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A Real Business Cycle Model For Ecuador: How Much Economic Fluctuations Can Be Explained by Exogenous Productivity Shocks?

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RESUMEN

Este trabajo muestra los resultados del primer modelo de ciclos económicos reales para el Ecuador con decisión de trabajo endógena. ¿Qué tanto pueden ser explicadas las fluctuaciones económicas por shocks exógenos? ¿que tanto puede la duración y la profundidad de los ciclos económicos diferir dependiendo del filtro aplicado a las series? Usando una aplicación de la razón "Kydland and Prescott" se llega a la conclusión que, en general, el modelo de ciclos reales muestra una buena explicación de los ciclos económicos del Ecuador—resultados que se asemejaron a los presentados por King & Rebelo (1999) para Estados Unidos—sin embargo, el modelo crea una economía 42% más volátil que la ecuatoriana. Adicionalmente, hay resultados contundentes sobre el filtro aplicado a las series, donde el filtro de Hamilton mide mayores desviaciones porcentuales que los dos filtros Hodrick and Prescott (HP) ("single and two-sided") en recesiones y alzas económicas; estas diferencias están entre el 8% y 5%. Además, el filtro de Hamilton también mide la duración más larga en tiempos de recesión.

Palabras claves: ciclos económicos reales, modelo de ciclos económicos reales, Ecuador, fluctuaciones economicas ecuatorianas, filtro de Hamilton, filtro Hodrick and Prescott.

ABSTRACT

This work shows the results of the first Real Business Cycle (RBC) model for Ecuador with endogenous labor choice. How much economic fluctuations can be explained by exogenous shocks? How much can the duration and deepness of the business cycles differ depending on the filter applied to the series? Based on an application of the "Kydland and Prescott" ratio, it is claimed a RBC model (calibrated for Ecuador) gives a general good account of the Ecuadorian business cycles—a results that is similar to the one presented by King & Rebelo (1999) for United States of America (USA)—however, the model shows an economy 42% more volatile than the Ecuadorian economy. Additionally, there are overwhelming differences based on the filter applied to the series, where Hamilton filter measures higher percentage deviations than HP (single and two-sided) filter in economic recessions and upswings; these differences are between 8% and 5%. Moreover, Hamilton filter also measures the longest duration in recession periods.

Keywords: real business cycles, real business cycle model, Ecuador, Ecuadorian economic fluctuations, Hamilton filer, Hodrick and Prescott filter.

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1 Introduction

The economic history of Ecuador shows an important break point after the severe downturn from 1998 to 2001. The main reason behind this is that authorities during that time decided to dollarize the economy as a desperate measure to correct skyrocketing exchange rates and the potential of hyperinflation. But something that escapes the naked eye is that dollarization also had an important change in the behavior of the Ecuadorian Business Cycles: Between 1995 and 1999 consumption was almost twice as volatile as output, but after dollarization this ratio fell to 0.90 showing some evidence in the direction of consumption smoothing. With this in mind, how much economic fluctuations can be explained by a simple RBC model for Ecuador after dollarization? How much can the duration and deepness of the business cycles differ depending on the filter applied to the series?

To answer these questions, I first present the main statistical features of Ecuadorian business cycles. Business cycles were measured by three different methods: Two- and one-sided HP filters, and the Hamilton alternative (2018), which is a more robust method to estimate the cycle within the statistical properties of the time series. From here, I build a typical RBC economy with exogenous productivity shocks and endogenous labor supply and calibrate this model for Ecuador.

In the classical RBC model (King & Rebelo, 1999), business cycles are driven mainly by large and cyclical volatile shocks of productivity. The mechanisms behind the model start with output; a variable that responds elastically to productive shocks. Then, changes in output affect consumption and investment; whereas investment receives the most of the variation. Moreover, labor supply is highly elastic, implying that work effort is very sensible to small variations in wages.

Based on the application of the three filters (Hamilton, single-sided HP, and two-sided HP) to the time series for Ecuador, I find that there are overwhelming differences. First, Hamilton filter measures higher percentage deviations than both HP (single- and two-sided) filters in economic recessions and upswings; these deviations are between 5% and 8%. Further, Hamilton filter also seems to estimate the longest duration in recession periods. Finally, some results change depending on the filter applied to the series; this occurs regarding the cyclicality of wages and interest rate. In particular, wages and interest rate are not procyclical neither countercyclical as the spurious results of two-sided and single-sided HP show.

In addition, for Ecuador, the RBC model produces output and consumption fluctuations that are significantly more volatile than their empirical counterpart. Moreover, 68% of the output fluctuations in the model are attributed to productive shocks. The volatility of consumption in the model represents 0.69 of output volatility. Furthermore, the RBC model and the data show the typical high persistence of macroeconomic aggregates, where the first order serial correlation found in the business cycle statistics are, on average, 0.85 (wages and hours worked are omitted).

The RBC model for Ecuador also exposes several discrepancies with the data. First of all, the Keyland-Prescott ratio shows that the RBC over-explain output and consumption business fluctuations. Moreover, the model produces strong procyclical investment, hours worked, interest rate, and wages; contradicting the empirical findings. Nonetheless, understanding the implications derived from the calibration of the RBC model for Ecuador is particularly important for a dollarized economy, since monetary policy management is not available.

This work contributes to the literature on real business cycles in emerging market economies (EMEs). In particular, it is the first study to calibrate a RBC model with endogenous labor choice for Ecuador. In this line, Cabezas (sf) calibrates an RBC model for Ecuador with exogenous labor. Moreover, the author uses the HP filter to measure business cycles, potentially producing spurious correlations and artificial forecasting properties in the series (Hamilton, 2018). Further, there are several previous works that analyze Ecuador, but not as the core of their study such as Lane (2003), Aguiar & Gopinath (2007), Fernández & Meza (2015), Arellano (2008), and Garcia-Cicco et al. (2010). Lane's research focuses on the business cycles fluctuations between industrialized and EMEs. He finds that industrialized countries present output that is less volatile than other countries. The second paper argues that in emerging countries consumption has a different relative behavior compared to the United States (King & Rebelo, 1999); in fact, consumption is more volatile than output. The last two studies show some variation of the classic RBC model to provide a better fit to the data.

Another important contribution of this work is in the field of measuring business cycles. While most of previous literature on business cycles use the classic method of Hodrick & Prescott (1997) for decomposing time series between trend and cycle.[1] I produce business cycle statistics using the Hamilton filter that offers more robust results (Hamilton, 2018). However, to keep my study comparable to previous literature, I also include statistics using two- and single(one)-sided HP filters. This also allows me to measure the biases produced by the HP filter for an Emerging Market.

This paper is organized as follows. In section 2, I present the Ecuadorian real business cycles. I first start showing how I acquire all the data for this work; some data are retrieved and other estimated based on available information. Then, I measure all the data with three different filters, and present their respective differences in the time period 1990-2017. After that, I compute the business cycles statistics for the Ecuadorian Economy, where I analyze if the results are consistent with the literature on business cycles. In section 3, I present the theoretical model and in section 4 I calibrate it for Ecuador. In section 5, I present the main results. Finally, section 6 concludes.

[1]See for example Banco Central del Ecuador (2019), Cabezas (sf), Neumeyer & Perri (2005), Fernández & Meza (2015), Aguiar & Gopinath (2007), Greenwood et al. (1988), Garcia-Cicco et al. (2010), and Christiano & Eichenbaum (1992).

2 Real Business Cycles in Ecuador

Analyzing the RBC in Ecuador imposes a challenge due to data accessibility. In this paper, I retrieve data from diverse sources (Central Bank of Ecuador, Central Bank of Peru, and *Instituto Nacional de Estadística y Sensos* (INEC)) and estimate based on accessible information. For this work, I use output, consumption, investment, hours worked, wages, stock of capital, interest rate, population, and technological shock. First, output, consumption, and investment are obtained from the Central Bank of Ecuador, where all variables are in 2007 dollars. To get quarterly data before the third quarter of 2003, hours worked and wages are estimated by an ordinary least square (OLS) equation; quarterly data after the second quarter of 2003 are retrieved from an Employment Household survey (ENEMDUs).[2] For quarterly stock of capital in 2007 dollars, I use the perpetual inventory method to get the time series from 1988-2017. I obtain interest rate from the Central Bank of Peru, where the Ecuadorian price index is used to get the real interest rate in 2007 dollars. For the quarterly data of population, I obtain the annual time series of population from the Central Bank of Ecuador; then, I apply quarter-to-quarter variation to estimate quarterly data. Finally, I estimate the technological shock.

2.1 Ecuadorian Hours Worked

I retrieve hours worked from an Employment Household survey (ENEMDU) made by INEC, where quarterly data is only available from the third quarter of 2003 until the fourth quarter of 2017. Before 2003, fourth quarter data are available until 1988. That is why, I use an OLS equation to estimate the first, second, and third quarter of hours worked from 1988-2003. In particular, I estimate the following equation:

$$ln(HoursWorked_t) = \beta_0 + \beta_1 * ln(Q1_t) + \beta_2 * ln(Q2_t) + \beta_3 * ln(Q3_t) + u_t, \quad (1)$$

[2]"Encuesta Nacional de Empleo, Desempleo y Subempleo" (ENEMDU).

where β_0 is the intercept of the linear equation. $Q1$, $Q2$, and $Q3$ are dummies variables for the quarters —first, second, and third respectively. Then, the term u_t represents a sequence of errors in the model, and t is the number of quarterly data—from 1 to 58 (the numbers of data from the third quarter of 2003 to the last quarter of 2017). Consequently, in this linear equation, the coefficients are capturing the relative effect of the first, second, and third quarter to the fourth one in logarithms.

I present the estimation of equation 1 in table 1, where the coefficients of first, second, and third quarter are displayed. All coefficients are positive, where the third one is greater than the others; however, all coefficients are not significant—there is insufficient evidence to conclude that there is effect at the population level. Graphically, the time series of hours worked is shown in figure 1. All the values estimated by the coefficients of table 1 are seen in the left side of the red vertical line of figure 1. Moreover, figure 1 exhibits an increasing trend before 2000, and a decreasing trend after 2000.

Table 1: Linear Model Regression for Hours Worked

		Quarterly Dummy		
	Constant	(1)	(2)	(3)
DV: ***ln(HoursWorked)***	3.694***	0.012	0.009	0.019
	(0.015)	(0.021)	(0.021)	(0.021)
Observations	58			

Notes: *p<0.1; **p<0.05; ***p<0.01

Values in parenthesis are the standard errors.

DV is for the Dependent Variable.

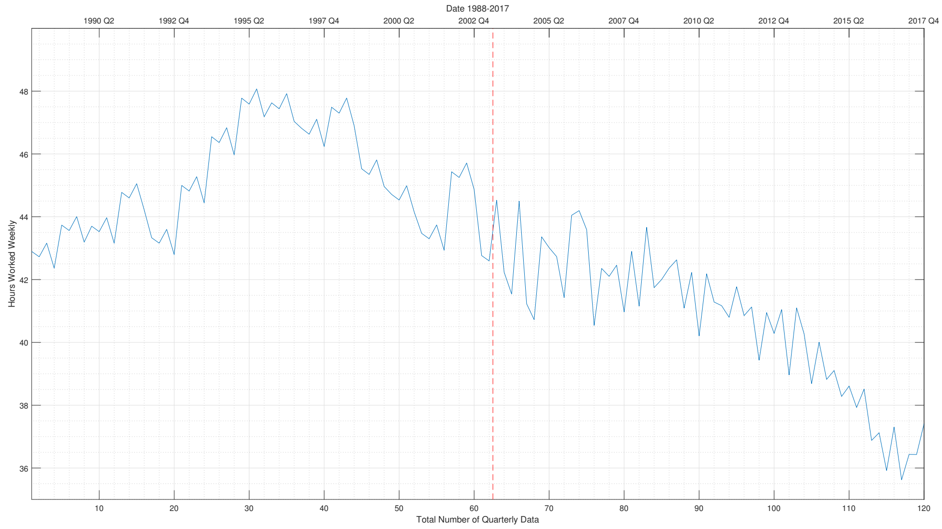

Figure 1: Ecuadorian Hours Worked 1988-2017. On the right side of the red line is the data—completely—retrieved from ENEMDUs, and on the left side is the data estimated. It seems there are two different trends (an increasing trend before 2000 and a decreasing trend after 2000).

2.2 Stock of Capital

I take Ecuadorian stock of capital from the Federal Reserve Bank of St. Louis (2019) annually measured in 2011 U.S. dollars. Using the gross fixed capital formation deflator, the data series are transformed to 2007 U.S. dollars; this procedure makes the time series comparable with the rest of data. Then, I apply the perpetual inventory method,

$$K_{t+1} = I + (1-\delta) * K_t, \tag{2}$$

to create quarterly time series. For this, investment and depreciation (δ) values are needed. The former is already available from the Central Bank of Ecuador, and the latter is estimated using the same equation in steady state—where $K_{t+1} = K_t$, so $\delta_t = \frac{I_t}{K_t} = 0.0446$ (on average); I use data from 1965 until 2014 to get a robust result. Then, dividing by four—stock of capital and investment are computed annually—the quarterly depreciation ($\delta = 0.0111$) is obtained. Using this value and quarterly investment, I estimate the quarterly stock of capital.[3] In the top of figure

[3]Using the annual value of the stock of capital in 2007, the equation estimates the value of the first quarter stock of capital 2008, and so on; then, rearranging the equation, the value of the third quarter stock of capital of 2007 is

2, I present my quarterly stock of capital for Ecuador from 1988 until 2017.

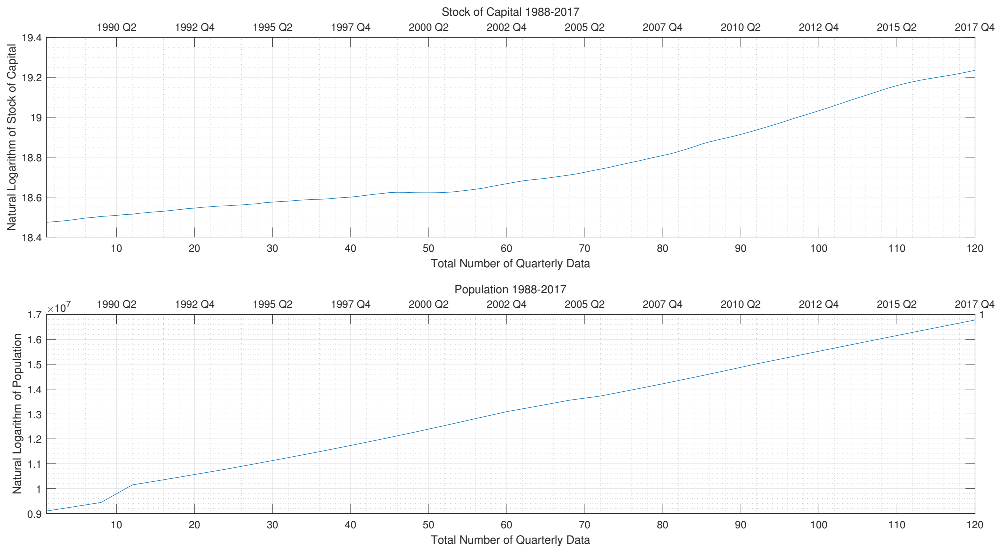

Figure 2: Quarterly Stock of Capital and Population 1988-2017. The graphic in the top is the Ecuadorian stock of capital from 1988-2017, and the graphic in the bottom is the Ecuadorian population from 1988-2017. In both graphs it is visible an increasing linear trend; however, population is more linear than stock of capital.

2.3 Population

I estimate population by assuming a linear trend. First, I obtain annual data of population from the Central Bank of Ecuador (2019). Then, I compute the variation between years and divide by four. Finally, I obtain the quarterly population by applying this variation. The time series in logarithms are shown in the bottom of figure 2.

2.4 Real Wages

I obtain the Ecuadorian real wages by a similar method to the one used for hours worked. Briefly, I define wages as the total amount of money employees earn in a month (to see the construction of the variable, go to the appendix section). First, I retrieve quarterly wages from ENEMDUs from the third quarter of 2003 until the last quarter of 2017. I compute the real quarterly wages by applying the Ecuadorian price index. Then, I estimated the first, second,

obtained, and so on until 1988.

and third quarter of data before the third quarter of 2003 by the OLS equation of table 2.

I show the estimation of the OLS equation of real wages in table 2. All coefficients are positive, where the third one is greater than the others; however, the third one is the only significant at 95% of confidence. Graphically, the time series of real wages are shown in figure 3. All the values estimated by the coefficients of table 2 are displayed in the left side of the red vertical line of figure 3. Moreover, figure 3 exhibits an increasing trend in the hole period.

Table 2: Linear Model Regression for Real Wage

		Quarterly Dummy		
	Constant	(1)	(2)	(3)
DV: ***ln(Real Wage)***	2.3334***	0.08429	0.07283	0.12649*
	(0.04974)	(0.07159)	(0.07159)	(0.07035)
Observations	58			

Notes: *p<0.1; **p<0.05; ***p<0.01

DV is for Dependent Variable.

Values in parenthesis are the standard errors.

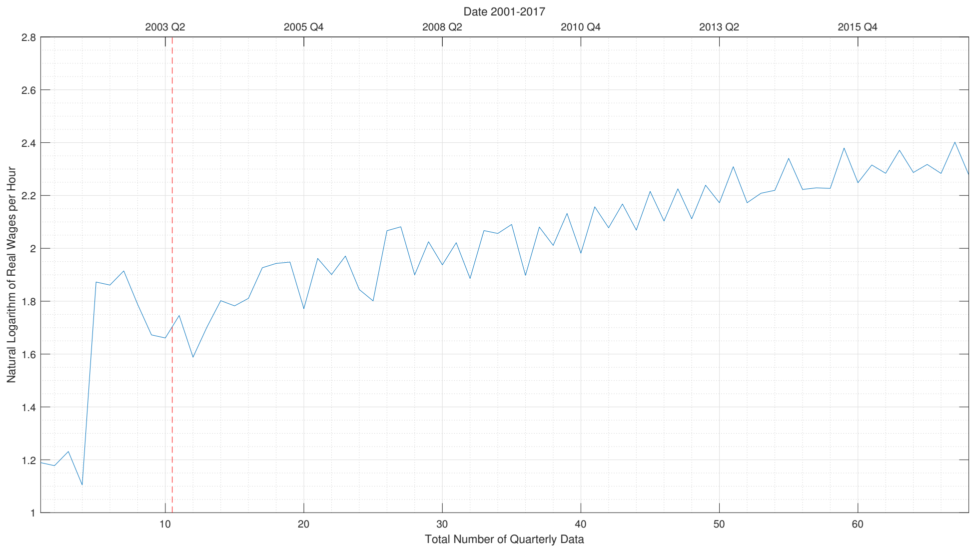

Figure 3: Quarterly Real Wages for Ecuador 2001-2017. Estimated wages are in the left side of the red line, and wages retrieved completely from ENEMDUs are in the right side of the red line.

2.5 Measuring Business Cycles

I use three different methods for decomposing the time series. First, I use the classic method proposed by Hodrick and Prescott (two-sided HP filter) (1981, 1997); this technique has been broadly used in academic research, policy studies, and private-sector analysis. Second, I use the “one-sided or single-sided HP filter”; this procedure is similar to the first one but with an adjustment—single-sided HP uses only available information at the time the assessment was made. [4] Third, I use the method proposed by James Hamilton, which is the filter used in the RBC model calibrated for Ecuador —before applying the filter, the data were log-linearizing. Moreover, note that Hamilton filter eliminates the first eleven observation in the data-set.

I use Hamilton filter because HP filter has several problems. One of the main arguments against Hodrick and Prescott is that “HP filter produces series with spurious dynamic relations that have no basis in the underlying data-generating process” (Hamilton, 2018); even the one-

[4] In fact, the two-sided HP filter applies large symmetrical weights to the endpoint of the observed values; which induce distortions to the filtered values at the most recent time periods (Van Vuuren, 2012). That is why the single-side HP filter tries to correct its estimation using only information available at the time the assessment was made.

sided HP filter does not eliminate spurious predictability. Another limitation for the HP filter is the value used for the parameter λ; Hodrick and Prescott suggest a set of constant smoothing parameter based on the periodicity of the time series; however, there are many authors like Ravn & Uhlig (2002) that recommend a set of parameters different to the ones suggested by Hodrick and Prescott. For example, in literature, λ usually is 100 for annual data; however, Ravn & Uhlig (2002) show in their work that λ should be 6.25. As a result, changing λ will come up with different estimations.

In figure 4, I present the results of output (trend and cycle) measured by Hamilton and HP (two- and single- sided) filter. On the top of figure 4, I show the trend of output, where two-sided HP displays the most linear trend. On the bottom of figure 4, I exhibit the cyclical component of output, where there are two recession periods (1998-2001 and 2014-2017). First of all, Hamilton filter measures the longest duration of recessions; this is more clear in the second recession where Hamilton filter shows a decreasing variation from 2012-2016, where both HP start their decreasing variation from 2014-2016. Second, the deepest recessions are measured with Hamilton filter. In fact, these recessions are about 7% and 5% more deviations than the results of both HP. On the other hand, the highest economic upswings(2004-2005 and 2010-2013) are also measured with Hamilton filter, where the difference with the other filters are around 8% and 5% deviations.

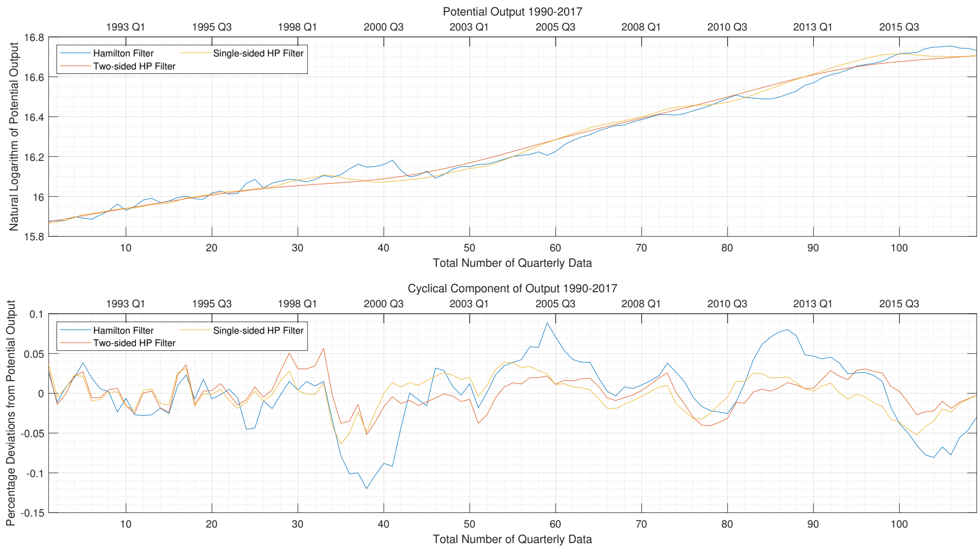

Figure 4: Potential and Cyclical Output Measured with the Three Filters 1990Q4-2017Q4. On the top of the figure, there is the potential output, where Hamilton filter seems to estimate the most non-linear trend. On the bottom of the figure, there is the cyclical component of output, where the classic two-sided HP filter seems to capture less volatility than the other two filters.

In figure 5, I present the cyclical component of consumption measured by Hamilton and HP (two- and single-sided) filter. In the first recession period (1998-2001), Hamilton filter shows consumption was about 20% deviations under potential consumption; a result that shows a difference of 12% deviations with two-sided HP, and 8% deviations with single-sided HP. In the second recession period (2014-2017), the results are quite similar with the three filters; however, Hamilton filter measures 4% deviations more than singled-sided HP and 5% deviations more than two-sided HP.

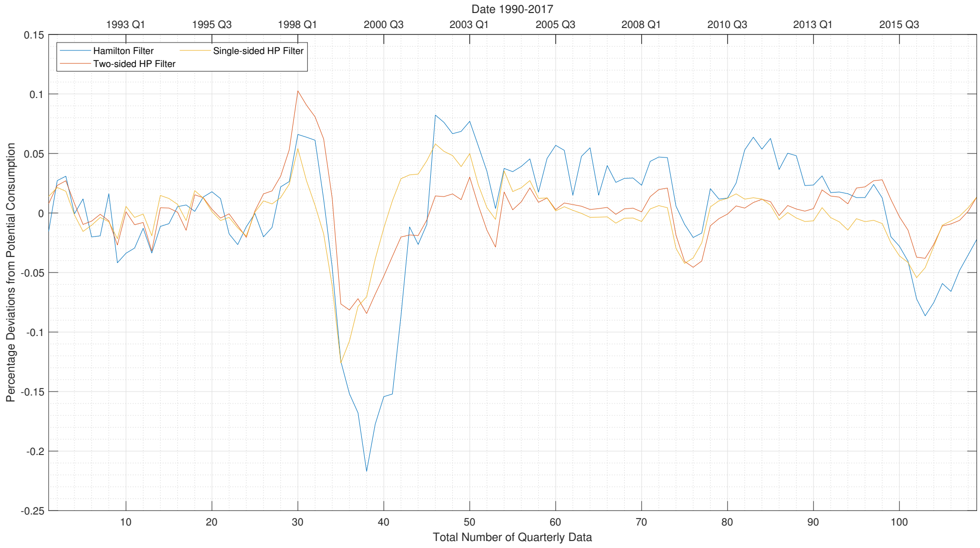

Figure 5: Cyclical Component of Consumption 1990Q4-2017Q4. The "y" axis represents the percentage of deviations from potential consumption. Hamilton filter seems to measure more volatility than the HP ones; clearly, this affirmation can be seen in the period of recession between 32 and 45 quarter.

In figure 6, I present the cyclical component of investment measured by Hamilton and HP (two- and single-sided) filter. In the second recession period (2014-2016), Hamilton filter shows more percentage deviations from potential investment than the others two filters; in fact, Hamilton filter measures almost -15% deviations, while HP (single- and two-sided) filters measure respectively -5% and -3% deviations. Moreover, Hamilton filter seems to measure more volatility than both HP; clearly, this affirmation is visible from 2008-2017.

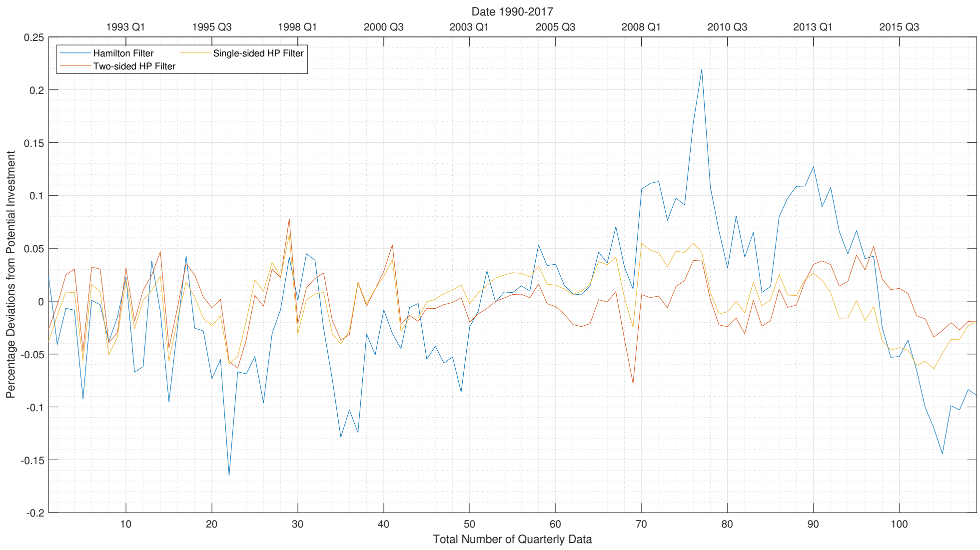

Figure 6: Cyclical Component of Investment 1990Q4-2017Q4. The "y" axis represents the percentage of deviations from potential investment. Hamilton filter seems to measure more volatility than the HP ones; clearly, this affirmation can be seen since the 65 quarter.

In figure 7, I present the cyclical component of hours worked measured by Hamilton and HP (two- and single-sided) filter. The results seem to be similar; however, Hamilton measures more volatility from 1990-2002. Additionally, in figure 8, I present the cyclical component of real interest rate measured by the three filters. The volatility estimated by single-sided HP filter seems to be grater that the other filters; this affirmation is visible from 1990-2009. Nevertheless, Hamilton filter keeps measure greater deviations than the others. Further, in figure 9, I present the cyclical component of real wages, where the three filters seem equally volatile.

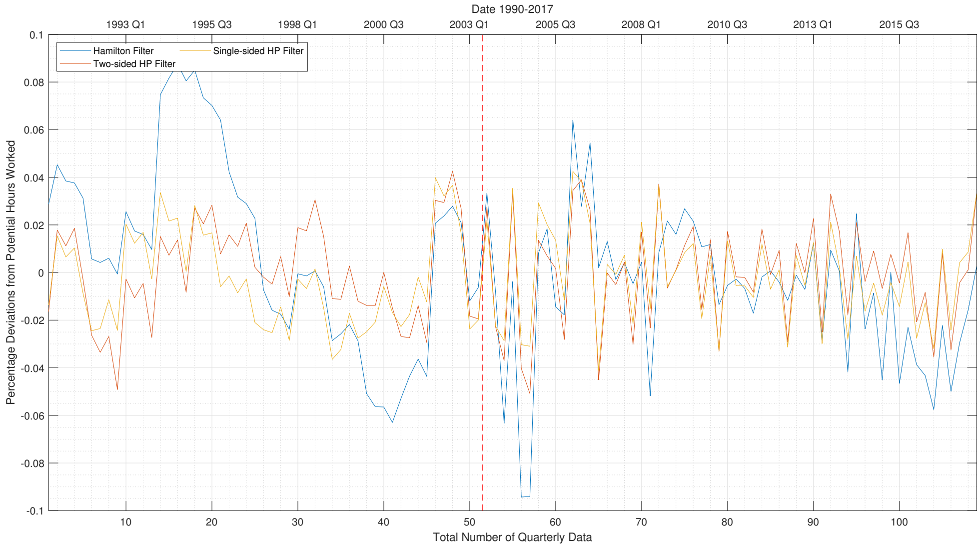

Figure 7: Cyclical Component of Hours Worked 1990Q4-2017Q4. The "y" axis represents the percentage of deviations from potential hours worked. Estimated hours worked are in the left side of the red line, and hours worked retrieved completely from ENEMDUs are in the right side of the red line. Hamilton filter measures more volatility than the HP ones; an affirmation that is clear in all the period.

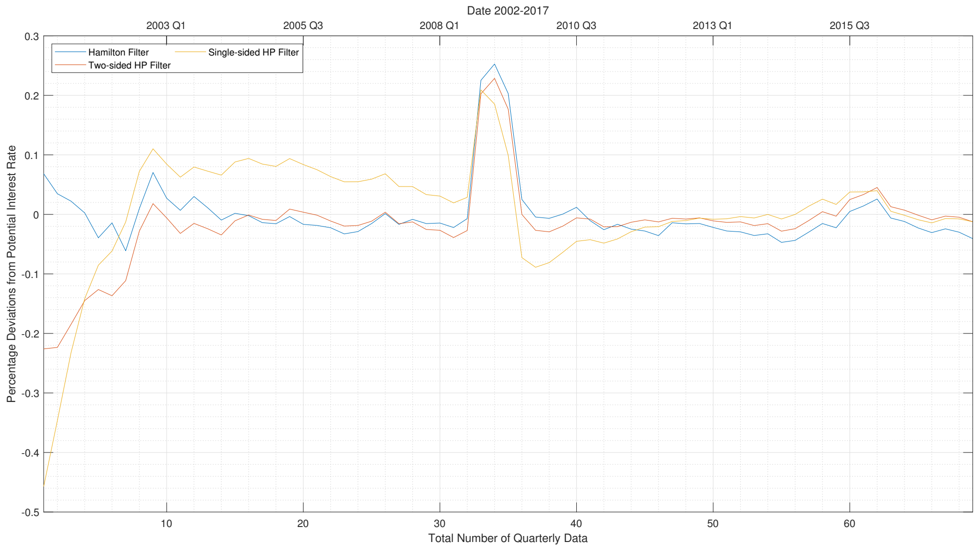

Figure 8: Cyclical Component of Interest Rate 2002Q4-2017Q4. The "y" axis represents the percentage of deviations from potential Interest Rate. Here, the single-sided HP filter seems to measure more volatility than the others (Hamilton filer and two-sided HP filter); especially, this affirmation can be seen from 2002-2008.

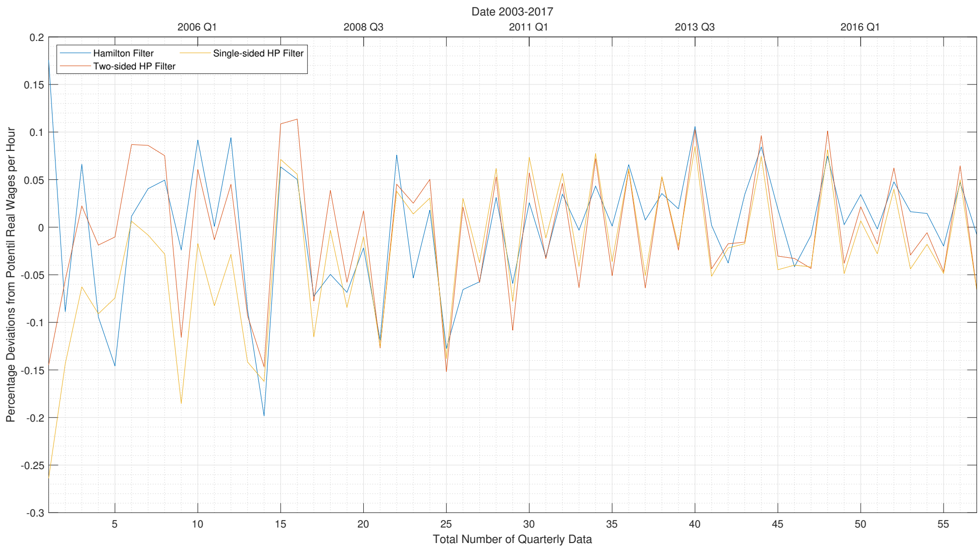

Figure 9: Cyclical Component of Real Wages 2003Q4-2017Q4. The "y" axis represents the percentage of deviations from potential Real Wages per Hour. Here, the volatility of the time series seems to be similar with the three filters.

2.6 Business Cycles Statistics for the Ecuadorian Economy

Summary statistics for the cyclical component of Ecuadorian aggregate data (measured by Hamilton filter) are displayed in table 3. Indeed, the standard deviation, the relative standard deviation with respect to the output standard deviation, the first order autocorrelation coefficient, and the contemporaneous correlation coefficient with respect to the output of each variable are computed. Briefly, the standard deviation (a measure of volatility) and the relative standard deviation present an inconsistent behavior in the data; consumption is more volatile than output. A fact that has been documented in the literature about business cycles in emerging economies (Aguiar & Gopinath, 2007); however, this only holds for the period 1995-1999.

Table 3: Business Cycles Statistics for the Ecuadorian Economy from 1990Q4 to 2017Q4

Variable	Volatility	Relative Volatility	First Order Autocorrelation	Correlation with Output
Output	4.33	1.00	0.90	1.00
Consumption	5.71	1.32	0.90	0.83
Investment	17.14	3.96	0.87	0.69
Hours Worked	3.66	0.85	0.70	0.27
Note:	*Cyclical component was measured by Hamilton Filter.*			

I divide the data in three periods, as shown in table 4, where the relative standard deviation of consumption with output presents two completely different behaviors; a value greater and lower than one. Indeed, the period from 1995 to 1999 shows the relative volatility of consumption with respect to output is almost double. A Chow test, where the null hypothesis is that the coefficients in two linear regressions on different data sets are equal (Chow, 1960), for a structural break is made for the first quarter of 2000 (as it is shown in table 5); the presence of a structural break is found (reject of the null hypothesis at the 99% confidence level). The principal reason of this break is the dollarization in Ecuador, an announcement that was officially made in January 2000 (Comercio, 2014). That is why the data used in the RBC model are from 2000-2017.

Table 4: Comparison of Business Cycles Statistics for the Ecuadorian Economy. This table shows that the relative volatility of consumption with output has a particular behavior in the period from 1995 to 1999.

Variable	Volatility	Relative Volatility
1990Q4-1994Q4		
Output	2.10	1.00
Consumption	2.08	0.98
Investment	7.71	3.65
1995Q1-1999Q4		
Output	5.13	1.00
Consumption	10.03	1.95
Investment	28.30	5.51
2000Q1-2017Q4		
Output	4.25	1.00
Consumption	3.86	0.90
Investment	13.19	3.10
Note:	*Cyclical Component was measured by Hamilton Filter.*	

Table 5: Chow Test for Structural Break, First Quarter of 2000

Test decision	**P-values**	**Test Statistics**	**Critical Values for the Test**
Reject	4.6511e-48	321.7559	3.0744
Note: The p-value is accepted for a 99% of confidence			

In table 6, I present the business cycles moments for Ecuador measured with the three filters (Hamilton, two-sided HP, and single-sided HP). The principal result is that Hamilton filter measures more volatility in the variables than the other filters—except with wages and interest rate. Another important difference is that Hamilton filter shows wages and interest rate acyclical; this affirmation is based on the correlation with output, where a positive value close to one indicates a procyclical behavior, and a negative value close to one indicates a countercyclical behavior. However, both HP filter show a procyclical or countercyclical behaviour with wages and interest rates—a result that is spurious.

In table 6, section A, I exhibit the results of Hamilton filter, where it shows that consumption, hours worked, and technological shock are less volatile than output; on the other hand, investment, interest rate, and wages are more volatile than output. These results are important because they are similar with the ones presented by King & Rebelo (1999), where consumption is less volatile than output, and investment is about three times as volatile as output. In addition, first order autocorrelation statistics show substantial persistence, because on average its coefficient is 0.85 (wages and hours worked are omitted)—it shows substantial persistence because its coefficients are close to 1. Moreover, almost all variables are procyclical (except wages and interest rate). Further, comparing the volatility of these results with USA, it can be claimed that EMEs are more volatile than industrialized economies (Lane, 2003). Additionally, Ecuadorian real wages are more volatile than output; an affirmation that does not occur in the United States (King & Rebelo, 1999).

Table 6: Business Cycles Moments for the Ecuadorian Economy from 2002Q4 to 2017Q4

Variable	**Volatility**	**Relative Volatility**	**First Order Autocorrelation**	**Correlation with Output**
Section A: Hamilton Filter.				
Output	4.16	1.00	0.93	1.00
Consumption	3.48	0.84	0.87	0.77
Investment	12.49	3.00	0.90	0.57
Hours Worked	2.91	0.70	0.29	0.25
Wages per Hour	6.80	1.63	-0.07	0.06
Interest Rate	5.61	1.35	0.73	-0.01
Tech. Shock	3.40	0.82	0.82	0.71
Section B: Single-sided Hodrick-Prescott Filter.				
Output	2.28	1.00	0.92	1.00
Consumption	2.14	0.94	0.84	0.80
Investment	6.13	2.70	0.76	0.56
Hours Worked	2.10	0.92	-0.16	0.18
Wages per Hour	7.38	3.24	-0.04	-0.16
Interest Rate	5.82	2.56	0.81	0.39
Tech. Shock	1.70	0.75	0.39	0.45
Section C: Two-sided Hodrick-Prescott Filter.				
Output	1.95	1.00	0.87	1.00
Consumption	1.72	0.88	0.71	0.70
Investment	6.46	3.32	0.74	0.59
Hours Worked	2.28	1.17	-0.24	0.16
Wages per Hour	7.02	3.61	-0.35	0.15
Interest Rate	4.89	2.51	0.67	0.19
Tech. Shock	1.86	0.96	0.35	0.51

Notes: Summary statistics for real wages were computed from 2003Q1 to 2017Q4. The compute of technological shock is shown further. All variables are in logarithms (except interest rate). Output, consumption, investment, and hours worked are in per capita terms. Real wages is the compensation per hour.

3 Theoretical Model

The RBC model assumes an economy with two representative agents; Household and Firm. Both agents maximize their benefits subject to their respective constraints in every period. Government is not included in this model, neither prices.

3.1 Household

For the Household, I write an utility function that is separable between consumption c_t and leisure x_t. On the other hand, I also write several constraints for this agent: budget, time, and transitivity condition. The first constraint means the Household must decide how much to consume today and how much to save for the future. Moreover, the Household has to distribute one unit of time between leisure and work. Additionally, with the transitivity condition, I guarantee that assets (a_t) and consumption (c_t) will converge to a steady state.

I write the Household's problem as

$$\begin{aligned}
\max_{c_t, a_{t+1}} \quad & \mathbb{E}_1 \sum_{t=1}^{\infty} \beta^{t-1}[U(c_t) + \psi V(x_t)] & \\
\text{s.t.} \quad & c_t + \gamma a_{t+1} = w_t l_t + (1+r_t)a_t & \text{Intertemporal budget constraint} \\
& x_t + l_t = 1 & \text{Time constraint} \\
& \lim_{t\to\infty} \beta^t \frac{\partial U(c_{t+1})}{\partial c_{t+1}} a_{t+1} = 0 & \text{Transitivity condition} \\
& c_t > 0 & \\
& a_{t+1} > 0, & \text{for } t > 0
\end{aligned}$$

where $\mathbb{E}$ is the expected value, β is the discount factor over time, $U(\ )$ and $V(\ )$ are the utility functions, and ψ is the relative weight of leisure with consumption. Therefore, γ is the rate of technological shock, l_t is the percentage of time dedicated to working, r_t is the interest rate, and a_t is the accumulation of assets in period t. Equally important, I write a constant elasticity of substitution (CES) function for the utility functions (U and V):

$$U(c) = \frac{c^{1-\eta}}{1-\eta} \qquad\qquad V(x) = \frac{x^{1-\eta}}{1-\eta}$$

Finally, η is the risk aversion coefficient; "a range of microeconomic and asset-pricing evidence suggest a coefficient of risk aversion of $\eta = 1$" (King & Rebelo, 1999).

As this is a dynamic model, I use the Bellman Equation to set up the problem:

$$\begin{aligned}
V(a_t, w_t, r_t) \quad = \quad \max_{c_t, x_t, a_{t+1}} \quad & U(c_t) + \psi V(x_t) + \beta \mathbb{E}_t V(a_{t+1}, w_{t+1}, r_{t+1}) \\
\text{s.t.} \quad & c_t + \gamma a_{t+1} = w_t l_t + (1+r_t)a_t \\
& x_t + l_t = 1.
\end{aligned}$$

Then, I applied the method of optimization of Lagrange to get the first order conditions:

$$\frac{\partial L}{\partial c_t} \Rightarrow \frac{\partial U}{\partial c_t} = \lambda_t, \tag{3}$$

$$\frac{\partial L}{\partial l_t} \Rightarrow \psi \frac{\partial V}{\partial l_t} - \lambda_t w_t = 0, \tag{4}$$

$$\frac{\partial L}{\partial a_{t+1}} \Rightarrow \beta \mathbb{E}_t \frac{\partial V(a_{t+1}, w_{t+1}, r_{t+1})}{\partial a_{t+1}} - \lambda_t \gamma = 0. \tag{5}$$

After replacing equations and doing some algebra, I could write the intertemporal first-order condition for this dynamic choice problem (Euler equation):

$$\beta \mathbb{E}_t (1 + r_t) \frac{\partial U}{\partial c_{t+1}} = \gamma \frac{\partial U}{\partial c_t}. \tag{6}$$

3.2 Firm

For the representative Firm, I write the firm's problem of maximizing profit by the production function minus the costs of employees and capital. The problem looks as

$$\max_{K_t, h_t} \qquad \pi(K_t, h_t) = A_t F(K_t, h_t X_t L_t) - w_t(h_t X_t L_t) - (r_t + \delta) K_t$$

where A_t is the technology shock, $F(\ )$ is the production function, K_t is stock of capital, h_t is the percentage of hours worked, X_t is the productivity of workers, and L_t is the labor of the economy. Moreover, the costs of the firm are the following: w_t is the workers' salary, r_t is the interest rate, and δ is the depreciation of the capital. In effective worker ($X_t L_t$) terms,

$$\pi(k_t, h_t) = A_t f(k_t, h_t) - w_t(h_t) - (r_t + \delta) k_t \tag{7}$$

represents the problem of the Firm; where equations:

$$\frac{\partial \pi}{\partial k_t} \Rightarrow r_t = A_t \frac{\partial f}{\partial k_t} - \delta, \tag{8}$$

$$\frac{\partial \pi}{\partial h_t} \Rightarrow w_t = A_t \frac{\partial f}{\partial h_t}, \tag{9}$$

are the first order conditions.

3.3 General Equilibrium

As Long Jr & Plosser (1983) illustrate in their work, a successful RBC model involves market clearing conditions. This mean, the three markets (spot markets for capital, labor, and output) need to be in equilibrium. With the Firm and Household maximizing respectively their utility and production, there are two markets in equilibrium. By Walras' law, if there are three markets, and two of them are in equilibrium, the third market is also in equilibrium (Shoven & Whalley, 1992).

4 Specifications of the RBC Model

4.1 Solow Residual

I estimate the Solow Residual from a Cobb-Douglas per capita equation in logarithms. The crucial assumption in the RBC model analysis is that the Solow residual can be separated between technological shock A (stochastic) and technological progress X (deterministic). The stochastic component follows an autoregressive—an AR(1) without constant—process in logs:

$$ln(A_{t+1}) = \rho \ln(A_t) + \varepsilon_{t+1}, \tag{10}$$

where ε_t follows a normal distribution with a mean 0 and variance σ^2. Additionally, the deterministic process responds to

$$X_{t+1} = \gamma X_t, \tag{11}$$

where $\gamma > 1$ is the growth rate of technological progress.

In the Cobb-Douglas equation:

$$Y_t = A_t K_t^{\alpha} (X_t h_t L_t)^{1-\alpha},$$

K_t is the stock of capital, α is a parameter representing the proportion capital in output, h is the proportion of time that the firm demands from the labor market, and L_t is the population. Since the production function is homogeneous of degree one, I can divide both sides of the Cobb-Douglas equation to compute production in per-capita terms. Then, applying logarithms I obtain,

$$ln(y_t) = \alpha \ln(k_t) + (1-\alpha) ln(h_t) + SR_t, \tag{12}$$

where $SR_t = ln(A_t) + (1-\alpha) ln(X_t)$ is the Solow residual. Since I have data on production, stock of capital, and hours worked, I can estimate equation 12 by OLS and obtain the SR_t.

Then, following King & Revelo, I recover the technological shock A_t by fitting a linear trend on the Solow residual. In particular, A_t are the residuals of this regression. These results are presented in figure 10, and the cyclical component of technological shock is displayed in figure 11.

Once A_t is extracted, all that remains is to estimate the underlying $AR(1)$ process.

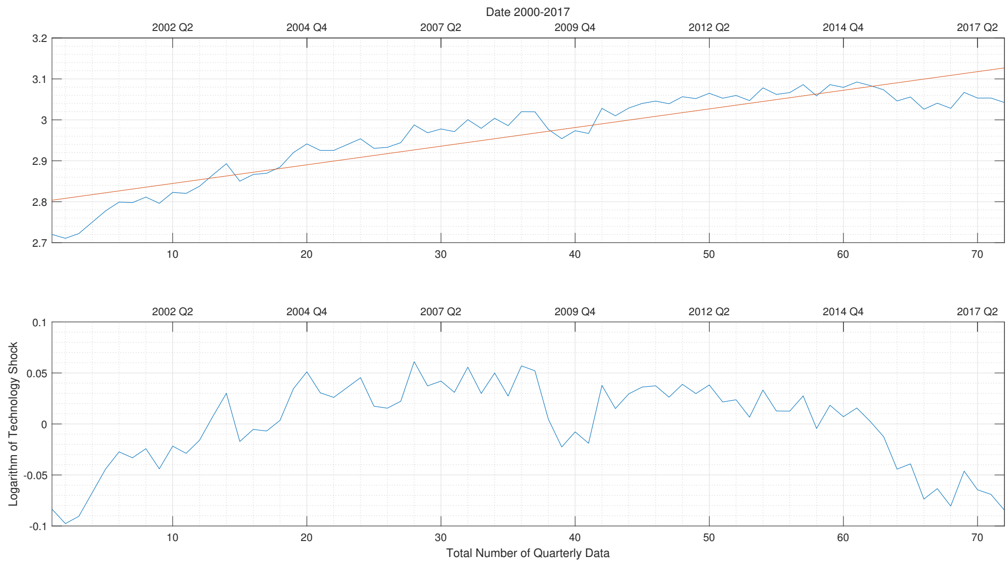

Figure 10: Quarterly Solow Residual and Technological Shock 2000-2017

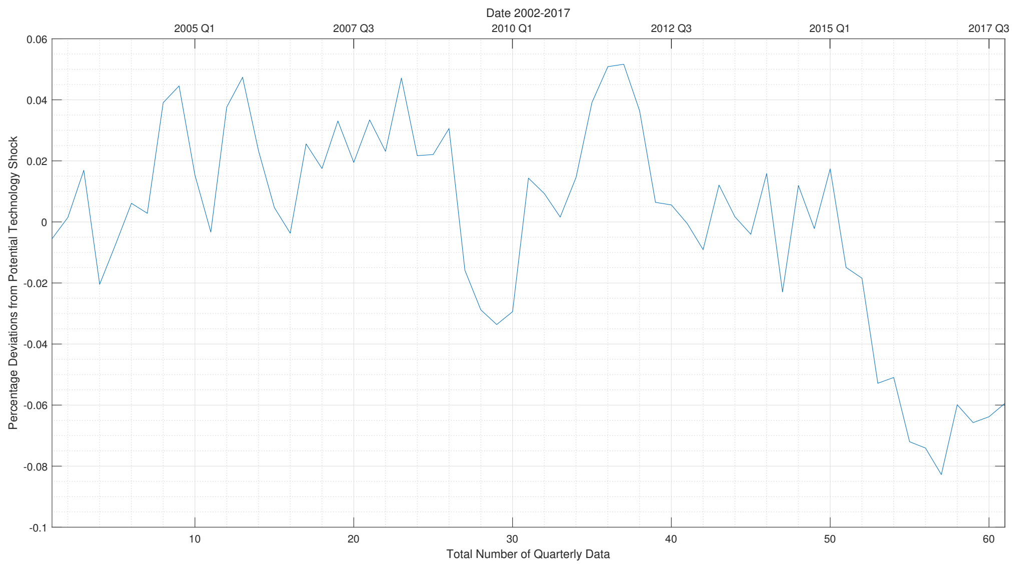

Figure 11: Cyclical Component of Technological Shock 2002Q4-2017Q4. The "y" axis represents the percentage of deviations from potential technological shock.

4.2 Calibration of the Model

The calibration of the model consists on two parts: Choosing functional forms and assigning parameter values. This parameter values represents key data in the economy. "The work of Kydland and Prescott (1982) and Long and Plosser (1983) illustrated the value of exploring the workings of stochastic dynamic models by using a 'reasonable' set of parameter values" (King & Rebelo, 1999). I used capital-output ratio and percentage of hours worked (in average) as targets for the RBC model; these parameters allow to compute not only β, but also ψ. Additionally, the value of alpha was taken from Grijalva et al. (2019). Equally important, δ was obtained from the perpetual inventory method in steady state—as shown in the preview section.[5] To sum up, all these "reasonable" values for the model are shown in table 7.

I use the "simulated method of moments" to get β and ψ. First, targets are computed, then the following loss function,

$$W = w_1(k-\hat{k})^2 + w_2(\phi - \hat{\phi})^2 \tag{13}$$

is applied. k is the target for the capital-output ratio and $\hat{k}$ is the corresponding simulated moment; similarly, ϕ denoted the target, and $\hat{\phi}$ is the simulated moment for hours worked. Additionally, w_i ($w_i = 1$ is set for all i) are the relative importance weights for each target. Finally, the process is the following: I set initial guesses for β and ψ, solve the general equilibrium, compute the simulated moments, apply the non-linear optimization algorithm "*Piecewise Cubic Hermite Interpolating Polynomial*" for several variables, and keep applying the algorithm until convergence—the convergence difference used was 1e-6.

Table 7: Calibration of the Model

β	ψ	γ	α	δ	σ	ρ	$\frac{K_t}{Y_t}$	$h_t(\%)$	η
0.8892	1.1483	1.0046	0.4315	0.0198	0.0200	0.8899	2.9941	0.3447	1
Note:	The depreciation rate (δ) is quarterly.								

5 Results

5.1 Business Cycles Moments

In table 8, I present the main empirical findings of the simulation—for 50,000 periods—of the RBC model calibrated for Ecuador. The summary statistics table, which summarizes the experience of the Ecuadorian economy, is comparable with the moments of the RBC

[5] The value of delta is computed with the estimated time series of stock of capital from 2000-2017.

model (table 6 and 8). First, it can be claimed that productive shocks produce an economic model as volatile as the Ecuadorian economy—in fact, the volatility of consumption, investment, and interest rate are almost the same found in the summary statistics of Ecuador—an affirmation that is made based on the extended Kydland and Prescott ratio (table 9), where the ratio of the variables (except hours worked and output) have values close to 1. This ratio suggests that the RBC model overexplains 42% of output business fluctuations. Moreover, it is attributed 68% of output fluctuations to productivity shocks. Further, the RBC model is consistent with literature on business cycles that investment is more volatile than output; in fact, the RBC model shows that investment is almost twice as volatile. Therefore, consumption is less volatile than output; a point that is not only consistent with the summary statistics of Ecuador, but also with the results found in the research of King & Rebelo (1999). Third, the RBC model is persistently high; the first order serial correlation for the variables has an average of 0.84; a result that is consistent with the summary statistics for Ecuador (wages and interest rate are omitted).

Table 8: Simulated Business Cycles Moments for the Ecuadorian Economy

Variable	**Volatility**	**Relative Volatility**	**First Order Autocorrelation**	**Correlation with Output**
Output	5.91	1	0.87	1
Consumption	4.10	0.69	0.89	0.97
Investment	11.16	1.89	0.79	0.91
Hours Worked	1.39	0.24	0.78	0.85
Wage	4.78	0.81	0.88	0.99
Interest Rate	4.23	0.71	0.79	0.72
Tech. Shock	4.03	0.68	0.85	0.99

After comparing the summary statistics with the simulated business cycles moments, we can observe that a RBC model produces a general good account of the Ecuadorian Economy. However, there are several evident discrepancies. First, the model—as previously said—overexplains the fluctuations for output and consumption. Furthermore, hours worked are less volatile in the RBC model than in the summary statistics of Ecuador. Moreover, the model produces strongly procyclical variables; a fact that does not reflect what can be observed in the data.

Table 9: Application of Kydland-Prescott Ratio

	Output	**Consumption**	**Investment**	**Wages**	**Interest Rate**	**Hours Worked**
Kydland-Prescott Ratio	1.420	1.178	0.893	0.702	0.754	0.477

5.2 Simulations of Ecuadorian Business Cycles

In figure 12, I present the time series generated by the RBC model driven by the Ecuadorian technological shock. The series of outputs show that the RBC model gives a good account of the quarter-to-quarter variation; a result that is similar to the one obtained from King & Rebelo (1999) with the USA economy. In consumption, there is a general good measure too, but the model seems to under-account in the moments of economic recession; this fact is clear from 2015-2017, where the economy seems to have the worst recession of the period. On the other hand, there are inconsistencies in the account of savings; during the period, the RBC model shows the savings are far more volatile than the ones in the economy. In hours worked, the RBC model also gives a poor account; the time series simulated are less volatile than the ones in Ecuador.

Moreover, in table 10, I present the real business cycles moments for the Ecuadorian economy driven by the Ecuadorian technological shock. Here, the relative volatility and the autocorrelation coefficient are similar to the ones presented in table 6—section A. However, the model still produce an economy high procyclical; an affirmation that does not occur in the data—especially with investment and hours worked.

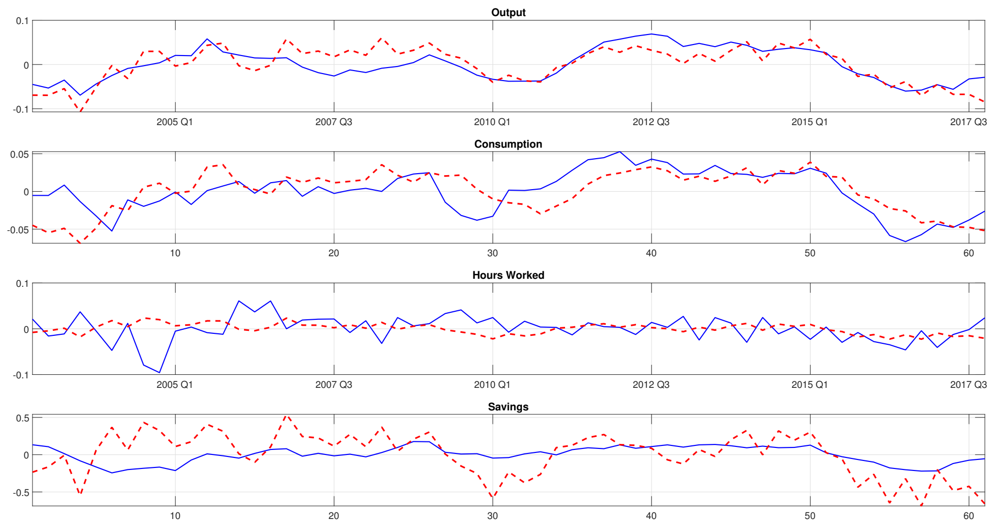

Figure 12: Comparison of Business Cycles Fluctuations with Ecuadorian Shock 2002Q4-2017Q4. Where the dashed line represents the simulated model driven by the Ecuadorian technological shock. On the top of the figure, the graph shows that Ecuador has had three economic recessions; the first from 2002-2004, the second from 2008-2011, and the third from 2016-2017. Further, savings are more elastic than consumption in periods of economic recession. Moreover, hours worked seem inelastic in periods of economic recession.

Table 10: The Real Business Cycles Moments for the Ecuadorian Economy from 2002Q4 to 2017Q4 (Driven by the Ecuadorian technological shock).

Variable	**Volatility**	**Relative Volatility**	**First Order Autocorrelation**	**Correlation with Output**
Output	3.67	1.00	0.91	1.00
Consumption	2.83	0.77	0.87	0.97
Investment	11.30	3.08	0.88	0.91
Hours Worked	2.85	0.78	0.26	0.85
Tech. Shock	2.91	0.79	0.69	0.99

6 Conclusions

Based on the application of the three filters (Hamilton, single-sided HP, and two-sided HP) to the time series, I found there were overwhelming differences. First, Hamilton filter measured higher percentage deviations than both HP (single- and two-sided) filters in economic recessions and upswings; these differences were between 8% and 5%. Further, Hamilton filter seemed to measure the longest duration in recession periods. Finally, some results changed based on the filter applied to the series; this occurs regarding the cyclicaloty of wages and interest rate. In particular, wages and interest rate were not procyclical neither countercyclical as the spurious results of two-sided and single-sided HP showed

In addition, for Ecuador, the RBC model produced output and consumption fluctuations that were significantly more volatile than their empirical counterpart. Moreover, 68% of the output fluctuations in the model were attributed to productive shocks. The volatility of consumption in the model represented 0.69 of output volatility. Furthermore, the RBC model and the data showed the typical high persistence of macroeconomic aggregates, where the first order serial correlation found in the business cycle statistics were, on average, 0.85 (wages and hours worked were omitted).

The RBC model for Ecuador also exposed several discrepancies with the data. First of all, the Keyland-Prescott ratio showed that the RBC over-explain output and consumption business fluctuations. Moreover, the model produced strong procyclical investment, hours worked, interest rate, and wages; contradicting the empirical findings. Nonetheless, understanding the implications derived from the calibration of the RBC model for Ecuador was particularly important for a dollarized economy, since monetary policy management is not available.

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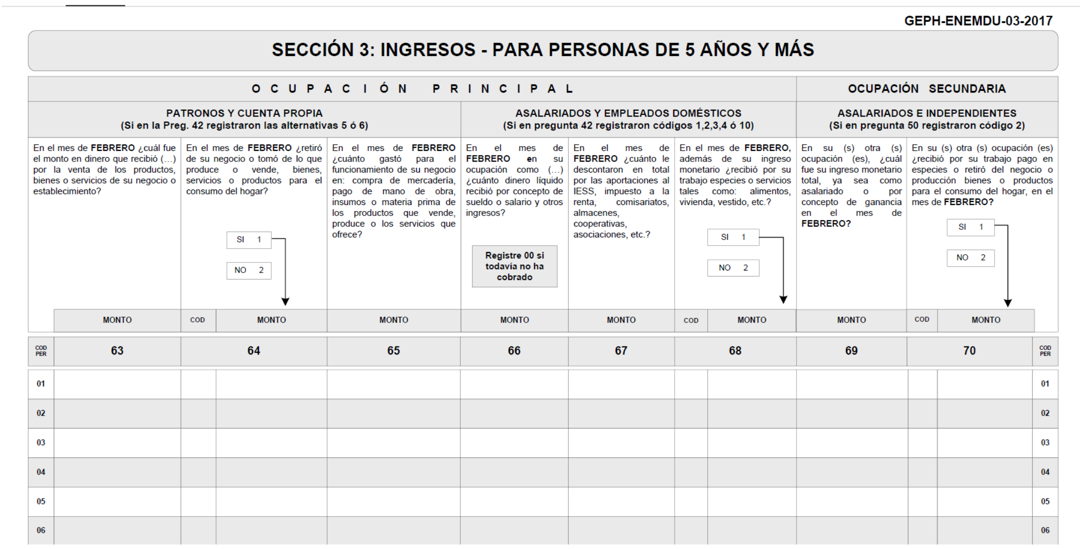
8 Appendix

8.1 Construction of Quarterly Wages

Wages are retrieved from the salary information of employees in ENEMDUs. The total amount of wages was the addition of net salary, salary deduction, and additional services or goods. Here, net salary is defined as the total amount of money received by the employee. Moreover, salary deduction includes social security, tax income, and so on. Additional services or goods are food, clothes, and so on. Figure 13 shows the survey, where wages are made by question 66, 67, and 68.



GEPH-ENEMDU-03-2017

SECCIÓN 3: INGRESOS - PARA PERSONAS DE 5 AÑOS Y MÁS

	O C U P A C I Ó N P R I N C I P A L								**OCUPACIÓN SECUNDARIA**			
	PATRONOS Y CUENTA PROPIA (Si en la Preg. 42 registraron las alternativas 5 ó 6)				**ASALARIADOS Y EMPLEADOS DOMÉSTICOS (Si en pregunta 42 registraron códigos 1,2,3,4 ó 10)**				**ASALARIADOS E INDEPENDIENTES (Si en pregunta 50 registraron código 2)**			
	En el mes de **FEBRERO** ¿cuál fue el monto en dinero que recibió (…) por la venta de los productos, bienes o servicios de su negocio o establecimiento?	En el mes de **FEBRERO** ¿retiró de su negocio o tomó de lo que produce o vende, bienes, servicios o productos para el consumo del hogar? SI 1 / NO 2		En el mes de **FEBRERO** ¿cuánto gastó para el funcionamiento de su negocio en: compra de mercadería, pago de mano de obra, insumos o materia prima de los productos que vende, produce o los servicios que ofrece?	En el mes de **FEBRERO en** su ocupación como (…) ¿cuánto dinero líquido recibió por concepto de sueldo o salario y otros ingresos? **Registre 00 si todavía no ha cobrado**	En el mes de **FEBRERO** ¿cuánto le descontaron en total por las aportaciones al IESS, impuesto a la renta, comisariatos, almacenes, cooperativas, asociaciones, etc.?	En el mes de **FEBRERO,** además de su ingreso monetario ¿recibió por su trabajo especies o servicios tales como: alimentos, vivienda, vestido, etc.? SI 1 / NO 2		En su (s) otra (s) ocupación (es), ¿cuál fue su ingreso monetario total, ya sea como asalariado o por concepto de ganancia en el mes de **FEBRERO?**	En su (s) otra (s) ocupación (es) ¿recibió por su trabajo pago en especies o retiró del negocio o producción bienes o productos para el consumo del hogar, en el mes de **FEBRERO?** SI 1 / NO 2		
	MONTO	COD	MONTO	MONTO	MONTO	MONTO	COD	MONTO	MONTO	COD	MONTO	
COD PER	**63**	**64**		**65**	**66**	**67**	**68**		**69**	**70**		COD PER
01												01
02												02
03												03
04												04
05												05
06												06

Figure 13: ENEMDU December 2017 Section 2: Income