_t) p_t^N y_t^N + \theta_t p_t^W y_t^N - p_t^N \kappa \left(\frac{\left(1 + \pi_t^N\right)}{\left(1 + \pi_{t-1}^N\right)^\iota (1 + \bar{\pi})^{1-\iota}} \right) \left(\frac{\left(1 + \pi_t^N\right)}{\left(1 + \pi_{t-1}^N\right)^\iota (1 + \bar{\pi})^{1-\iota}} - 1 \right) \\
& + \mathbb{E}_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} p_{t+1}^N \kappa \left(\frac{\left(1 + \pi_{t+1}^N\right)}{(1 + \bar{\pi})^{1-\iota} \left(1 + \pi_t^N\right)^\iota} \right) \left(\frac{\left(1 + \pi_{t+1}^N\right)}{(1 + \bar{\pi})^{1-\iota} \left(1 + \pi_t^N\right)^\iota} - 1 \right) \right]
\end{aligned} \tag{54}
$$

where θ_t is an exogenous markup shock, which evolves according to

$$\theta_t = \rho_\theta \, \theta_{t-1} + (1 - \rho_\theta) \log\left(\bar{\theta}\right) + \varepsilon_t^\theta. \tag{55}$$

The retailers' profits are

$$\xi_t^N = p_t^N y_t^N - p_t^W y_t^N - p_t^N \frac{\kappa}{2} \left(\frac{\left(1 + \pi_t^N\right)}{\left(1 + \pi_{t-1}^N\right)^\iota (1 + \bar{\pi})^{1-\iota}} - 1 \right)^2 \tag{56}$$

where $\kappa = \frac{\epsilon}{(1-\epsilon)(1-\epsilon\beta)} (\theta_t - 1)$ is a parameter that determines the slope of the Phillips curve in the nontradable sector.

Banks

The banking sector operates under perfect competition and each bank is owned by households. Banks can make commercial loans to entrepreneurs by taking deposits from households and borrowing b_t^* from international financial markets at the interest rate, r_t^*. This financial intermediation process is subject to frictions, in particular a costly state verification problem on the side of the asset side of the banks, which shows up in loan interest rates in the form of spreads. In addition, banks can also purchase sterilization bonds, b_t, from the central bank. The rate of return of these bonds is r_t. Thus, the balance sheet of the banks is $b_t + b_t^N + b_t^T = d_t + q_t b_t^*$. Therefore, interest rates are related by the following conditions

$$1 + r_t = \mathbb{E}_t \left[\frac{q_{t+1}}{q_t} \left(1 + r_t^* \right) \right] \tag{57}$$

$$\mathbb{E}_t \left[r_{t+1}^{kN} \right] = \left(\frac{n_t^N}{p_t^{kN} k_t^N} \right)^{-\nu_t^N} \left(1 + r_t \right) \left(rp_t \right) \tag{58}$$

$$\mathbb{E}_t \left[r_{t+1}^{kT} \right] = \left(\frac{n_t^T}{p_t^{kT} k_t^T} \right)^{-\nu_t^T} \left(1 + r_t \right) \left(rp_t \right). \tag{59}$$

Both ν_t^T and ν_t^N are exogenous spread shocks which evolve according to

$$\nu_t^T = \rho_{\nu^T} \, \nu_{t-1}^T + \left(1 - \rho_{\nu^T} \right) \log \left(\overline{\nu}^T \right) + \varepsilon_t^{\nu^T} \tag{60}$$

$$\nu_t^N = \rho_{\nu^N} \, \nu_{t-1}^N + \left(1 - \rho_{\nu^N} \right) \log \left(\overline{\nu}^N \right) + \varepsilon_t^{\nu^N} \tag{61}$$

Equations (58) and (59) state that real interest rates of commercial loans are a decreasing function of the net worth (relative to capital) in each of the sectors. This function is equivalent to a more detailed description of the BGG financial accelerator with one exception, the term rp_t, which introduces a "regulation premium". This premium captures the essence of the role of regulation on interest rate spreads. It enlarges the interest rate spreads in response to rapid aggregate credit growth, for instance. The precise mechanism by which this happens is not explicit in our paper, but we believe this term could represent any regulation measure, like countercyclical buffers, capital requirements, reserve requirements, or any mechanism which makes private credit more costly.

Government and Central Bank

We characterize the government and the central bank as a set of policy rules:

a monetary policy rule, that responds to deviations of inflation relative to the target $\bar{\pi}$,

$$i_t = i_{t-1}^{\rho_i} \left(\bar{i} \left(\frac{\pi_t}{\bar{\pi}} \right)^{\varphi_\pi} \right) \exp\left(\varepsilon_t^\mu \right) \tag{62}$$

a FX intervention rule, which responds to real exchange rate deviations from its steady state value,

$$q_t ri_t^* = \bar{r}i^* - \Psi_q \left(\frac{q_t}{\bar{q}} - 1 \right) \tag{63}$$

a regulation premium rule, which responds to total credit deviations from its steady state value,

$$rp_t = \exp\left(\mu_{rp} \left(\frac{credit}{\overline{credit}} - 1 \right) \right) \tag{64}$$

and a set of accounting equations that have to be satisfied every period:

$$q_t ri_t^* = b_t \tag{65}$$

$$\tau_t = b_{t-1} + q_t \left(1 + r_{t-1}^* \right) ri_{t-1}^* - \left((1 + r_{t-1}) b_{t-1} + q_t ri_{t-1}^* \right) . \tag{66}$$

The first equation is the balance sheet of the central bank: on the left hand side appears the value of the international reserves (in real terms of local currency) and on the right hand side the bonds issued to perform sterilized operations. The second equation states that the proceeds of the central bank operations are the result of bond sales and FX purchases (both net of interest payments). These proceeds are transferred back to households in a lump-sum way.

Oil sector

The problem of the representative oil firm is identical to the one used for the previous model, except that oil prices and discoveries follow these autoregressive processes:

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

$$d_t = \rho_d \, d_{t-1} + (1 - \rho_d) \log \left(\overline{d} \right) + \varepsilon_t^d.$$

Note that for simplicity we keep discoveries to be an independent process of oil prices, although to make the model more realistic we could argue that they could depend positively on oil prices. If discoveries depended positively on oil prices, a permanent price reduction would increase oil reserves even further. Discoveries would fall implying a lower oil extraction in the steady state increasing the long-run stock of oil reserves.

Risk premium

One key aspect of the model is the role of the risk premium. The economy faces an upward sloping supply of credit financing when borrowing abroad. We model the interest rate that the economy faces in international financial markets as:

$$i_t^\star = \overline{i} \, z i_t^\star \, \exp \left\{ \nu \left(\frac{q_t b_t^\star}{GDP_t} - \overline{b} \right) \right\} \exp \left\{ -\nu_{Oil} \left(p_t^x s_t - \overline{s} \overline{p^x} \right) \right\} \tag{67}$$

with $GDP_t = q_t p_t^x x_t + p_t^N y_t^N + p_t^T y_t^T$ and

$$z_t^{i^*} = \rho_{z^{i*}} \, z_{t-1}^{i^*} + (1 - \rho_{z^{i*}}) \log \left(\overline{z}^{i^*} \right) + \varepsilon_t^{z^{i^*}}$$

$$\pi_t^* = \rho_{\pi^*} \, \pi_{t-1}^* + (1 - \rho_{\pi^*}) \log \left(\overline{\pi}^* \right) + \varepsilon_t^{\pi^*}$$

being exogenous external shocks. This equation states that the interest rate at which the economy borrows abroad grows as the stock of external debt increases but falls with the value of the stock of oil in the economy. Besides helping to close the small open economy model, this device is a simple way to capture the idea that an economy which discovers new oil or enjoys higher oil prices, not only relaxes the households budget constraint but also makes the economy more credit-worthy and reduces its "risk premium". Although this is an *ad-hoc* device, we believe it captures the idea that a real asset, like the stock of oil available for extraction, influences the external borrowing premium. For instance, a country like Venezuela with a large stockpile of oil, faces a lower external premium when compared to other countries with fewer oil reserves.

Appendix 3: Financial frictions model estimation

We give parameters two different treatments. We fix one set of parameters and we estimate another. The set of calibrated parameters are those that affected the steady state of the model and therefore are chosen in order to match the long run relations observed in the data. Table 13 shows the values of the calibrated parameters.

We begin by discussing the parameters that affect the utility function. The discount factor β is set in order to obtain a real interest rate of 3.5% in the long run. The risk aversion coefficient $\sigma = 1$, implying a logarithmic utility function in consumption. The parameter η is also set to one, therefore the labor supply elasticity is unitary. And finally, as is standard in the literature, the parameter χ is chosen in order to obtain an average supply of hours of $1/3$. The external real interest rate, $\overline{r}^\star$, is also set to 3.5% and the domestic and external inflation targets, $\overline{\pi}$ and $\overline{\pi}^\star$, are set to 3%. This implies a long run real depreciation in the model equal to zero.

The consumption bundle in the model is composed by nontradable and tradable goods. In the three-good model calibration we obtained a high elasticity of substitution, $\omega = 0.76$, between these two goods and since γ affects the share of nontradable consumption in the bundle, the parameter is chosen to match the three-good model parameter too. The nontradable technology in the model includes labor and capital, the elasticity of substitution between them, ω_N, is set near to one and the share of labor in the production function, α^N, implies a labor intensive technology. The total amount of labor used in the production combines labor supplied by the household and supplied inelastically by the entrepreneurs h^{Ne}. The share of household labor relative to total labor, Ω^N, is set to 0.95, in line with the share of business owners in the total labor workforce as reported in Mejía [2009].

Another parameters that affect production are those related with the capital demand from the entrepreneurs. In this case, the external finance premium depends on $\overline{\nu}^N$, depends also on the parameter ϕ_N which defines the consumption for the entrepreneurs and depends on the depreciation rate, δ^N. All these parameters are chosen in order to fix observed long run value of the interest rate spread. In addition, the model assumes imperfect competition in the nontradable sector. The elasticity of substitution between the differentiated nontradable goods $\overline{\theta}$, implies a mark up of 25%. This value is taken from previous studies for Colombia, like Hamann et al. [2009] and Perez [2006]. The same arguments are used to pick the parameters for the tradable sector, the only difference arises because in this sector there is perfect competition and therefore there is no mark up.

Our model includes an optimal extraction decision of a representative oil producer who faces an international price and a technological constraint. When price increases, oil firms

Parameter	Description	value
β	Discount Factor	0.9914
σ	Risk aversion	4
η	Inverse of labor supply	1
χ	Scale parameter	6.2574
$\bar{r}^{\star}$	External real interest rate	1.0086
$\bar{\pi}$	Inflation Target	1.0074
$\bar{\pi}^{\star}$	External inflation target	1.0074
ω	Elasticity of substitution b/w T and NT	0.78
γ	Share in consumption bundle b/w T and NT	0.56
ω_N	Elasticity of substitution b/w Labor and Capital	0.9000
α_N	Share of labor in the production	0.6000
Ω^N	Share of household labor in total labor	0.9000
$\bar{\nu}^N$	External finance premium parameter	0.0100
ϕ_N	Share of net worth consumed by entrepreneur	0.9000
δ_N	Depreciation rate	0.0250
h^{Ne}	Entrepreneur labor supply	0.0100
$\bar{\theta}$	Elasticity of substitution b/w intermediate goods	5.0000
ω_T	Elasticity of substitution b/w Labor and Capital	0.9000
α_T	Share of labor in the production	0.6000
Ω^T	Share of household labor in total labor	0.9000
$\bar{\nu}^T$	External finance premium parameter	0.0100
ϕ_T	Share of net worth consumed by entrepreneur	0.9000
δ_T	Depreciation rate	0.0250
h^{Te}	Entrepreneur labor supply	0.0100
$\bar{b}^{\star}$	Stock of net foreign assets	1.2000
$\overline{ri}^{\star}$	Stock of international reserves	0.1000
$\overline{oil}$	Stock of oil reserves	5.1812
ζ	Extraction rate	0.9500
$\bar{z}^T$	Mean exogenous technological process	1.0000
$\bar{z}^N$	Mean exogenous technological process	1.0000
$\bar{z}^{i^{\star}}$	Mean exogenous external interest rate process	1.0000
$\bar{z}^u$	Mean exogenous preferences process	1.0000
$\bar{z}^{x^T}$	Mean exogenous investment process	1.0000
$\bar{z}^{x^N}$	Mean exogenous investment process	1.0000

expand oil supply by reducing reserves. The oil supply price elasticity will depend on the costs function of extraction. In particular, as we increase κ, the marginal cost of extraction increases for any level of oil production, and therefore, the effect over reserves becomes lower. We set $\kappa = 10$, in order to capture high adjustment cost of reserves.In addition, the parameters related with oil price mean and oil discoveries will determine the share of oil sector's benefits to income and the ratio of oil extraction to reserves. The remaining parameters associated with the oil sector are estimated.

The parameter $\bar{b}^*$ determines ratio of net foreign assets to GDP and $\overline{ri}^*$ determines the ratio of international reserves to GDP. As is standard in the literature, we set $\rho^i = 0.7$ and $\varphi^i = 1.5$. Finally, the mean for all exogenous process are set equal to one. The table 14 shows the long run relations obtained from the calibrated parameters and their empirical counterparts.

The second set of parameters are estimated using Bayesian techniques. These parameters mainly affect the dynamic behavior of the model and are related with investment adjustment costs, nominal rigidities, interest rate spreads, the policy rule coefficients and the parameters for the exogenous process. During the estimation the parameters that determine the FX intervention Ψ_q and the macroprudential regulation μ_{rp} are set equal to zero. The parameter Table 15 shows their prior-posterior distributions.

The data used in the estimation is expressed in quarterly growth rates and is assumed to have a measurement error. We included output in tradable, nontradable and mining sectors, total consumption (public and private), total investment, commercial loans for tradable and nontradable and saving deposits. Additionally we included tradable and non tradable inflation, nominal devaluation, interbank lending rate and a measure of external interest rate augment with risk premium. We also included oil extraction and oil price. In appendix 4 there is detailed description of the database used for the estimation of the model.

Table 14: Long run relations

Relations	Model	Data
Labor	23.01%	28.58%
Real interest rate	3.50%	2.50%
Inflation rate	2.99%	3.00%
Nominal interest rate	6.59%	6.07%
Nominal nontradable loan rate	13.09%	13.86%
Nominal Tradable loan rate	13.10%	10.24%
Consumption / GDP	68.41%	82.34%
Consumption nontradable / Consumption	53.20%	87.32%
Consumption tradable / Consumption	47.51%	12.82%
Investment / GDP	12.38%	21.22%
Investment nontradable / Investment	54.53%	59.95%
Investment tradable / Investment	45.47%	40.20%
Nontradable output/ GDP	54.79%	59.03%
Tradable output/ GDP	38.32%	33.76%
Oil production/ GDP	6.89%	7.21%
Stock of oil / Annual GDP	49.19%	64.63%
Net foreign assets / Annual GDP	20.00%	28.29%
International reserves/ Annual GDP	10.00%	13.13%
Credit / Annual GDP	59.29%	28.02%

	Prior Mean			Posterior Mean	
	distribution	Mean	std	Mean	std
parameters					
ϵ	beta	0.5000	0.15	0.5540	0.0550
$\rho_{p^{T\star}}$	beta	0.5000	0.15	0.9889	0.0034
ρ_{z^h}	beta	0.5000	0.15	0.8812	0.0362
ρ_{z^T}	beta	0.5000	0.15	0.5375	0.1952
ρ_{z^N}	beta	0.5000	0.15	0.3726	0.1627
$\rho_{i^\star}$	beta	0.5000	0.15	0.8006	0.0315
$\rho_{\pi^\star}$	beta	0.5000	0.15	0.1092	0.1079
ρ_θ	beta	0.5000	0.15	0.4951	0.1756
ρ_{z^u}	beta	0.5000	0.15	0.9826	0.0408
$\rho_{z^{xN}}$	beta	0.5000	0.15	0.0755	0.0336
$\rho_{z^{xT}}$	beta	0.5000	0.15	0.3333	0.0887
ρ_{ν^T}	beta	0.5000	0.15	0.8258	0.0397
ρ_{ν^N}	beta	0.5000	0.15	0.9520	0.0174
ρ_{oil}	beta	0.5000	0.15	0.9960	2.45E(-7)
ρ_{dis}	beta	0.5000	0.15	0.9487	0.0179
ψ_N	gamma	5.0000	1.5	12.374	2.0944
ψ_T	gamma	5.0000	1.5	8.0854	1.4127
ν_{b^*}	gamma	0.0100	0.005	0.0011	0.0006
ν_{oil}	gamma	0.0100	0.005	0.0021	0.0004
variances					
ε^{oil}	inv_gamma	0.0125	Inf	0.1289	0.0011
ε^{dis}	inv_gamma	0.0125	Inf	0.3935	0.0011
ε^{z^T}	inv_gamma	0.0125	Inf	0.0043	0.0011
ε^{z^N}	inv_gamma	0.0125	Inf	0.0084	0.0037
$\varepsilon^{z^{i^\star}}$	inv_gamma	0.0125	Inf	0.0035	0.0004
$\varepsilon^{\pi^\star}$	inv_gamma	0.0125	Inf	0.0075	0.0006
ε^μ	inv_gamma	0.0125	Inf	0.0031	0.0003
ε^θ	inv_gamma	0.0125	Inf	0.5830	0.0677
ε^{z^u}	inv_gamma	0.0125	Inf	0.0267	0.0029
ε^{z^h}	inv_gamma	0.0125	Inf	0.0435	0.0050
$\varepsilon^{z^{xT}}$	inv_gamma	0.0125	Inf	0.0174	0.0016
$\varepsilon^{z^{xN}}$	inv_gamma	0.0125	Inf	0.0184	0.0017
$\varepsilon^{p^{T\star}}$	inv_gamma	0.0125	Inf	0.0505	0.0045
ε^{ν^T}	inv_gamma	0.0125	Inf	0.0079	0.0021
ε^{ν^N}	inv_gamma	0.0125	Inf	0.0045	0.0007

Appendix 4: Data set

Commercial debt portfolio: We took the commercial monthly real debt portfolio of the Colombian financial sector and converted it to quarterly frequency using the value for the last month in the quarter. This data is available from 1998Q4 to 2013Q2.

Sectoral commercial debt portfolio: We built a tradable and non tradable commercial debt portfolio measure by adding up sectoral data. In particular, for the tradable measure, we take the commercial debt portfolio of the agriculture, fishing, mining, manufacture and wholesale and retail commerce sectors. For the non tradable sector, we take the hotel and restaurant, transportation, financial intermediation, real estate, public administration, education, health, other social services, households with domestic service and extraterritorial organs sectors. These measure are then deflated using the CPI and seasonally adjusted using Census x12. This data is available from 1999Q1 to 2013Q2.

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

Oil Price: Quarterly prices are calculated from daily data by taking an unweighted average of the daily closing spot prices for BRENT. We took the seasonally adjusted series and deflate it by the United States CPI. We used the cyclical component of oil price after a Hodrick-Prescott filter. This data is available from 1999Q1 to 2013Q2.

Consumption: We took disaggregated quarterly data of total private consumption from 2000Q1 to 2013Q2. In particular, this disaggregation divides consumption in non durable, durable and semi durable goods, and services. We then approximate tradable consumption as the sum between consumption in durable and semi-durable goods, and non tradable consumption as the sum between consumption non durable goods and services.

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

GDP: We build a measure of tradable and non tradable GDP using sectoral data. Specifically, tradable GDP is approximated using the sum between 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 is then computed as the difference between total and tradable

GDP. We also compute a measure of tradable GDP excluding the mining sector. This data is available from 2000Q1 to 2013Q2.

Inflation: We build a measure of tradable and non tradable inflation based on the CPI of the same sectoral data as that of the GDP. These CPI measures (tradable and non tradable) are then seasonally adjusted using Census x12 and then turned to quarterly frequency by taking the value for the last month in the quarter. This CPI data is then used to compute quarterly inflation. These inflation measures are available from 1999Q2 to 2013Q2.

Deposits: We took the quarterly savings account data starting in 1984Q1 and ending in 2013Q2. We then seasonally adjust this measure using Census x12.

Interest rates: We took the monthly data for inter-bank interest rate, home building interest rate (different from social housing) and 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 is then approximated using the corporate commercial interest rate. On the other hand, the non tradable interest rate is approximated using the home building interest rate. This data is available from 2002Q2 to 2013Q2.

Appendix 5: Transitional dynamics sensitivity to country risk elasticities

Figure 15: Sensitivity of transitional dynamics of macro variables after a permanent fall in oil price
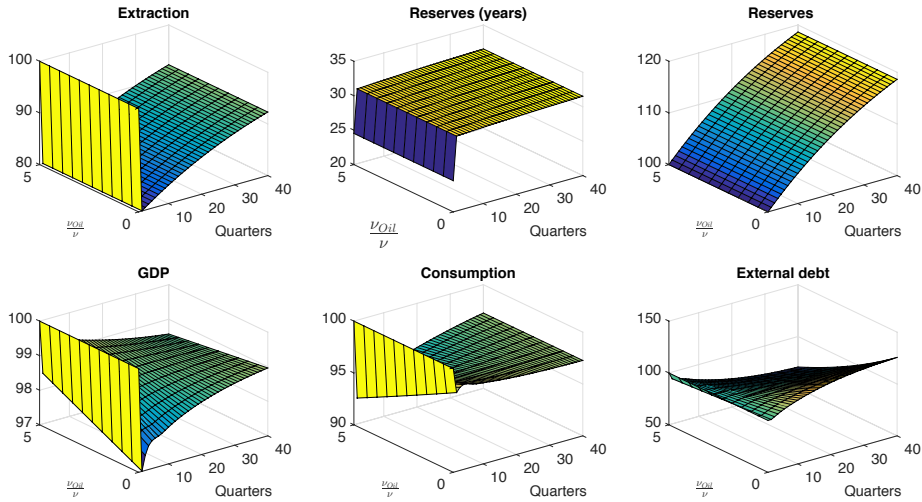

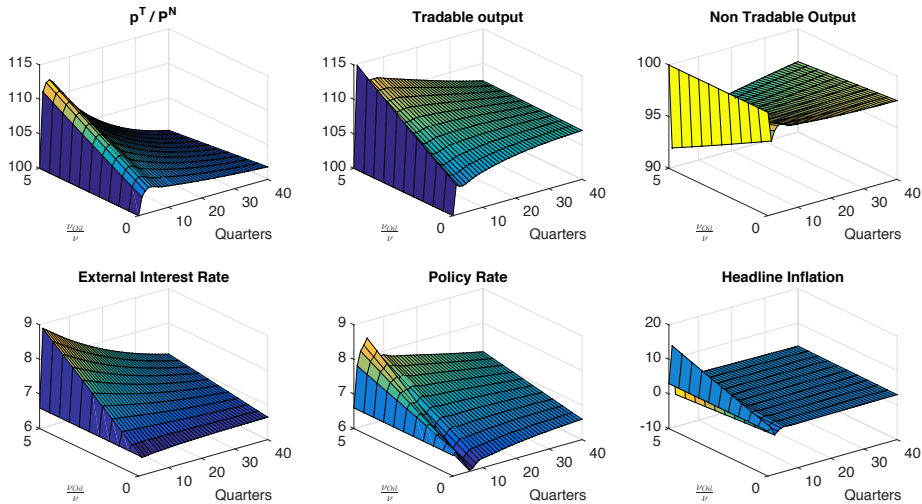Figure 16: Sensitivity of transitional dynamics of macro variables after a permanent fall in oil price

Figure 17: Sensitivity of transitional dynamics of financial variables after a permanent fall in oil price
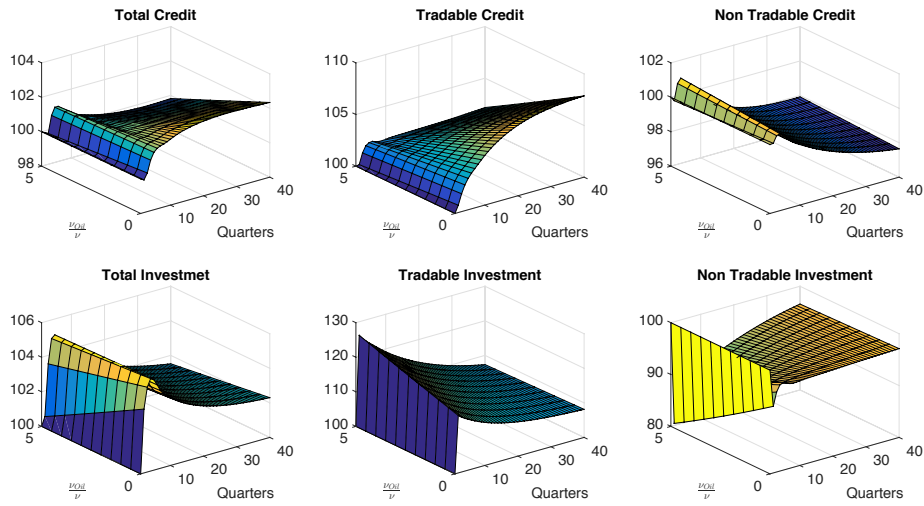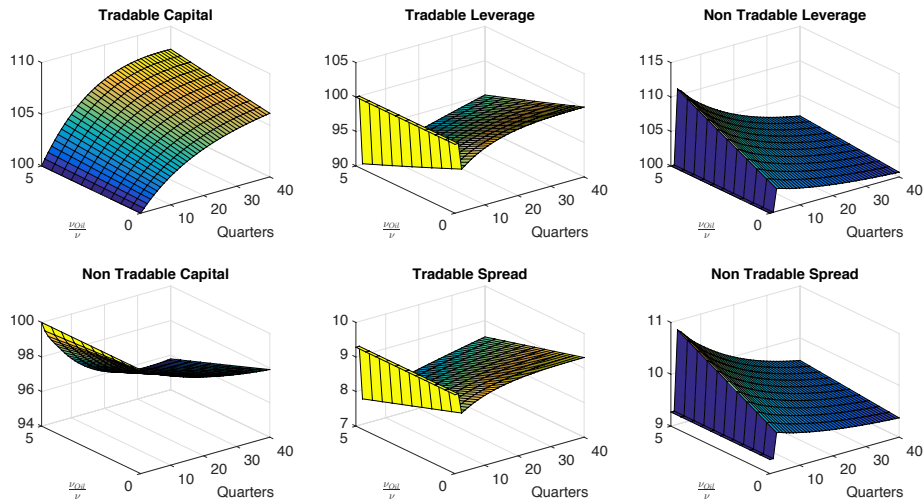

Figure 18: Sensitivity of transitional dynamics of financial variables after a permanent fall in oil price