Ciclos de negócios reais em economias "tropicais"? uma exploração bayesiana

Andrés Fernández[*]

Os modelos de economia pequena e aberta sem fricções e impulsionada unicamente por choques tecnológicos podem explicar os ciclos econômicos nos países em desenvolvimento? Não encontramos evidências que o comprovem. Construímos um modelo dinâmico e estocástico de equilíbrio geral (DSGE, pelas sues siglas em inglês) que inclui, além de choques tecnológicos, perturbações reais tais como políticas fiscais pró-cíclicas, flutuações nos termos de intercâmbio, perturbações no tipo de juros externo junto com fricções financeiras. Estimamos o modelo de uso de métodos bayesianos, com dados de alta e baixa frequência de um país em desenvolvimento —e "tropical"—: Colômbia. Encontramos que os choques no tipo de interesse são decisivos e que as fricções financeiras jogam um papel fundamental e mecanismos de propagação dos choques de tecnologia de transição. Com apenas essas duas forças é possível reproduzir as propriedades do ciclo de negócios na Colômbia. Outros choques estruturais, tais como as flutuações nos termos de intercâmbio e os câmbios de nível no processo da tecnologia, não parecem ter sido relevantes na última década e média, mas a sua importância aumenta quando se estudam dados correspondentes a um períodos de tempo mais longos.

Classificação JEL: E32, F41, F47, C11.

Palavras chave: Os ciclos econômicos, as economias em desenvolvimento, os modelos dinâmicos estocásticos de equilíbrio geral (DSGE) modelos de economia aberta e pequena, a estimativa Bayesiana.

¿Ciclos de negocios reales en economías "tropicales"? una exploración bayesiana

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¿Pueden los modelos de economía pequeña y abierta con choques tecnológicos explicar los ciclos económicos en países en desarrollo? No encontramos evidencias que lo comprueben. Construimos un modelo dinámico y estocástico de equilibrio general (DSGE, por sus siglas en inglés) que incluye, además de choques tecnológicos, perturbaciones reales tales como políticas fiscales procíclicas, fluctuaciones en los términos de intercambio, perturbaciones en el tipo de interés externo junto con fricciones financieras. Estimamos el modelo usando métodos Bayesianos con datos de alta y baja frecuencia de un país en desarrollo —y "tropical"—: Colombia. Encontramos que los choques en el tipo de interés son decisivos y que las fricciones financieras juegan un papel fundamental como mecanismos de propagación de choques tecnológicos transitorios. Con sólo estas dos fuerzas es posible reproducir las propiedades del ciclo económico colombiano. Otros choques estructurales, tales como las fluctuaciones en los términos de intercambio y los cambios de nivel en el proceso de la tecnología, no parecen haber sido relevantes en la última década y media, pero su importancia aumenta cuando se estudian datos correspondientes a períodos de tiempo más largos.

Clasificación JEL: JEL: E32, F41, F47, C11.

Palabras clave: Ciclos económicos; economías en desarrollo, modelos dinámicos, estocásticos de equilibrio general (DSGE); modelos de economía pequeña y abierta; estimación Bayesiana.

"Tropical" real business cycles?
a bayesian exploration

Andrés Fernández[*]

Can frictionless small open economy models driven solely by technology shocks account for business cycles in developing countries? We do not find evidence of it. We build a DSGE model that jointly includes a variety of real perturbations in addition to technology shocks, such as procyclical fiscal policies, terms of trade fluctuations, and perturbations to the foreign interest rate coupled with financial frictions. We estimate it using Bayesian methods on high and low frequency data from a developing —and "tropical"— country, Colombia. We find interest rate shocks to be crucial and that financial frictions play a central role as propagating mechanisms of transitory technology shocks. These two driving forces alone can account well for the observed properties of the Colombian business cycle. Other structural shocks, such as terms of trade fluctuations and level shifts in the technology process, do not appear to be relevant in the past decade and a half, but their importance increases when a longer span of data is considered.

JEL classification: E32, F41, F47, C11

Keywords: Business Cycles; Developing economies; dynamic stochastic general equilibrium models; small open economy models; Bayesian estimation.

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I.   INTRODUCTION

Understanding business cycle regularities in developing countries is a crucial step in the process of designing appropriate stabilization policies and sound macroeconomic management in developing countries. A first step toward this understanding must take into account the differences on the business cycles properties in developing countries relative to their developed counterparts. As will be shown below, observed business cycles in emerging countries are more volatile relative to their developed counterparts; their trade balance-to-output ratio is countercyclical, and consumption is more volatile than output at business cycle frequencies. Explaining these contrasts between emerging and industrialized economies is at the top of the research agenda in small-open-economy macroeconomics (Uribe, 2007).

What are the main driving forces of business cycles in developing countries? To what extent are they responsible for the differences in business cycles properties between developed and developing countries? Can technology shocks alone, in the spirit of the real business cycle literature, account for these differences? By addressing these questions, the goal of this paper is to contribute to the understanding of business cycles in developing countries.

To do so we use the following approach: First, we make a brief survey of the literature on business cycles in developing countries. As will be documented, the use of frictionless small open economy models driven solely by technology shocks has been a controversial topic in the literature on business cycles in developing countries. On one strand of the literature, some authors have claimed that, to properly account for the business cycle in these economies, one can rely exclusively on pure technology

forces in the form of transitory or permanent deviations in the total factor productivity process (e.g., Kydland and Zarazaga, 2002; Aguiar and Gopinath, 2007). Others have stressed as key driving forces the interaction between technology shocks and other real driving forces such as terms of trade (*e.g.*, Mendoza, 1995), or interest rates in world capital markets coupled with financial frictions (*e.g.*, Neumeyer and Perri, 2005). Second, we use data from Colombia, a developing —and "tropical"— economy that has not yet been analyzed by the literature surveyed above. Using both high frequency/quarterly and low frequency/yearly data, we document the similarities and differences of Colombian business cycles relative to those observed in other developing economies. Based upon these stylized facts about the Colombian business cycle, the third element of our approach is to build a dynamic stochastic general equilibrium (DSGE) model that can account for them. Motivated by the observation that, to date, there has been little empirical analysis of the role played by individual shocks —within a multiple-shock setting— in driving business cycle movements in aggregate variables from developing countries, a central element in our DSGE model is the inclusion of real driving forces other than technology shocks. Based on the literature surveyed in the next section, we include three structural driving forces to the standard neoclassical framework: (1) shocks to the interest rate in world capital markets coupled with financial frictions; (2) terms of trade fluctuations; and (3) a procyclical government spending process. While each one of the driving forces has been independently stressed by different strands of the literature on emerging market business cycles, to our knowledge, this is the first time where they will be jointly considered as alternative driving forces to technology shocks. The role of each driving force is empirically quantified by estimating the parameters of the exogenous shocks' processes, along with a few other crucial parameters, within a Bayesian framework and using Colombian macroeconomic data. Thus, we take the model as provider of a complete statistical characterization of the data in the form of a likelihood function. The performance of the model in accounting for the Colombian business cycle is then assessed.

We obtain several results of interest. The data is informative, particularly in terms of the size of the structural shocks impacting the economy. Shocks to the interest rate in world capital markets are key driving forces of the Colombian business cycle. Transitory technology shocks appear to be relevant as well, to a large extent because financial frictions amplify their macroeconomic effects in the economy. These two driving forces alone can account well for the observed properties of the Colombian business cycle, notably the smooth consumption process, the volatile investment and the strong countercyclicality of the trade balance-to-GDP ratio, and are almost

entirely responsible for the sharp macroeconomic downturn experienced in the late 1990s. Other structural shocks, such as terms of trade fluctuations and level shifts in the technology process, do not appear to be relevant in the past decade and a half, but their importance increases when a longer span of data is considered. Demand shocks, in the form of government consumption innovations, account only for a trivial role of the variance of the macroeconomic aggregates, but they appear to be relevant for the out-of-sample forecasting fit of the model.

The paper is divided into six sections, including this introduction. The second section presents a brief review of the theoretical and empirical literature on business cycles in developing countries and describes the main aspects of the Colombian business cycle. The third section lays out the model. The fourth section describes the Bayesian estimation. The fifth section presents the results. Concluding remarks are given in the sixth section[1].

II.   BUSINESS CYCLES IN DEVELOPING COUNTRIES

A.   A BRIEF LITERATURE REVIEW

As mentioned above, business cycles in developing countries are different from the ones observed in developed countries. Using the dataset by Aguiar and Gopinath (2007) for a sample of thirteen developed and thirteen developing countries, Table 1 presents the main second moments for these two groups of countries. Comparing the upper and middle panels in Table 1, three dimensions in which these differences manifest are: (1) observed business cycles in emerging countries are more volatile; (2) the trade balance-to-output ratio is more countercyclical in emerging countries than in developed countries; and (3) consumption appears to be more volatile than output at business cycle frequencies. These stylized facts, among others, have been widely documented in Mendoza (1995), Agenor et al. (2000), Rand and Tarp (2002), Neumayer and Perri (2005), Aguiar and Gopinath (2007) and Garcia-Cicco *et al.* (2010).

A brief review of the literature does not show a consensus on the best approach to account for the differences observed in developing and developed economies' business

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1 An appendix with details on the data and the MATLAB codes used in this paper can be downloaded from the author's website, http://econweb.rutgers.edu/afernandez/RESEARCH.htm

cycles. One strand of the literature has tried to explain business cycles in developing economies within a neoclassical growth framework augmented by real driving forces that interact with technology shocks. Mendoza (1995) expands a real business cycle model to account for tradable/nontradable goods in which the terms of trade are an additional driving force. Since emerging countries typically specialize in exports of few primary commodities —for which they are small players in the world markets for the goods they export or import—, it follows that the terms of trade can be regarded as an exogenous source of aggregate fluctuations. Mendoza (1995) finds they account for 45 to 60 percent of the observed variability of GDP.

Table 1
Business Cycles Moments

Variable	$sd(X)$	$sd(X)/sd(gY)$	$Corr(X_t, X_{t-1})$	$Corr(X_t, gY_{t-s})$			$Corr(X_t, dTBY_t)$
				s = 1	s = 0	s = -1	
Developed Countries							
gY	0.97	1.00	0.10	0.10	1.00	0.10	0.06
gC	0.87	0.91	0.07	0.17	0.43	0.19	-0.18
gI	3.41	3.50	0.06	0.17	0.46	0.22	-0.29
dTBY	0.98	1.07	-0.15	-0.12	0.06	-0.10	1.00
Developing Countries							
gY	1.87	1.00	0.23	0.23	1.00	0.23	-0.27
gC	2.82	1.62	0.11	0.21	0.53	0.21	-0.51
gI	7.14	4.13	0.11	0.34	0.51	0.22	-0.45
dTBY	2.49	1.56	0.11	-0.24	-0.27	-0.21	1.00
Colombia							
gY	1.22	1.00	0.20	0.20	1.00	0.20	-0.53
gC	0.83	0.67	0.33	0.36	0.65	0.34	-0.49
gI	6.05	4.94	0.25	0.29	0.81	0.11	-0.84
dTBY	1.05	0.86	0.30	-0.43	-0.53	-0.16	1.00
gR*	0.46	0.37	0.05	0.00	0.03	-0.21	-0.11
gToT	5.29	4.32	0.12	0.01	0.33	0.09	-0.39
gG	2.29	1.87	0.30	0.07	0.17	0.06	0.06

Note: gX and dX denote log differences and linear difference, respectively. Y is output; C is private consumption; I is investment; TBY is trade balance-to-GDP ratio; R* is a proxy for the gross risky interest rate available to emerging economies similar to Colombia; ToT is a proxy of Colombian terms of trade index; and G is the level of public consumption. The source of data for Developed and Developing countries was Aguiar and Gopinath (2007). Colombian data is quarterly from 1994:1 to 2008:4. For more details on the data see the Appendix at the author's website.

The argument of stronger real shocks has also been extended to financial markets. The motivation for this idea comes from the fact that developing economies often exhibit low levels of aggregate savings, forcing them borrow heavily in international financial markets. Under these conditions, perturbations in financial markets may have potentially large and destabilizing real effects in developing economies. Uribe and Yue (2006) explore the significant correlation between the business cycles in emerging markets and the interest rate that these countries face in international financial markets. They find that one third of business cycles in emerging economies is explained by disturbances in external financial variables (*e.g.*, the foreign interest rate and the spread). Moreover, they find evidence of a further increase in the volatility of domestic variables because of the presence of a feedback mechanism from domestic variables to country spreads. Similarly, Neumayer and Perri (2005) find that eliminating country risks lowers Argentine output volatility by 27%.

Another strand of research for some of the stylized facts of business cycles in developing economies explores the role of macroeconomic policies in amplifying the cycle, as documented by Agenor *et al.* (2000), and Kaminsky *et al.* (2004). These works have identified fiscal policies that are procyclical (i.e., government spending increases in good times and falls in bad times) for the majority of developing countries. Thus, it is likely that such policies further amplify aggregate fluctuations, causing the differences in business cycle between developing and developed economies.

In line with the real business cycle literature, some authors have relied exclusively on pure technology forces when accounting for the business cycle in developing economies. Kydland and Zarazaga (2002) argue that nominal factors do not seem to be able to account for any significant fraction of the business cycles in Latin-American countries, in general. They argue that, in the case of Argentina, the predictions of a standard neoclassical growth model driven solely by stationary technology shocks, conform rather well to the observations during the Argentinean "lost decade" years. More recently, Aguiar and Gopinath (2007) have claimed that shocks to the productivity trend growth are the primary source of fluctuations in emerging markets. Their underlying premise is that such shocks capture frequent regime switches motivated mainly by dramatic reversals in economic policy in these economies. Thus, the higher volatility of consumption can be explained as agents seeking to smooth their consumption levels (observe changes in the permanent component of the trend). Aguiar and Gopinath´s conclusion is driven by an estimated volatility of the technological growth process in the Mexican economy, four to five times higher than the volatility

of the transitory technology shock. In another paper, Aguiar and Gopinath (2006) find this result to be robust under the presence of stochastic interest rate shocks.

The idea that developing countries' business cycles are, by and large, driven by shifts in the productivity level has, nonetheless, received criticism in the recent literature. Garcia-Cicco *et al.* (2010) have argued that in order to properly estimate the parameters of the stochastic trend, long time series are needed. Accordingly, they estimate the Aguiar and Gopinath model on a yearly dataset for Argentina —covering over a century of aggregate data— and find that the model performs poorly when trying to mimic some of the main moments in the Argentinian macroeconomic data, in particular the higher volatility of consumption and the trade balance autocorrelation function. They show how an expanded model that includes other structural shocks can overcome these empirical shortcomings. In the same line, Chang and Fernández (2010) show that a model with foreign interest rate shocks and financial frictions outperforms the Aguiar and Gopinath model if a ranking is made using the models' marginal likelihood functions.

B.   THE COLOMBIAN BUSINESS CYCLES

The lower panel of Table 1 presents the second moments in the main Colombian quarterly macroeconomic aggregates for the period 1994:1 to 2008:4. Colombian data is characterized by some of the main stylized facts from the sample of developing economies highlighted in the middle panel of Table 1. Relative to developed economies, there is a higher macroeconomic volatility measured by the variance of output, and the trade balance share is significantly more countercyclical, even when compared to the average developing country. The latter is almost entirely driven by the properties of the time series for investment, which exhibit a much higher volatility relative to that of output. There is, however, no evidence of a high volatility of Colombian aggregate consumption. In fact, the standard deviation of consumption appears even lower than the one observed for the average developed country. Importantly, when computing second moments from Colombian data we exclude durable (and semidurable) goods consumption from aggregate consumption, and include it on investment as it is standard in business cycles analysis (see Cooley and Prescott,

1996). It should be noted, however, that the low volatility of consumption with respect to output does not depend on this transformation[2].

The last three rows in Table 1 present additional data on three potential driving forces of the Colombian business cycle that will be included in the theoretical model presented in the next section: (1) gR^*, a proxy for the growth in the gross risky interest rate that countries similar to Colombia have faced in international capital markets, computed adding the real interest rate on US, T-Bills and the average EMBI+ spreads for Latin-American economies; (2) $gToT$, a proxy for the growth in the terms of trade faced by Colombian consumers and firms; and (3) the growth in the level of public consumption[3]. Three key stylized facts emerge from the analysis of the second moments of these three variables. First, the interest rate is countercyclical and leads the cycle, the same pattern that Neumeyer and Perri (2005) documented for a pool of emerging economies. Second, the terms of trade are highly volatile and procyclical, with a correlation of 0.33 with Colombian GDP, which is close to the value found by Mendoza (1995) for a pool of developing countries (0.39). Third, while government expenditure is procyclical, its correlation with output growth (0.17) is lower when compared to studies that have looked at other developing countries, *e.g.*, Kaminsky *et al.* (2004).

To summarize, business cycles in Colombia —within the last decade and a half— are characterized by (1) a moderately high variance of output; (2) a trade balance share of income strongly countercyclical; (3) a significantly volatile level of investment; (4) a smooth aggregate consumption path; (5) a leading and countercyclical interest rate in world capital markets; (6) volatile and procyclical terms of trade; and (7) a moderately procyclical government expenditure. The following sections will build and estimate a business cycle model of the Colombian economy and its performance will be assessed along these dimensions, among others.

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2 If aggregate consumption is measured including consumption of durable and semidurable goods (as reported by DANE), the standard deviation of consumption growth increases only to 1.04, which is still lower than the output's volatility. It is not specified in Aguiar and Gopinath (2007) whether they also remove durable goods consumption from the aggregate consumption data they report.

3 For more details on the data see the Appendix at the author's website.

III.   A BUSINESS CYCLE MODEL FOR A SMALL, OPEN, AND "TROPICAL" ECONOMY

The model presented here is built following the canonical real business cycle model of a small open and centralized economy, first developed by Mendoza (1991). A decentralized version of this model was extended by Chang and Fernández (2010) by introducing permanent shocks to technology, as discussed by Aguiar and Gopinath (2007), and foreign interest rate shocks that interact with financial imperfections, as discussed by Neumeyer and Perri (2005) and Uribe and Yue (2006). In what follows, we modify the model by Chang and Fernández (2010) in two dimensions: first, we allow for the presence of domestically produced and foreign consumption and investment goods; second, we include the presence of a procyclical government expenditure process.

A.   FIRMS AND TECHNOLOGY

Time is discrete and indexed by $t = 0, 1, 2, \ldots$ The domestic good is produced by a representative firm in each period with a Cobb-Douglas technology given by:

$$Y_t = a_t K_t^{1-\alpha} (\Gamma_t h_t)^\alpha \tag{1}$$

where Y_t denotes output, K_t capital available in period t, h_t labor input. We use upper case letters to denote variables that trend in equilibrium, and lower case letters to denote variables that do not[4]. The exogenous variables a_t and Γ_t represent productivity processes to be specified later.

The firm hires labor for which it pays a wage, W_t, per worker and rents capital in competitive markets at a rental rate, u_t. It faces a friction in the technology for transferring resources to its workers: in order to hire workers, the firm needs to set aside a fraction θ of the wage bill, $W_t h_t$, at the beginning of each period. Thus, because it is assumed that production becomes available at the end of each period, the firm has to borrow $\theta W_t h_t$ in international markets, for which it has to pay an interest rate of equilibrium at the end of the last period, R_{t-1}. There are no frictions in the market for capital. When output becomes available firms use the resources to honor the remaining

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4 The only exceptions will be the spread, S_t, and the world and domestic gross interest rates, R_t^* and R_t, to be defined later, which do not trend in equilibrium.

debts to workers, $(1-\theta)W_t h_t$, and to the financial system $\theta W_t h_t R_{t-1}$, and pay for rented capital, $u_t K_t$.

Given W_t, u_t and R_{t-1}, the firms' problem is to choose labor and capital in order to maximize profits, Π_t, given by:

$$\Pi_t = Y_t - W_t h_t - u_t K_t - (R_{t-1} - 1)\theta W_t h_t$$

subject to the technology available given by (1). The firms' two profit maximizing conditions are then given by:

$$u_t = a_t (1-\alpha) K_t^{-\alpha}(\Gamma_t h_t)^\alpha \tag{2}$$

$$W_t[1 + \theta(R_{t-1} - 1)] = a_t \alpha K_t^{1-\alpha}(\Gamma_t h_t)^{\alpha-1}\Gamma_t \tag{3}$$

where the latter implies that the marginal product of labor equals the wage rate inclusive of financing costs. This assumption, first introduced in the literature on business cycles in emerging markets by Neumeyer and Perri (2005), allows for changes in real interest rates to have real supply side effects.

B.   HOUSEHOLDS

Households own the capital and labor stock available in the economy. At the beginning of each period, a representative household supplies labor and rents its capital to firms in competitive markets. At the end of the period, the household receives the salary and rent resources from the two inputs and makes consumption and investment decisions. These decisions are made according to the household's preferences that we assume of the GHH type, following the work by the Greenwood, Hercowitz and Huffman (1988):

$$E\sum_{t=0}^{\infty} \beta^t \frac{(C_t - \tau\Gamma_{t-1}h_t^\omega)^{1-\sigma}}{1-\sigma} \tag{4}$$

where β is a discount factor between zero and one, C_t denotes consumption and $E(.)$ is the expectation operator. As discussed by Neumeyer and Perri (2005) and others, GHH preferences have been shown to help reproducing some emerging economies' business cycles facts by allowing the labor supply to be independent of consumption

levels. We follow Aguiar and Gopinath (2007) in including Γ_{t-1} in the period utility function to allow for balanced growth.

The resources used for gross investment cover the net increase in the capital stock, the depreciated capital and the costs incurred by adjusting capital, as follows:

$$I_t = K_{t+1} - K_t + \delta K_t + \frac{\phi}{2} \left(\frac{K_{t+1}}{K_t} - \mu \right)^2 \tag{5}$$

where the last term is a quadratic capital adjustment cost function that is a standard device in business cycle models in order to avoid excessive volatility of investment.

Given that households can also consume goods produced abroad which are assumed to be imperfect substitutes with domestically produced goods, consumption will be defined by an aggregator function:

$$C_t = \left[\gamma_C^{1/v_c} \left(C_t^F \right)^{\frac{v_c - 1}{v_c}} + (1 - \gamma_C)^{1/v_c} \left(C_t^H \right)^{\frac{v_c - 1}{v_c}} \right]^{\frac{v_c}{v_c - 1}}, \quad \gamma_C \in (0, 1), \ v_c > 0 \tag{6}$$

where C_t^F and C_t^h are "respectively" the consumption levels of foreign and domestic goods, γ_C is the share of consumption of foreign goods in total consumption, and v_c is the elasticity of substitution between home and foreign goods. Total real expenditure on consumption can be written as follows:

$$p_t^C C_t = p_t^H C_t^H + p_t^F C_t^F \tag{7}$$

where p_t^C is the aggregate price level of consumption; p_t^H and p_t^F are, respectively, the price levels of home and foreign goods. Clearly, only two of these prices are independent, so we choose to express every price in terms of the foreign goods, noting that $p_t^H/p_t^F \equiv tot_t$ is therefore the terms of trade of this economy, which we assume to follow an exogenous process. Given predetermined levels of aggregate consumption and relative prices, the household's intratemporal problem is to maximize (6) subject to (7), with associated optimality conditions:

$$C_t^H = C_t(1 - \gamma_C)(p_t^{HC})^{-v_c} \tag{8}$$

$$C_t^F = C_t \gamma_C (p_t^{FC})^{-v_c} \tag{9}$$

and $p_t^{HC} \equiv p_t^H/p_t^C$, $p_t^{FC} \equiv p_t^F/p_t^C$, are relative prices that can be shown, after some algebra, to be determined by the terms of trade, as follows:

$$p_t^{HC} = \left[\gamma_C tot_t^{v_c-1} + (1 - \gamma_C) \right]^{\frac{1}{v_c-1}} \tag{10}$$

$$p_t^{FC} = \left[\gamma_C + (1 - \gamma_C) tot_t^{1-v_c} \right]^{\frac{1}{v_c-1}} \tag{11}$$

Households can also invest in home goods or foreign investment goods. Thus, gross investment will also be defined by an aggregator function:

$$I_t = \left[\gamma_I^{1/v_I} (I_t^F)^{\frac{v_I-1}{v_I}} + (1 - \gamma_I)^{1/v_I} (I_t^H)^{\frac{v_I-1}{v_I}} \right]^{\frac{v_I}{v_I-1}}, \gamma_I \in (0,1), \ v_I > 0$$

where I_t^F and I_t^H are respectively, the investment levels of foreign and domestic goods, γ_I is the share of investment in foreign goods in total investment, and v_I is the elasticity of substitution between home and foreign investment goods. Total real investment can be written as follows:

$$p_t^I I_t = p_t^H I_t^h + p_t^F I_t^F \tag{12}$$

It is thus straightforward to see that the optimality conditions for investment will be similar to the ones for consumption:

$$I_t^H = I_t(1 - \gamma_I)(p_t^{HI})^{-v_I} \tag{13}$$

$$I_t^F = I_t \gamma_I (p_t^{FI})^{-v_I} \tag{14}$$

$$p_t^{HI} = \left[\gamma_I tot_t^{v_I-1} + (1 - \gamma_I) \right]^{\frac{1}{v_I-1}} \tag{15}$$

$$p_t^{FI} = \left[\gamma_I + (1 - \gamma_I) tot_t^{1-v_I} \right]^{\frac{1}{v_I-1}} \tag{16}$$

Having specified the intratemporal problem of the household, we are ready to specify the household's sequential budget. Recalling that the representative agent has access to a world capital market for one-period noncontingent debt, the budget constraint is, therefore:

$$p_t^{HC} W_t h_t + p_t^{HC} u_t K_t + p_t^{FC} q_t D_{t+1} = C_t + p_t^{IC} I_t + p_t^{FC} D_t + p_t^{HC} T_t \tag{17}$$

where the first two terms in the LHS are labor and capital income in period t in terms of consumption goods. In addition, q_t is the price at which the household can sell a promise of a unit of goods to be delivered at $t + 1$, while D_{t+1} is the number of such promises issued. The first three terms in the RHS describe expenditures in period t, given by consumption, investment, and debt payments; where:

$$p_t^{IC} = p_t^{FI} / p_t^{FC} \tag{18}$$

and the last term is given by lump sum taxes paid to the government.

The household chooses consumption, labor, next period debt, and capital to maximize its utility function (4) subject to the sequential budget constraint (17), the capital law of motion (5) and a no-Ponzi condition of the form:

$$\lim_{j \to \infty} \frac{E_t D_{t+j}}{R^j} \leq 0 \tag{19}$$

Letting λ_t denote the Lagrange multiplier associated with the sequential budget constraint, the first order conditions of the household's maximization problem are (17), (5), (19), holding with equality, and

$$\lambda_t = (C_t - \tau \Gamma_{t-1} h_t^\omega)^{-\sigma} \tag{20}$$

$$\tau \Gamma_{t-1} \omega h_t^{\omega-1} = p_t^{HC} W_t \tag{21}$$

$$\lambda_t p_t^{FC} q_t \Gamma_{t-1}^{-\sigma} = \beta \Gamma_t^{-\sigma} E_t \lambda_{t+1} p_{t+1}^{FC} \tag{22}$$

$$
\begin{aligned}
& p_t^{IC} \lambda_t \left[1 + \phi \left(\frac{K_{t+1}}{K_t} - \mu \right) \right] \Gamma_{t-1}^{-\sigma} \\
= \ & \beta \Gamma_t^{-\sigma} E_t \lambda_{t+1} \left[p_{t+1}^{HC} u_{t+1} + p_{t+1}^{IC} (1 - \delta) + p_{t+1}^{IC} \frac{\phi}{2} \left(\left(\frac{K_{t+2}}{K_{t+1}} \right)^2 - \mu^2 \right) \right]
\end{aligned} \tag{23}
$$

C.   GOVERNMENT

The government in this economy simply sets taxes equal to an exogenous level of government expenditure in each period:

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$$T_t = GOV_t \tag{24}$$

Finally, note that, in equilibrium, the trade balance-to-output ratio will be determined as follows:

$$TBY_t = \frac{Y_t - C_t - I_t - GOV_t}{Y_t} \tag{25}$$

D.   INTEREST RATES AND COUNTRY RISK

We close the model by providing a simple theory for R_t, the interest rate faced by emerging economies, following Neumeyer and Perri (2005) and Chang and Fernández (2010). First, the price of the household's debt is assumed to be given by a debt-elastic interest rate function:

$$1/q_t = R_t + \psi \left[\exp(\frac{D_{t+1}}{\Gamma_t} - d) - 1 \right] \tag{26}$$

where R_t is the specific rate at which international investors are willing to lend to the small, open, and tropical economy. Formally, this interest rate is defined as follows:

$$R_t = S_t R_t^* \tag{27}$$

where R_t^* is the world interest rate for risky asset and S_t is the country specific spread over that rate, both of which will be assumed to be a stochastic process to be defined next.

E.   DRIVING FORCES

There will be five sources of uncertainty in this economy. First, the transitory technology process is assumed to follow an AR(1) process in logs:

$$\log a_t = \rho_a \log a_{t-1} + \varepsilon_t^a \tag{28}$$

where $\mid \rho_a \mid < 1$ and ε_t^a is an i.i.d. shock with mean zero and variance σ_a^2.

Second, Γ_t is a term allowing for labor augmenting productivity growth. Following Aguiar and Gopinath (2007), we allow it to grow at a stochastic growth rate, g_t. Formally:

$$\Gamma_t = g_t \Gamma_{t-1} \tag{29}$$

where

$$\ln(g_{t+1}/\mu) = \rho_g \ln(g_t/\mu) + \varepsilon_{t+1}^g \tag{30}$$

$\mid \rho_g \mid < 1$, ε_t^g is an i.i.d. process with mean zero and variance σ_g^2, and μ represents the mean value of labor productivity growth. A positive realization of ε_t^g implies that the growth of labor productivity is temporarily above its long-run mean. Such a shock, however, is incorporated in Γ_t, and hence, results in a permanent productivity improvement.

Third, deviations of the world interest rate for risky assets, R_t^*, from its long-run level are assumed to follow an AR(1) process:

$$\ln \left(R_t^*/R^* \right) = \rho_r \ln \left(R_{t-1}^*/R^* \right) + \varepsilon_t^r \tag{31}$$

where $\mid \rho_r \mid < 1$ and ε_t^r is an i.i.d. innovation with mean zero and variance σ_r^2. Following Chang and Fernandez (2009), we allow for both permanent and transitory shocks to affect the country specific spread. To implement this idea, we assume that deviations of the country spread from its long-run level are functions of deviations in the total factor productivity (Solow residual):

$$\log(S_t/S) = -\eta E_t \log(sol_{t+1}/sol) \tag{32}$$

where sol_t is the Solow residual, defined as $sol_t = a_t g_t^a$ and $sol = \mu^\alpha$.

Fourth, the terms of trade are assumed to evolve according to a simple AR(1) process in logs:

$$\log tot_t = \rho_{tot} \log tot_{t-1} + \varepsilon_t^{tot} \tag{33}$$

where $|\rho_{tot}| < 1$ and ε_t^{tot} is an i.i.d. shock with mean zero and variance σ_{tot}^2. Importantly, this specification differs from Mendoza (1995) in that we do not allow for domestic productivity and terms of trade to be correlated.

Finally, following Canova (2007), the government expenditure process is assumed to be a function of its own past and lagged deviations in the level of output. Formally:

$$\ln(GOV_{t+1}/GOV) = \rho_{gov}\ln(GOV_t/GOV) + \rho_{GY}\ln(Y_t/Y) + \varepsilon_{t+1}^{Gov} \qquad (34)$$

where $|\rho_{gov}| < 1$ and ε_t^{gov} is an i.i.d. shock with mean zero and variance σ_{gov}^2, and $\rho_{GY} \in \mathbb{R}$ is intended to capture the degree of procyclicality of public expenditure documented for developing economies.

F.   COMPETITIVE EQUILIBRIUM

A competitive equilibrium path for this economy is a set of stationary processes along a balanced growth path for twelve allocations:

$$\{Y_t, K_t, D_t, C_t, C_t^H, C_t^F, I_t, I_t^H, I_t^F, h_t, TBY_t, T_t\}_{t=0}^{\infty}$$

and ten relative prices:

$$\{R_t, q_t, \lambda_t, W_t, u_t, p_t^{HC}, p_t^{HI}, p_t^{FC}, p_t^{FI}, p_t^{IC}\}_{t=0}^{\infty}$$

satisfying the three optimality conditions for firms, (1)-(2)-(3); the fifteen intratemporal and intertemporal optimality conditions for the household (5)-(8)-(9)-(10)-(11)-(13)-(14)-(15)-(16)-(17)-(18)-(20)-(21)-(22)-(23); the government balanced budget rule (24); the trade balance-to-output definition (25); and the country specific interest rate and spread processes (26)-(27), given the initial conditions for K_0 and D_0, Γ_{-1} and the stochastic processes $\{a_t, \Gamma_t, g_t, R_t^*, tot_t, GOV_t, sol_t\}_{t=0}^{\infty}$.

IV.   ESTIMATION

We follow a Bayesian estimation strategy that has been increasingly used in the estimation of dynamic stochastic general equilibrium models[5]. The following sections briefly describe the estimation technique.

A.   BAYESIAN ESTIMATION FRAMEWORK

We normalize the variables that trend in equilibrium by dividing them by the (lagged) trend level, Γ_{t-1}. Following Schmidt-Grohe and Uribe (2004), the stationary dynamic system of equations is log-linearized and written in the canonical state-space form:

$$
\begin{aligned}
x_{1,t+1} &= M(\Theta) x_{1t} + v_{t+1} \\
x_{2,t} &= C(\Theta) x_{1,t}
\end{aligned}
\tag{35}
$$

where $\{x_1, x_2\}$ are, respectively, state and control variable vectors, v_{t+1} is a vector of structural perturbations, and the matrices $M(\Theta)$ and $C(\Theta)$ are a function of the vector of structural parameters, Θ. This system can be compactly written as a law of motion equation:

$$
\Psi_{t+1} = \Phi(\Theta)\Psi_t + Bv_{t+1}
\tag{36}
$$

On the other hand, having observed a time series data on a vector X_t, it can be expressed as a noninvertible linear combination of the state variables in a measurement equation:

$$
X_t = \Gamma\Psi_t + \epsilon_t
\tag{37}
$$

where Γ is a conformable matrix that maps the observable time series of the elements X_t to their theoretical counterparts in Ψ_t, while ϵ_t are exogenous i.i.d. measurement errors. Equations (36) and (37) are the starting point for a time invariant Kalman filter with which one can recursively construct the likelihood function over the T data points of X_t:

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5 See An and Schorfheide (2007) for an excellent survey of the theory and applications on Bayesian estimation of DSGE models. For a textbook explanation see also DeJong and Dave (2007).

$$\mathcal{L}\left(X|\Theta\right) = \prod_{t=1}^{T} \mathcal{L}\left(X_t|\Theta\right) \tag{38}$$

From a Bayesian perspective, the observation of X is taken as given and inference regarding Θ centers on statements regarding probabilities associated with alternative specifications on Θ conditional on X. By satisfying the likelihood principle, the Bayesian approach uses all information from the data to make the probability statements on Θ. Bayes' theorem is used to update our beliefs about Θ. Formally:

$$p(\Theta \mid X) \propto p(\Theta)\mathcal{L}(X \mid \Theta) \tag{39}$$

where $p(\Theta)$ is the prior distribution. The posterior distribution then allows us to make probability statements regarding the unknown parameters in our model.

As mentioned in the introduction, we use as a benchmark quarterly data from Colombia from 1994:1 to 2008:4 with four macroeconomic aggregates: gross domestic product (Y), consumption (C), investment (I), and the trade balance-to-GDP (TBY_t)[6]. While the first three are observed in log-differences, the latter is observed in first differences. Hence, the observation of X is:

$$X = \{\Delta \ln Y_t, \Delta \ln C_t, \Delta \ln I_t, \Delta TBY_t\}_{t=1994:1}^{2008:4} \tag{40}$$

and the system of measurement equations (37) is:

$$
\begin{aligned}
\Delta \ln Y_t &= \ln \mu + (\hat{y}_t - \hat{y}_{t-1}) + \hat{g}_{t-1} + \epsilon_t^{Y} \\
\Delta \ln C_t &= \ln \mu + (\hat{c}_t - \hat{c}_{t-1}) + \hat{g}_{t-1} + \epsilon_t^{C} \\
\Delta \ln I_t &= \ln \mu + (\hat{i}_t - \hat{i}_{t-1}) + \hat{g}_{t-1} + \epsilon_t^{I} \\
\Delta TBY_t &= \widehat{tby}_t - \widehat{tby}_{t-1} + \epsilon_t^{TBY}
\end{aligned}
\tag{41}
$$

where ϵ_t^{N} is the distributed i.i.d. measurement error with mean zero and variance $\sigma_N^2, N = Y, C, I, TBY$.

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6 For more details on the data see the Appendix at the author's website.

In order to report posterior statistics we need to be able to make random draws from the posterior distribution. For this, we will make use of advances in Monte Carlo Markov Chain (MCMC) theory to get dependent draws from the posterior distribution, $p(\Theta \mid X)$. We follow, for the most part, the random walk Metropolis algorithm presented in An and Schorfheide (2007) to generate draws from the posterior distribution $p(\Theta \mid X)$. The algorithm constructs a Gaussian approximation around the posterior mode, which we first find via a numerical optimization of $\ln \mathcal{L}(X \mid \Theta) + \ln p(\Theta)$, and use a scaled version of the inverse of the Hessian computed at the posterior mode to efficiently explore the posterior distribution in the neighborhood of the mode. It proved useful to repeat the maximization algorithm using random starting values for the parameters drawn from their prior support in order to gauge the possible presence of many modes in the posterior distribution[7]. Once this step is completed, the algorithm is used to make 150,000 draws from the posterior distribution of each case. The initial 50,000 draws are discarded.

Once $p(\Theta \mid X)$ is approximated, point estimates as well as confidence intervals of the parameters can be obtained from the generated draws, in addition to functions of these parameters. Given that one of our goals is to assess the relative role of each driving force, two of these functions we will be particularly interested in are structural variance decompositions and impulse responses.

B. BENCHMARK CALIBRATION AND PRIORS

We choose to calibrate some of the deep parameters in the model while we estimate the rest. The choice of which parameters to estimate or calibrate is guided by the objectives of our investigation, which is the study of the sources of fluctuations. For that reason we estimate the parameters of the five exogenous driving forces along with other key parameters in determining business cycles. Formally, let $\Theta = [\Theta_1, \Theta_2]'$, where Θ_1 is the vector of parameters that we calibrate:

$$\Theta_1 = [\sigma, \omega, \mu, \psi, \delta, d]' \tag{42}$$

The calibrated parameters are given in Table 2 and take conventional values. The coefficient of relative risk aversion is set at 2, and ω is set so as to imply a labor supply

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7 The MATLAB codes that solve all the model's extensions, as well as the ones that carry out the estimation, are at the author's website.

elasticity of 1.6. The labor's share of income is set to be 68 percent[8]. We calibrate the long-run productivity growth, μ, equal to 1.0077, consistent with a mean yearly GDP growth rate of 3.1 percent in the dataset. As it is common in the literature on small open economy models, we set the parameter ψ, determining the interest rate elasticity to debt, to a minimum value that guarantees the equilibrium solution to be stationary (Schmitt-Grohe and Uribe, 2003). The quarterly depreciation rate is assumed to be 20 percent so as to get an investment to GDP ratio close to 0.3, as it is observed in Colombian data. We calibrate d, the debt-to-GDP ratio, to 0.23, the average of external debt as fraction of output in Colombia reported by Avella (2004). The steady state values of some of the variables in the model are also set according to long-run means in the data. We calibrate the government expenditure-to-GDP ratio to 0.19, and the annualized gross risky interest rate to 1.0816. We assume that there is no spread in the steady state, $S = 1$, and that τ is endogenously determined so as to match a third of the time spent working in the long run, *h = 1/3*. Under this parameterization, the discount factor is pinned down in steady state to be $\beta = 0.9976$.

The vector Θ_2 gathers the other twenty two parameters we estimate:

$$\Theta_2 = \left[\begin{array}{c} \rho_a, \rho_g, \rho_r, \rho_{gov}, \rho_{tot}, \sigma_a, \sigma_g, \sigma_r, \sigma_{gov}, \sigma_{tot}, \\ \phi, \sigma_Y, \sigma_C, \sigma_I, \sigma_{TBY}, \theta, \gamma_C, \gamma_I, \eta, \upsilon_C, \upsilon_I, \rho_{GY} \end{array} \right]' \tag{43}$$

Our prior beliefs over the estimated parameters are described in Table 3 and follow an agnostic approach as rather diffuse priors are assumed. All the priors over the AR(1) coefficients in the five stochastic processes are assumed to be distributed with a Beta distribution with mean 0.16 and a large standard deviation of 16 percent. The priors over the standard deviation of both the structural shocks and the data measurement errors are assumed to be distributed with a Gamma distribution with mean 2 percent and a standard deviation of 1 percent. The capital adjustment cost parameter is assumed to be distributed with a Beta distribution with mean 6 and a standard deviation of 346 percent.

Previous studies provide little statistical information on the size of the elasticity of the spread to the country's fundamentals, η, and the fraction of the wage bill held as working capital, θ. We use a Gamma distribution with mean of 1.0 and a standard

---

8 Note that because of the presence of working capital requirements, α is not exactly equal to labor share but it is rather calibrated as α = *LaborShare**[1+(R - 1)θ]. Thus, it will have an entire distribution determined by the posterior distribution of θ.

Table 2
Calibrated Parameters

Parameter	Description	Calibrated Value
$\sigma_,$	Intertemporal Elasticity of Substitution [$1/\sigma$]	2.0
ω	Labor Supply Elasticity $\left[\frac{1}{\omega-1}\right]$	1.6
h-Share	Labor Share of Income	0.68
R*	Gross Annual Foreign Interest Rate	1.0816
μ	Long-run Gross Productivity Growth Rate	1.0077
Ψ	Debt Elastic Interest Rate Parameter	0.001
β	Discount Factor	0.9976
S	Long-run Gross Country Interest Rate Premium	1.0
$\delta_,$	Depreciation Rate of Capital	0.20
d	Debt-to-GDP Ratio *(D/Y)*	0.100
G/Y	Government Expenditure Share of Income	0.19
h	Labor in steady state	1/3

deviation of 50 percent for η, close to the value calibrated by Neumeyer and Perri (2005) to match the volatility of the interest rate faced by Argentina's residents in international capital markets. As for θ, we decided to specify a very diffuse prior, with the only restriction that it must lie between zero and one. For this purpose we used a Beta distribution with mean 0.5, and a considerable standard deviation of 22.4 percent.

The weight of importables in the consumption and investment aggregator functions are assumed to be distributed with a Beta function with mean 0.2 and a 10 percent standard deviation. This is motivated by the fact that imports are between 15-25 percent of total GDP in Colombia. The elasticity of substitution in the aggregator of both functions is chosen to be a Gamma distribution with mean 1.0 and a large standard deviation of 50 percent. Finally, the parameter governing the degree of countercyclicality in government expenditure is chosen to be normally distributed with mean 0.0 and a standard deviation of 100 percent.

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Table 3
Prior Distributions

	Parameter	Range	Density	Mean	S.D (%)	90% Conf. Interval
ρ_S	AR(1) Coeff. in five driving processes, $S = a, g, r, gov, tot$	[0,1)	Beta [5.0 ; 2.0]	0.72	16	[0.42 ; 0.94]
σ_S	S.D. of Shock in five driving processes (%), $S = a, g, r, gov, tot$	R^+	Gamma [4.0 ; 0.005]	2.00	1.0	[0.70 ; 3.91]
ϕ	Capital Adjustment Cost Fct. Parameter	R^+	Gamma [3.0 ; 2.0]	6.00	346	[1.62 ; 12.6]
σ_X	S.D. (%) of Measurement Error in $X = Y, C, I, TBY$	R^+	Gamma [4.0 ; 0.005]	2.00	1.0	[0.70 ; 3.91]
θ	Working Capital Parameter	[0,1]	Beta [2.0 ; 2.0]	0.50	22.4	[0.13 ; 0.87]
γ_J	Weight of Importables in aggregator of $J = C, I$	[0,1]	Beta [3.0 ; 12.0]	0.20	10.0	[0.06 ; 0.39]
η	Spread Elasticity	R^+	Gamma [4.0 ; 0.25]	1.00	50	[0.35 ; 1.95]
υ_J	Elasticity of substitution in aggregator of $J = C, I$	R^+	Gamma [4.0 ; 0.25]	1.00	50	[0.35 ; 1.95]
ρ_{GY}	Elasticity of Gov. Expenditure to lagged deviations in output	R	Normal [0.0 ; 1.0]	0.00	100	[-1.66 ; 1.66]

V.   RESULTS

This section presents the results of the paper. First the posterior distribution of the estimated parameters is reported, together with functions of these parameters, variance decompositions and impulse response functions. Second, the performance of the estimated model in matching some of the main stylized facts of the Colombian business cycle is assessed, as well as its out-of-sample forecasting performance. Finally, a robustness analysis is conducted by using a much longer and yearly dataset, spanning from 1925 to 2008.

A.   POSTERIOR DISTRIBUTIONS

Table 4 reports the posterior distributions for the twenty two parameters estimated in Θ_2. The table reports for each parameter both the posterior mode and mean together with the 90 percent confidence interval. In addition, a plot of prior and posterior distribution is also presented in Graph 1. Finally, impulse response functions and variance decompositions of the main macroeconomic aggregates are computed from the prior distributions and are presented, respectively, in Graph 2 and Table 5. A series of findings emerge from these results.

First, the data is to be informative for most of the parameters as the posterior distributions significantly differ from the diffuse prior distributions, particularly for the parameters governing the standard deviations of the shocks, the degree of financial frictions, and the persistence of the shocks.

Second, the results clearly favor innovations in the transitory technology process and the interest rate faced in world markets as the most important driving forces of the Colombian business cycle. The forecast error variance decomposition results assign to technology shocks the 74 percent of the variance in output; 43 percent in consumption; 60 percent in investment; and 19 percent in the trade balance-to-GDP ratio. The share of the variability associated to interest rate shocks is most important for the trade balance-to-GDP ratio (76 percent); investment (37 percent); consumption (20 percent); and output (17 percent). From Graph 2, the impulse response of output —measured as deviations from its steady state—, following an estimated one standard deviation shock to the transitory technology process peaks near 3 percent; while that associated to a positive interest rate shock makes output fall near 2 percent an its effects are more persistent through time.

Third, and perhaps surprisingly, the other three driving forces play a minor role in accounting for the Colombian business cycles. The estimated posterior mode ratio of the volatilities in the two technology processes is $\sigma_a/\sigma_g = 0.72 / 0.36 = 2.0$, which is clearly at odds with Aguiar and Gopinath (2007)'s finding for Mexico, where they obtain a ratio $0.48/2.481 = 0.2$. Furthermore, using Aguiar and Gopinath (2007)'s measure for the random walk component of the Solow residual, a nonlinear function of the relevance of trend shocks relative to transitory shocks and defined as follows:

$$RWC = \frac{\alpha^2\sigma_g^2/(1-\rho_g)^2}{[2/(1+\rho_z)^2]\,\sigma_a^2 + [\alpha^2\sigma_g^2/(1-\rho_g^2)]}$$

Table 4
Prior / Posterior Distributions

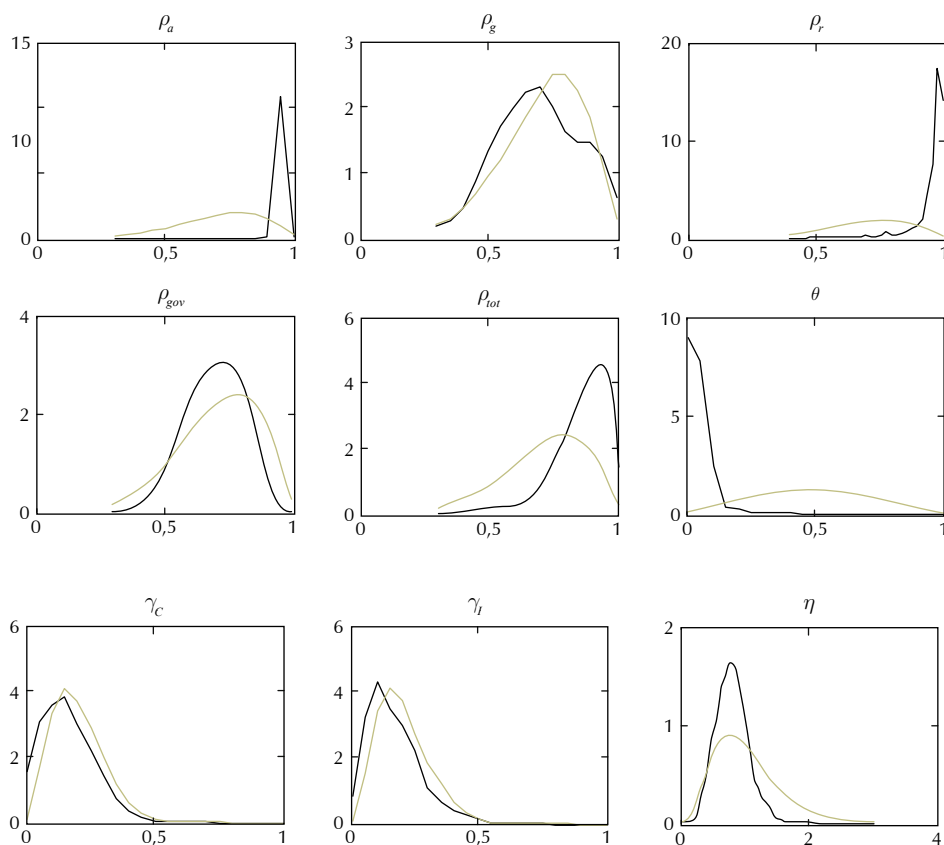| Parameter	Prior Distribution	Posterior Distribution		Parameter	Prior Distribution	Posterior Distribution	
		Mode	Mean			Mode	Mean
ρ_a	0.72 [0.42, 0.94]	0.97	0.97 [0.94, 0.99]	$100\sigma_Y$	2.00 [0.70, 3.91]	0.27	0.30 [0.11, 0.51]
ρ_g	0.72 [0.42, 0.94]	0.65	0.69 [0.43, 0.96]	$100\sigma_C$	2.00 [0.70, 3.91]	0.37	0.43 [0.15, 0.67]
ρ_r	0.72 [0.42, 0.94]	0.98	0.96 [0.83, 0.99]	$100\sigma_I$	2.00 [0.70, 3.91]	2.32	2.58 [1.96, 3.24]
ρ_{gov}	0.72 [0.42, 0.94]	0.78	0.70 [0.51, 0.86]	$100\sigma_{TBY}$	2.00 [0.70, 3.91]	0.26	0.25 [0.09, 0.51]
ρ_{tot}	0.72 [0.42, 0.94]	0.86	0.85 [0.64, 0.98]	γ_C	0.20 [0.06, 0.39]	0.18	0.16 [0.02, 0.34]
$100\sigma_a$	2.00 [0.70, 3.91]	0.72	0.71 [0.56, 0.87]	γ_I	0.20 [0.06, 0.39]	0.15	0.16 [0.03, 0.37]
$100\sigma_g$	2.00 [0.70, 3.91]	0.36	0.27 [0.09, 0.50]	η	1.00 [0.35, 1.95]	0.89	0.79 [0.41, 1.21]
$100\sigma_r$	2.00 [0.70, 3.91]	0.66	0.55 [0.25, 0.81]	υ_C	1.00 [0.35, 1.95]	0.75	0.78 [0.23, 1.61]
ϕ $100\sigma_{gov}$	2.00 [0.70, 3.91]	0.84	0.90 [0.30, 1.72]	υ_I	1.00 [0.35, 1.95]	0.75	0.76 [0.21, 1.58]
$100\sigma_{tot}$	2.00 [0.70, 3.91]	1.64	1.65 [0.40, 3.38]	ρ_{GY}	0.00 [-1.66, 1.66]	1.04	1.30 [0.66, 1.94]
	6.00 [1.62, 12.6]	6.89	5.77 [3.15, 9.38]	RWC	2.73 [0.70, 24.59]	0.77	0.64 [0.04, 27.84]
θ	0.50 [0.13, 0.87]	0.04	0.04 [0.00, 0.12]				

Note: Estimates obtained using four observables, {gY, gC, gI, dTBY} from the Colombian quarterly data, 1994:1-2008:4 (See the appendix in the author's website for further details on the data and the MATLAB codes used http://econweb.rutgers.edu/afernandez/RESEARCH.htm for data sources). Estimations were done using measurement errors in all four variables. RWC refers to the random walk component, see text for details. Numbers in brackets report the 90 percent confidence intervals from each posterior distribution.

the mode of the RWC is found to be 0.77, close to two thirds the value estimated for Mexico in Aguiar and Gopinath (0.96). Consequently, the role played by growth shocks in accounting for the variance of the main macroeconomic aggregates is

less than 7 percent, except for consumption (26 percent). Likewise, the share of government expenditure and terms of trade perturbations in accounting for the macro volatility is lower than 2 percent for any of the four time series, except for the share of terms of trade in accounting for consumption variability (11 percent). Finally, the impulse response functions for output after an estimated one standard deviation shock to any of these three structural shocks is either small and nonpersistent, (0.2 following a growth shock) or non-statistically significant.

Graph 1
Prior / Posterior Distribution Plots

Graph 1 (Continued)

Graph 1 (Continued)

$$\rho_{GY} \qquad \sigma_a/\sigma_g \qquad \text{Random Walk Component}$$
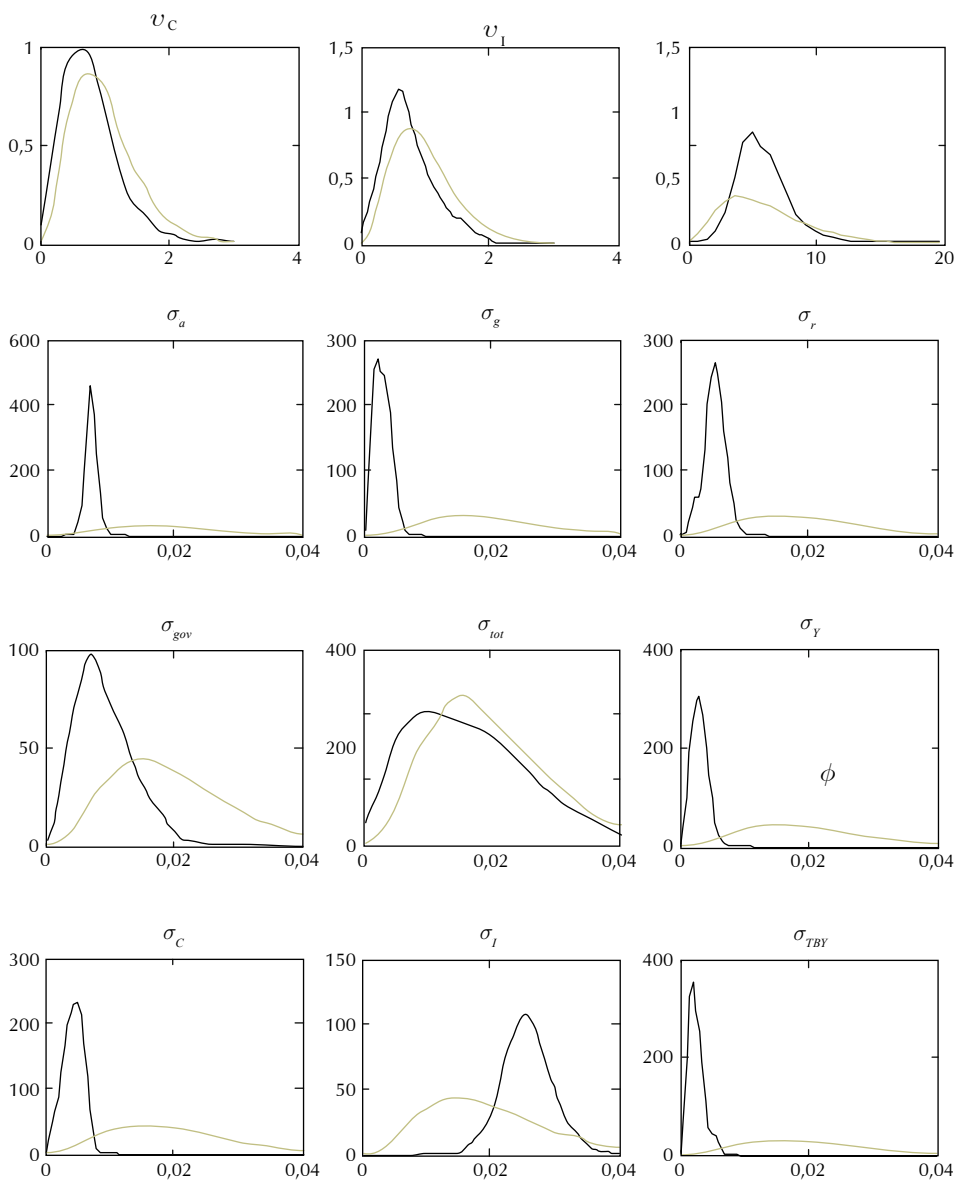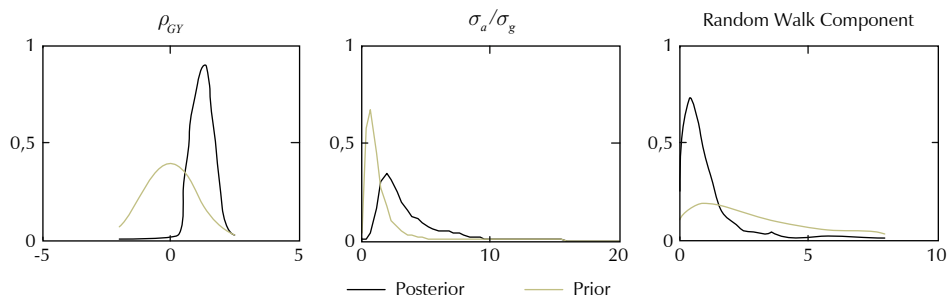
—— Posterior   —— Prior

Note: Each plot presents the kernel smoother of prior and posterior distributions.

Graph 2
Estimated Impulse Response Functions
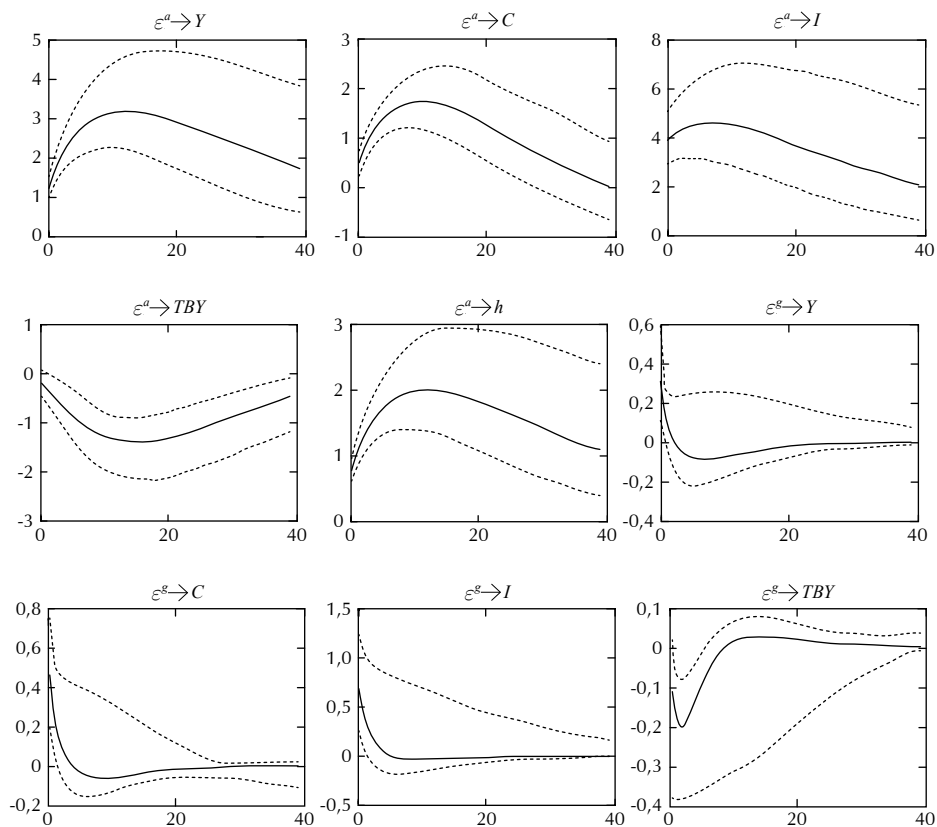
Graph 2 (Continued)
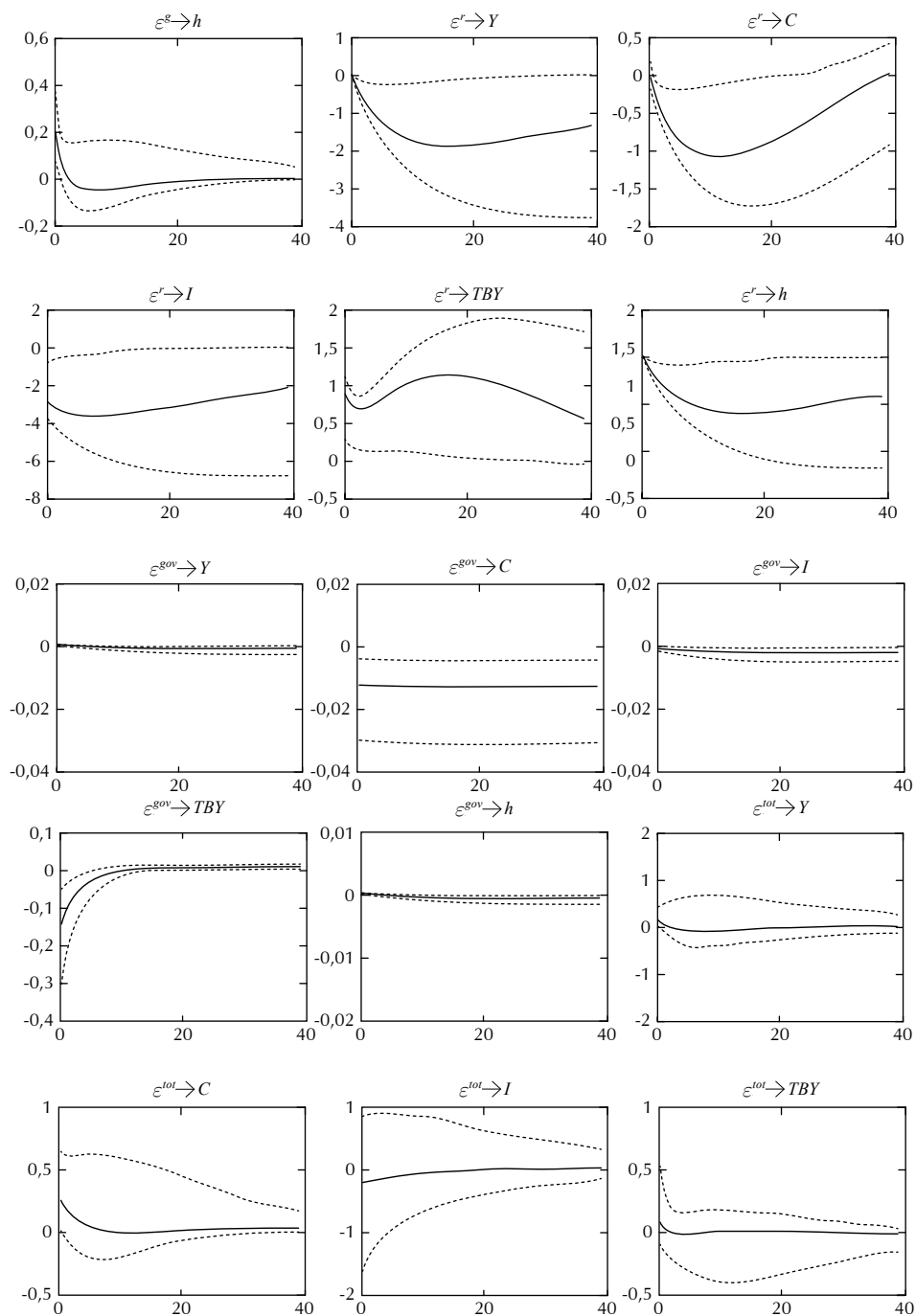
Graph 2 (Continued)
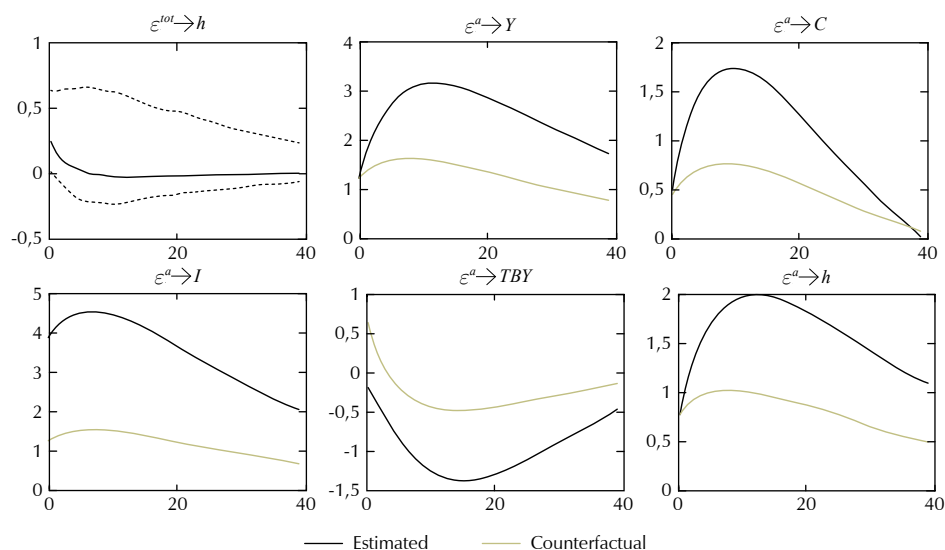
Note: The plots track the response of output (Y); consumption (C); investment (I), trade balance-to-GDP ratio (TBY); and employment (h), as deviations from steady states, after an estimated one standard deviation shock to the transitory technology process (plots 1-5); the growth process (plots 6-10); the interest rate process (plots 11-15); the government expenditure process (plots 16-20); the terms of trade process (plots 21-25). Dotted lines depict 90% confidence interval based upon the posterior distribution. The last 5 plots present the estimated impulses after a one standard deviation shock to the transitory technology process under the standard modelo (solid) and the counterfactual experiment, $\eta = 0$ (dotted).

Fourth, while the posterior estimate for η was high, the one for θ was close to zero, implying that the degree of financial frictions is important but mainly through the effects that transitory technology shocks have on the spread. The role of this financial friction in propagating transitory technology shocks is of crucial importance. This is evident from the last five plots of impulse response functions presented in Graph 2, where we plot the counterfactual case setting $\eta = 0$. It is immediate to see that more than half of the response in output and the other variables is reduced when we artificially set the elasticity of the spread to expected movements in the country fundamentals to zero.

Fifth, the size of the sum of the standard deviation in the measurement errors is rather small when compared to the size of the estimated structural shock's, signaling that misspecification is not a serious problem and that the model successfully accounts for most part of the variability exhibited in the observables.

Sixth, the (little) information that appears to be in the data validates a small share of importables in total consumption and investment, and a low elasticity between

home and foreign goods. Last, the data also shows evidence of a procyclical government expenditure.

Table 5
Forecast Error Variance Decompositions

Structural Shock	gY	gC	gI	dTBY
ε^a	74.2	43.1	60.4	19.3
ε^g	6.9	26.0	2.1	1.9
ε^r	17.0	19.9	37.4	75.5
ε^{gov}	0.0	0.0	0.0	2.0
ε^{tot}	1.9	11.0	0.2	1.4

Note: gX denotes log-differences, dX denotes first differences. Variance decompositions computed from the estimation using four observables and measurement errors in all variables. Numbers reported using posterior mode estimates. Standard Errors are omitted for brevity but are available upon request. In the variance decomposition computations only the role of the structural shocks was taken into account. A time horizon of 40 quarters was used when computing the variance decomposition.

B.   MODEL PERFORMANCE

The performance of the estimated model in matching some of the main stylized facts of the Colombian business cycle is assessed here by running two separate experiments. First, the model-based second moments of the main macroeconomic aggregates are computed and compared to those computed from the Colombian data. Second, a historical decomposition of the structural shocks is performed by using the smoothing properties of the Kalman filter, and their accuracy in replicating the sharp business cycle observed in the late 1990s is assessed.

1.   Selected second moments

Table 6 presents the unconditional second moments derived from the estimated model. The model-based moments were computed using the posterior modes for the estimated parameters. Thus, it should be noted that the comparison between the theoretical and sample second moments of the main four macroeconomic aggregates is clearly a stringent test on the model, given that the estimation was not designed to match these moments in particular, unlike other methods such as GMM. And it is clearly an even more stringent test for the comparison of the second moments in the main driving forces, given that these were not even observed in the estimation.

The model achieves, nonetheless, a moderately good fit along most of the important dimensions highlighted in the second section. Indeed, the model successfully replicates the smooth consumption process, the volatile investment and the strong countercyclicality of the trade balance-to-GDP ratio, largely explained by investment variability. In terms of the driving forces, the model also matches closely the leading and countercyclical properties exhibited by the real interest rate. As for the terms of trade, while the model partially replicates the procyclicality observed in this variable it misses in matching its large volatility. And the model fails completely by grossly overstating the procyclicality of the government expenditure.

2. Historical decomposition

The second experiment by which the performance of the estimated model is assessed starts by computing a historical decomposition of the structural shocks using the smoothing properties of the Kalman filter. Following Hamilton (1994) and DeJong and Dave (2007), we use the state space representation (36), together with the observable equation (37), to construct an estimate of the state vector of variables along with innovations to these variables using the information contained in the entire sample:

$$\left\{ x_{1t|T}, \upsilon_{t|T} \right\}_{t=1994:1}^{T=2008:4}$$

where the latter can be thought of as a measure of the structural shocks. Next, we use a subset of these structural shocks to simulate the evolution of the main four Colombian macroeconomic aggregates. In particular, we are interested in the accuracy of the model in replicating the sharp business cycle observed in the Colombian economy in the late 1990s, where a sustained period of growth that started in 1994 was followed by a sharp reversal in 1998 and particularly in 1999.

The time series of the smoothed driving forces together with their innovations are plotted in Graph 3. It is immediate to see that a sharp volatility characterizes the years 1996 to 2000. Positive transitory technology shocks characterize the early years (1996-1997), while a reversal of this trend along with a sharp increase in the smoothed interest rate process characterized the following years (1998-1999).

The accuracy of the structural shocks in replicating the sharp Colombian business cycle in the late 1990s is assessed in Graph 4. Only shocks to transitory technology and to the interest rate processes are considered. In order to gauge the relevance of financial frictions and interest rate shocks during this episode, the panels in the left column report the simulation using only transitory technology shocks and shutting down the

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degree of financial frictions, $\eta = \theta = 0$; while the panels to the right include interest rate shocks and set the value of η and θ equal to their posterior modes.
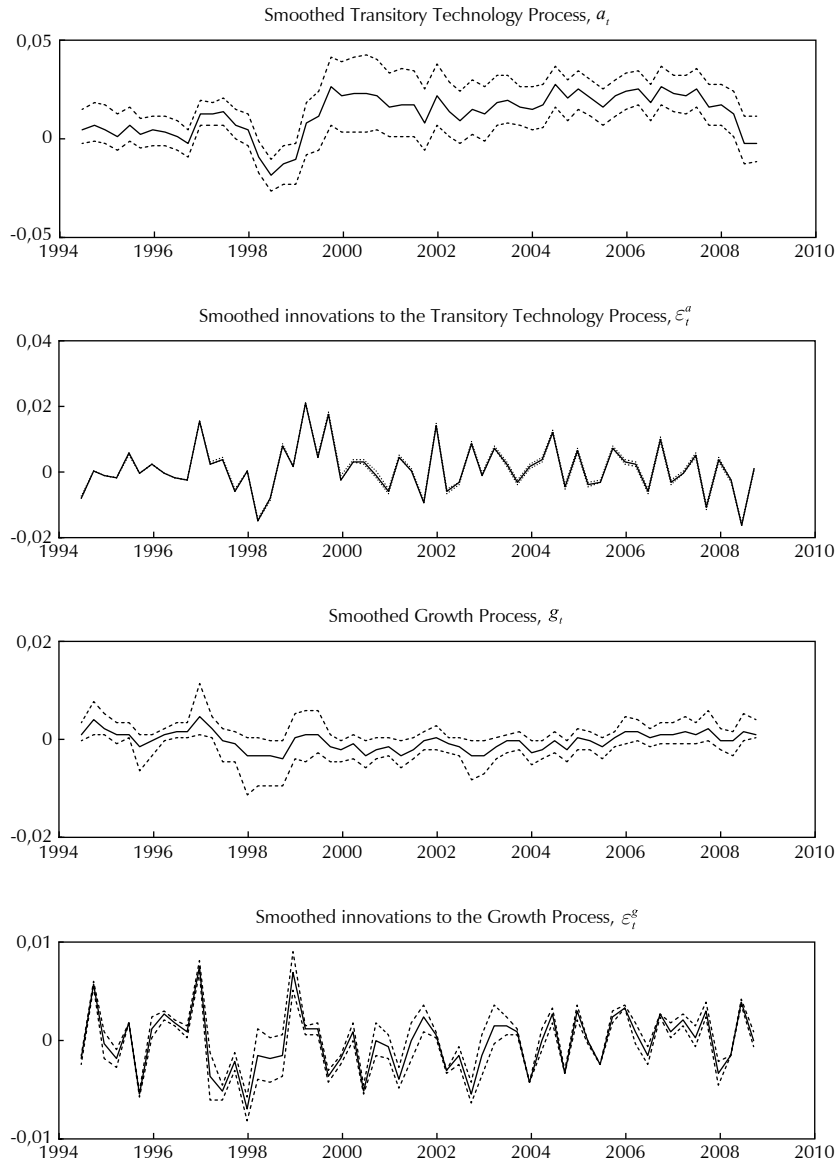
The results of this experiment are quite surprising. The simulation incorporating solely technology shocks and no financial frictions that propagate these shocks (left panels) misses virtually all the distinctive properties of the Colombian cycle in this period. While the simulation produces only a very moderate fall in GDP, it does not exhibit any fall in consumption nor investment, and even counterfactually produces a fall in the trade balance-to-GDP ratio. On the contrary, the simulation that includes both interest rate shocks and financial frictions remarkably matches the evolution of the Colombian macroeconomic time series. In particular, the sharp reversal in the trade balance and the downfall in investment are properly recovered. This corroborates what was mentioned above regarding (1) the relevance of interest rate shocks in accounting for the Colombian business cycle, and (2) the central role played by financial frictions as propagating mechanisms of other real driving forces (*i.e.*, transitory technology shocks).

Table 6
Sample and Model-Based Business Cycles Moments

Variable	sd(X)	sd(X) / sd(gY)	Corr(X$_t$, X$_{t-1}$)	Corr(X$_t$, gY$_{t-s}$)			Corr (X$_t$, dTBY$_t$)
				s=1	s=0	s=-1	
Colombia							
gY	1.22	1.00	0.20	0.20	1.00	0.20	-0.53
gC	0.83	0.67	0.33	0.36	0.65	0.34	-0.49
gI	6.05	4.94	0.25	0.29	0.81	0.11	-0.84
dTBY	1.05	0.86	0.30	-0.43	-0.53	-0.16	1.00
gR*	0.46	0.37	0.05	0.00	0.03	-0.21	-0.11
gToT	5.29	4.32	0.12	0.01	0.33	0.09	-0.39
gG	2.29	1.87	0.30	0.07	0.17	0.06	0.06
Model Based Moments							
gY	1.79	1.00	0.53	0.53	1.00	0.53	-0.30
gC	1.26	0.71	0.55	0.55	0.81	0.48	-0.28
gI	5.62	3.14	0.08	0.12	0.61	0.37	-0.59
dTBY	1.18	0.66	0.20	-0.31	-0.30	-0.38	1.00
gR*	0.66	0.37	-0.01	0.01	0.02	-0.19	0.80
gToT	1.70	0.95	-0.07	-0.01	0.13	-0.02	0.10
gG	5.56	3.11	0.92	0.74	0.52	0.44	-0.51

Note: gX and dX denote log differences and linear difference, respectively. See the appendix in the author's website for further details on the data. Model-based moments were computed using posterior mode. Confidence intervals are omitted for brevity but are available upon request.

Graph 3
Smoothed Driving Forces and Innovations

Smoothed Transitory Technology Process, a_t

Smoothed innovations to the Transitory Technology Process, ε_t^a

Smoothed Growth Process, g_t

Smoothed innovations to the Growth Process, ε_t^g

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Graph 3 (Continued)

Smoothed Interest Rate Process, R^*_t

Smoothed innovations to the Interest Rate Process, ε^r_t

Smoothed Goverment Expenditure Process, gov_t

Smoothed innovations to the Goverment Expenditure Process, ε^{gov}_t

Graph 3 (Continued)

Smoothed Terms of Trade Process, tot_t

Smoothed innovations to the Terms of Trade Process, ε_t^{tot}

Note: The plots track the smoothed driving force processes and the smoothed innovations to these driving forces. Both are computed using the Kalman smoother and red dashed lines depict 90% confidence interval based upon the posterior distributions.

Graph 4
Simulating the Colombian Business Cycle: 1997-2000

Simulation using only transitory technology shocks and no financial frictions

Simulation using only transitory technology shocks and interest rate shocks with financial frictions

Output

Output

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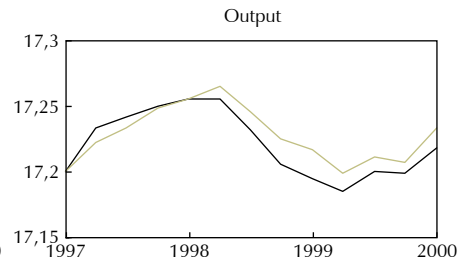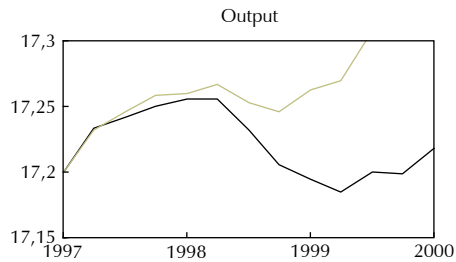
Graph 4 (Continued)

Note: The first column tracks the evolution of the main Colombian macro aggregates in logs (except for the trade balance-to-GDP ratio) using the Kalman-smoothed process of the transitory technology process assum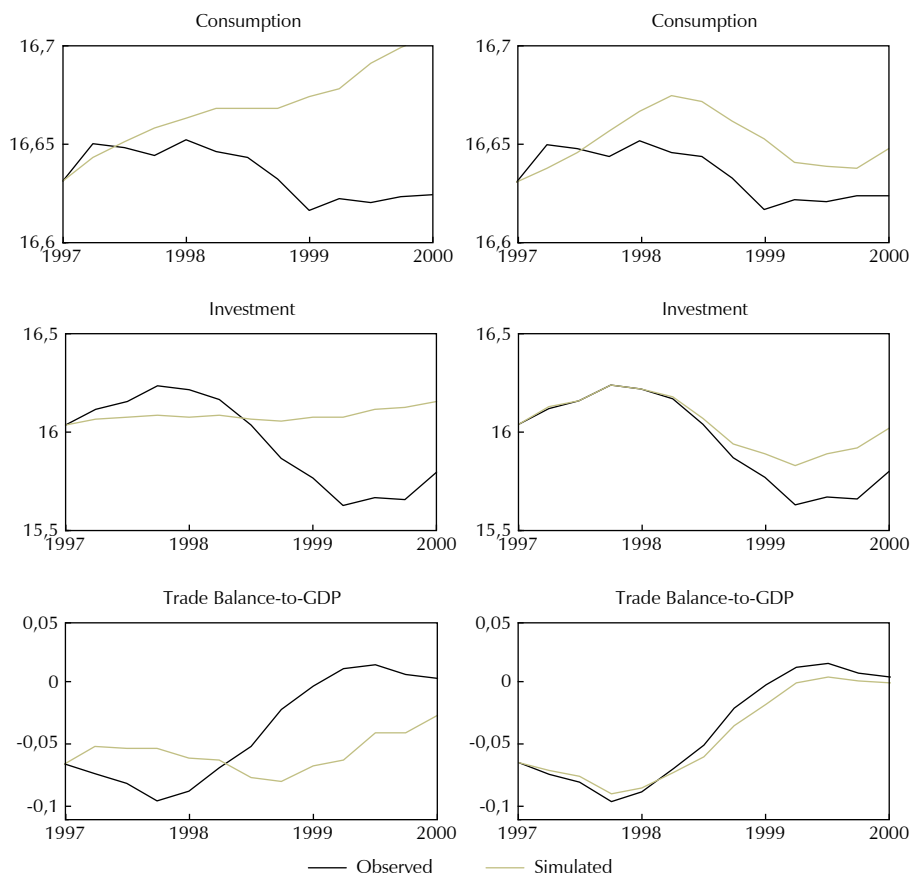ing no financial frictions ($\eta = \theta = 0$). The second column tracks the evolution of the same aggregates using the Kalmansmoothed processes of the transitory technology and the interest rate and setting the parameters governing the degree of financial frictions (η, θ) equal to their posterior mode estimates. The smoothed innovations were obtained using posterior modes. The simulations were computed without the smoothed measurement errors.

C.   BAYESIAN MODEL COMPARISON AND FORECASTING PERFORMANCE

When conducting Bayesian estimation of DSGE models, researchers often are interested in the out-of-sample forecasting performance of the model (see An and Schorfheide, 2007). This is achieved by computing the marginal likelihood, which is done next. Rewriting (39) exactly, the Bayes Theorem implies that posterior beliefs about Θ must respect:

$$p(\Theta|X) = \frac{\mathcal{L}(X|\Theta)\,p(\Theta)}{p(X)}$$

where $p(X)$ is the model's marginal likelihood, defined as:

$$p(X) = \int \mathcal{L}(X \mid \Theta)p(\Theta)d\Theta$$

Following An and Schorfheide (2007) the log-marginal likelihood can be rewritten as:

$$
\begin{aligned}
\ln p(X) &= \sum_{t=1}^{T} \ln p(x_t \mid X^{t-1}) \\
&= \sum_{t=1}^{T} \ln \left[\int p(x_t \mid X^{t-1}, \Theta)p(\Theta \mid X^{t-1})d\Theta \right]
\end{aligned}
$$

thereby implying that marginal data densities capture the relative one-step-ahead predictive performance of the model.

The upper panel in Table 7 reports the log-marginal likelihood for the estimated model along with the likelihood and posterior values evaluated at the posterior mode. In order to gauge the forecasting performance of the various structural shocks, we conducted two separate experiments. First, we estimated the model adding only two structural shocks, one of which was always transitory technology shocks, yielding four possible combinations. Second, we estimated the model removing only one shock at a time, with the exception of transitory technology shocks, again yielding four possible combinations. Posterior and marginal likelihood for the first and second experiments are reported in the middle and lower panels of Table 7. While the full model does better than most of the restricted models, interestingly, the out-of-sample performance of government shocks appears to be relevant. In that sense, while government expenditure shocks do not appear to contribute much to the in-sample fit of the model, they appear to be relevant for the out-of-sample fit of it.

D.   A LONGER DATASET, COLOMBIA 1925-2008.

Garcia-Cicco *et al.* (2010) have recently argued that a more accurate estimation of the relative weight of the growth component in developing countries' business cycles

Table 7
Bayesian Model Comparison

Models	Log-Likelihood	Log-Posterior	Marginal Log-Likelihood
Estimating the Full Model: with 5 Structural Shocks: $\{\varepsilon^a, \varepsilon^g, \varepsilon^r, \varepsilon^{gov}, \varepsilon^{tot}\}$			
Full Model	702.59	723.72	650.92
Estimating the Model with Only Two Structural Shocks:			
$\{\varepsilon^a, \varepsilon^g\}$	669.86	680.68	642.43
$\{\varepsilon^a, \varepsilon^r,\}$	668.73	680.01	638.08
$\{\varepsilon^a, \varepsilon^{gov}\}$	685.94	694.58	654.96
$\{\varepsilon^a, \varepsilon^{tot}\}$	672.06	687.46	645.25
Estimating the Model Removing Only One Shock at a Time			
No Interest Rate Shocks $\{\varepsilon^a, \varepsilon^g, \varepsilon^{gov}, \varepsilon^{tot}\}$	699.87	715.59	655.23
No Terms of Trade Shocks $\{\varepsilon^a, \varepsilon^g, \varepsilon^r, \varepsilon^{gov}\}$	701.53	716.27	651.94
No Growth Shocks $\{\varepsilon^a, \varepsilon^r, \varepsilon^{gov}, \varepsilon^{tot}\}$	702.66	721.25	657.31
No Government Expenditure Shocks $\{\varepsilon^a, \varepsilon^g, \varepsilon^r, \varepsilon^{tot}\}$	669.42	687.35	627.28

Note: Log-Likelihood levels computed in the posterior mode. Results on marginal data densities are approximated by Geweke's harmonic mean estimator with truncation parameter 0.5.

should be done using dataset that span over many years. Following this work, we estimate the model on a yearly Colombian dataset covering the period 1925-2008.

The upper panel of Table 8 summarizes the main aspects of this dataset using the same second moments used for the quarterly dataset. While some of the stylized facts remain valid, particularly the strong countercyclicality of the trade balance share of income, two noticeable characteristics emerge. First, there is a sharp increase in the volatility of virtually all variables, particularly in investment, the terms of trade and government expenditure. Second, consumption exhibits now a higher volatility than output[9].

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9 Importantly, due to data availability, in these dataset it was impossible to exclude durable (and semidurable) goods consumption from aggregate consumption and include it on investment as was done before.

Table 8
Sample and Model-Based Bussines Cycles Moments
Annual Data: 1925-2008

Variable	sd(X)	sd(X) / sd(gY)	Corr(Xt, Xt-1)	Corr(Xt, gYt-s)			Corr (Xt, dTBYt)
				s=1	s=0	s=-1	
Colombia							
gY	2.44	1.00	0.32	0.32	1.00	0.32	-0.28
gC	6.12	2.51	-0.23	0.11	0.55	0.00	-0.46
gI	17.78	7.29	-0.21	0.27	0.26	0.30	-0.60
dTBY	3.72	1.53	-0.16	-0.25	-0.28	-0.15	1.00
gR*				n.a			
gToT	14.44	5.92	0.00	0.02	0.09	-0.01	-0.06
gG	11.28	4.63	-0.09	0.15	0.20	0.01	-0.05
Model Based Moments							
gY	3.29	1.00	0.42	0.42	1.00	0.42	0.11
gC	5.71	1.74	-0.05	0.18	0.44	-0.07	-0.24
gI	17.66	5.37	-0.13	-0.11	0.24	0.43	-0.48
dTBY	3.80	1.16	0.02	0.18	0.11	-0.03	1.00
gR*	0.79	0.24	-0.02	0.03	0.03	-0.33	-0.01
gToT	4.75	1.45	-0.22	0.03	0.17	-0.16	0.67
gG	14.79	4.50	0.95	0.30	0.10	0.02	-0.22

Note: gX and dX denote log differences and linear difference, respectively. See appendix for data sources. Model-based moments were computed using posterior mode. Confidence intervals are omitted for brevity but are available upon request.

We estimate the model using this longer dataset and run a similar analysis as before. The lower panel in Table 8 reports the model based moments, Table 9 reports posterior modes and compares them with the estimates using the shorter dataset; and Table 10 presents the results of the variance decomposition. Several results stand out. First, the role of growth shocks becomes significantly more relevant now. The ratio σ_a/σ_g falls from 2.0 to 0.2 and the random walk component increases from 0.77 to 4.19. As a consequence of this almost half (46 percent) of output's variance is explained by growth shocks, although the share of these shocks in the variance of the other main aggregates is not higher than 19 percent. Second, the role of terms of trade shocks is now much more important, particularly when accounting for the variance of investment (48 percent) and the trade balance share (64 percent). Third, interest rate shocks continue to be relevant, notably in explaining the variance of consumption (81 percent), and their share in output variance remains close to the

levels estimated in the quarterly sample (17 percent). Fourth, the model successfully accounts for the new stylized facts as can be seen from the lower panel in Table 8. In particular, the higher volatilities of investment and government expenditure are matched together with the relative higher standard deviation of consumption. The model, nonetheless, does not generate a countercyclical trade balance share.

Table 9
Prior / Posterior Distributions
Estimation with Annual Data: 1925-2008

Parameter	Prior Mode	Posterior Distribution		Parameter	Prior Mode	Posterior Distribution	
		Mode 1994:1-2008:4	Mode 1925-2008			Mode 1994:1-2008:4	Mode 1925-2008
ρ_a	0.72	0.97	0.98	$100\sigma_Y$	2.00	0.27	0.49
ρ_g	0.72	0.65	0.63	$100\sigma_C$	2.00	0.37	1.19
ρ_r	0.72	0.98	0.96	$100\sigma_I$	2.00	2.32	2.73
ρ_{gov}	0.72	0.78	0.99	$100\sigma_{TBY}$	2.00	0.26	0.95
ρ_{tot}	0.72	0.86	0.55	γ_C	0.20	0.18	0.07
$100\sigma_a$	2.00	0.72	0.37	γ_I	0.20	0.15	0.25
$100\sigma_g$	2.00	0.36	1.86	η	1.00	0.89	0.61
$100\sigma_r$	2.00	0.66	0.78	υ_C	1.00	0.75	0.67
$100\sigma_{gov}$	2.00	0.84	1.36	υ_I	1.00	0.75	0.72
$100\sigma_{tot}$	2.00	1.64	4.19	ρ_{GY}	0.00	1.04	0.04
ϕ	6.00	6.89	2.41	RWC	2.73	0.77	4.19
θ	0.50	0.04	0.80				

Note: Estimates obtained using four observables, {gY, gC, gI, dTBY} from the Colombian annual data, 1925-2008 (see Appendix for data sources). Estimations were done using measurement errors in all four variables. RWC refers to the random walk component, see text for details.

Table 10
Forecast Error Variance Decompositions
Estimation with Annual Data

Structural Shock	gY	gC	gI	dTBY
ε^a	26.9	1.4	9.9	1.0
ε^g	45.7	15.3	18.6	12.3
ε^r	16.8	80.9	23.1	22.6
ε^{gov}	0.0	0.1	0.0	0.0
ε^{tot}	10.6	2.3	48.3	64.0

Note: gX denotes log-differences, dX denotes first differences. Variance decompositions computed from the estimation using four observables and measurement errors in all variables. Numbers reported using posterior mode estimates. Standard Errors are omitted for brevity but are available upon request. In the variance decomposition computations only the role of the structural shocks was taken into account. A time horizon of 40 quarters was used when computing the variance decomposition.

VI. CONCLUDING REMARKS

There exists a consensus regarding the differences in the business cycle patterns in developing and developed economies. Where a consensus does not seem to be emerging is on the key driving forces that can account for these differences. While some studies argue that a standard RBC-type model, driven only by transitory and/ or permanent shocks to the technology process, is enough to properly model business cycles in developing economies, others present conflicting evidence based on dataset covering longer periods or stress the role of other real driving forces.

We contribute to this debate by exploring the business cycle properties of Colombia, a developing —and "tropical"— economy. Our approach is more ambitious in the sense that not only do we test for role of technology shocks but we also incorporate other potential real impulses. Motivated by the observation that, to date, there has been little empirical analysis of the role played by individual shocks —within a multiple-shock setting— in driving business cycle movements in developing countries, we build a DSGE model that adds a menu of real driving forces in addition to technology shocks, including shocks to the interest rate in world capital markets coupled with financial frictions, terms of trade fluctuations, and a procyclical government spending process. The role of each driving force is empirically quantified by estimating the parameters of the exogenous shocks processes, along with a few other crucial parameters, within a Bayesian framework, using Colombian macroeconomic data.

We find interest rate shocks to be crucial in accounting for the Colombian business cycle while financial frictions play a central role as propagating mechanisms of other real driving forces, in particular transitory technology shocks. These two driving forces alone can account well for the observed properties of the Colombian business cycle, such as the smooth consumption process, the volatile investment and the strong countercyclicality of the trade balance-to-GDP ratio. They both are entirely responsible for the sharp economic downturn experienced in the late 1990s. Other structural shocks, such as terms of trade fluctuations and level shifts in the technology process, do not appear to be relevant in the past decade and a half, but their importance increases when a longer span of data is considered. Demand shocks, in the form of government consumption innovations, account only for a trivial role of the variance of the macroeconomic aggregates but they appear to be relevant for the out-of-sample forecasting fit of the model.

We are thus skeptic as to whether business cycles in developing economies can be modeled with a standard RBC model driven *solely* by technology shocks and hope that our findings help stimulate more research into more elaborated models of the business cycles observed in developing economies.

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