CENTER FOR LATIN AMERICAN MONETARY STUDIES

MONETARIA

English Edition
Volume I, Number 2
July-December 2013

MONETARIA

English Edition

Volume I, Number 2, July-December 2013

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Assessing the Impact of Nonperforming Loans on Economic Growth in The Bahamas

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Output Gap and Neutral Interest Measures for Colombia

Abstract

Three new measures of the Colombian output gap and the real neutral interest rate are proposed. Instead of relying only on statistical filters, the proposed measures use semi-structural New Keynesian models,

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adapted for a small open economy. The output gap measures presented are in line with previous works for Colombia and capture all the turning points of the Colombian business cycle, as measured by Alfonso et al., 2011. They are also strongly correlated with inflation and precede its movements along the sample. The neutral interest rate computed indicates that the monetary policy stance has been overall countercyclical, but has failed to anticipate the output gap's movements, or at least react strongly enough to them.

Keywords: output gap, New Keynesian model, neutral interest rate.
JEL Classification: E23, E32, E43.

1. INTRODUCTION

The conduct of monetary policy requires information on the current state of the economy and a measure of the monetary stance. This information is crucial for policy makers but is by nature unobservable, and thus subject to great uncertainty, implying the need for methodologies capable to account for both things (Taylor, 1999, and Woodford, 2003a). This document uses semi-structural New Keynesian models to obtain such information for the Colombian economy in the 1994-2011 period.

The state of the economy is summarized in the output gap, defined as the difference between observed and potential output, the latter understood as the level of economic activity in absence of inflationary pressures. The output gap is therefore an indicator of inflation pressures and the dynamics of the aggregate demand.

The monetary policy stance is measured by the difference between the real interest rate and the neutral interest rate (Blinder, 1999), defined as an interest rate level at which the monetary authority exerts no influence over the behavior of the aggregate demand, in other words: "Any higher real interest rate constitutes *tight money* and will eventually imply falling inflation; and any lower real rate is *easy money* and signals eventually rising inflation" (Blinder, 1999, pp. 33). Note that the neutral rate is not equal to the natural rate of interest, for the latter is "the real rate of interest required to keep aggregate demand equal at all times to the natural rate of output" (Woodford, 2003a, p. 248). The natural rate is interpreted as a desirable level for the real interest rate, whereas the neutral rate only indicates the effect of the real interest rate over the output gap.

The output gap and the neutral interest rate must be inferred from the macroeconomic information available. For the output gap, the techniques to do so rely on the use of statistical tools such as filters, VARs, factor models, among others, that allow the decomposition of output in its trend component (associated with the potential output) and its cyclical component (associated with the output gap).[1] The neutral interest rate is more difficult to extract because its value is not necessarily related to a trend or smooth component of the real interest rate, moreover, this last variable is also unobservable, for it depends on the agents' inflation expectations.

In order to jointly estimate the desired variables it is necessary to account for the structural relations between them and other variables as the inflation rate, as well as variables that affect a small open economy, as the real exchange rate, the foreign interest rate, etc. Because of this, we expand a statistical model, the local linear trend model, with a New Keynesian model adapted for a small open economy. Three alternative specifications of the model, which differ in the way expectations are formed, are considered. This is done in order to present different measures of the output gap and the monetary stance while recognizing the lack of consensus in the literature over the way in which expectations should be modeled.[2] It must be noted that, although the use of several models helps to account for

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[1] Most of these techniques imply unwanted results over the relations of output's permanent and transitory component, making them completely correlated or orthogonal, depending on the method (Canova, 2007, Ch. 3).

[2] For example Rudebusch and Svensson (1999) argue for the use of backward looking expectations, Woodford (2003b) for forward looking expectations and Galí and Gertler (1999) for hybrid expectations.

the variability in the measurement due to model specification, it is not intended to address (nor solve) the inherent model uncertainty to which the measurement of this variables is subject (Orphanides and Williams, 2002).

In the first specification of the model, agents are assumed to follow predetermined rules when forming expectations. These rules are a function of current and lagged values of the variable over which the expectation is formed. In this way the model has a direct state space representation and the output gap can be extracted by means of the Kalman filter. In the second and third specifications, agents are assumed to have rational expectations about the future, taking into account all information available. In order to extract the output gap, the solution to the rational expectations equilibrium of the models has to be computed, and then the state space representation can be formulated.

The approach taken here is similar to the previous work of Echavarría et al. (2007) and Berg et al. (2006), and seeks to complement a literature already existing for Colombia, noting the works of González et al. (2011), Torres (2007), Rodríguez et al. (2006), Gómez and Julio (1998) and Cobo (2004) among many others. It is also closely related to various articles that seek to jointly estimate the dynamics of the output gap and the natural interest rate. This is the case of Laubach and Williams (2003), Garnier and Wilhelmsen (2009), Mesonnier and Renne (2007) and Castillo et al. (2006).

The description of the models is covered in Section 2. The models are estimated with Colombian data, this is described in Sections 3 and 4. Afterward they are used to extract the output gap measures for Colombia, this is discussed in Section 5. Finally, results for neutral interest rate estimates are presented in Section 6.

2. MODELS

Three models are used to extract information about the output gap and the neutral interest rate for Colombia in the 1994-2011 period. All models are built on top of a local linear trend model, introducing the neutral interest rate, and a more elaborate definition of the output gap, using a semi-structural new-Keynesian model for a small open economy. The models differ in the way expectations are defined. One of the models has backward looking expectations, another has forward looking expectations and in the last one expectations are formed in a hybrid manner, taking into account both past and future values of the variables.

The motivation for these models is twofold. First, they give economic structure to the output gap, and introduce the notion of a neutral interest rate, as opposed to the use of a purely statistical model. This allows to extract information from series other than the GDP when computing the output gap, and infer the dynamics of the neutral rate. This same strategy was used by González et al.(2011) for computing a measure of the Colombian natural interest rate, showing the differences between purely statistical and macroeconomic models. Second, since there is some degree of uncertainty regarding the mechanisms by which agents form inflation expectations we consider necessary to present different measures of the output gap and the neutral interest rate using different approaches to agents expectations in line with previous literature on New Keynesian models.

The remaining of this Section presents the main features of each model, Appendix A contains complete set of equations.

2.1 Local Linear Trend Model

The local linear model will be used as a base for building the more elaborate macroeconomic models that are shown below. It is a purely statistical model that decomposes output (y) into a trend component with an stochastic drift $(\overline{y}_t)$ and the output gap $(\tilde{y}_t)$.

The output gap is given by:

1 $$\tilde{y}_t = y_t - \overline{y}_t \,.$$

The output trend component is assumed to follow a random walk with a stochastic drift:

$$\overline{y}_t = \overline{y}_{t-1} + g_t + \varepsilon_t^{\overline{y}} . \quad (2)$$

The drift $\left(g_t\right)$ is the growth rate of the trend component of output and is given by:

$$g_t = \left(1-\tau\right)\overline{g}_{ss} + \tau g_{t-1} + \varepsilon_t^g , \quad (3)$$

both $\varepsilon_t^{\overline{y}}$ and ε_t^g are i.i.d. Gaussian disturbances. The shocks' variances $\left(\sigma_{\overline{y}}^2, \sigma_g^2\right)$ and τ are parameters to be estimated.

Note that $\varepsilon_t^{\overline{y}}$ and ε_t^g account for permanent shocks to the level of potential output, providing an explanation for movements in that variable. This feature allows to use data on the GDP level when estimating the output gap. However, the local linear model does not give any economic structure to the output gap, and does not include other variables, also relevant for monetary policy. Because of that, this model is complemented with economic structural relations as described in the models below.

2.2 Backward Looking Semi-structural Model

The model consists in equations 1, 2, and 3, an IS curve, a Phillips curve, an uncovered interest parity (UIP) condition, and equations for the dynamics of the real interest rate and the real exchange rate.

The IS curve is given by:

$$\tilde{y}_t = \beta_1 \tilde{y}_{t-1} - \beta_2 \left(r_{t-1} - \overline{r}_{t-1}\right) + \beta_3 \tilde{q}_{t-1} + z_t^y . \quad (4)$$

According to this representation, the output gap depends on its past value, the real interest rate gap (being $\overline{r}_t$ the neutral rate of interest), the real exchange rate gap $\left(\tilde{q}_t\right)$ and an exogenous variable z_t^y that stands for the effects of demand shocks $\left(\varepsilon_t^y\right)$ in the is curve. z_t^y is assumed to follow an AR(1) process:

5 $$z_t^y = \rho_y z_{t-1}^y + \varepsilon_t^y .$$

Note that when the real interest rate r_t is equal to $\overline{r_t}$ the term of the is curve involving the real interest rate is canceled, thus eliminating the effect of the real interest rate over the output gap. This is why the variable $\overline{r_t}$ is taken as the neutral interest rate.

The Phillips curve for the annualized quarterly inflation rate, is given by:

6 $$\pi_t = \pi_{t+1|t}^e + \lambda_2 \tilde{y}_{t-1} + \lambda_3 \left(q_t - q_{t-1}\right) + z_t^\pi ,$$

where $\pi_{t+1|t}^e$ denotes the period t expectations over period $t+1$ inflation, q_t is the real exchange rate level, and z_t^π is an exogenous variable that stands for the effects of supply shocks $\left(\varepsilon_t^\pi\right)$ over the Phillips curve. As before, z_t^π is assumed to follow an AR(1) process:

7 $$z_t^\pi = \rho_\pi z_{t-1}^\pi + \varepsilon_t^\pi .$$

Inflation expectations are defined as an average between the inflation target $(\overline{\pi})$ and lagged annual inflation $\left(\pi_{4,\,t-1}\right)$, this is:

8 $$\pi_{t+1|t}^e = \lambda_1 \overline{\pi} + \left(1 - \lambda_1\right) \pi_{4,\,t-1} ,$$

as for the annual inflation $\left(\pi_{4,t}\right)$ it follows from the definition of π_t that:

9 $$\pi_{4,t} = \frac{1}{4}\left(\pi_t + \pi_{t-1} + \pi_{t-2} + \pi_{t-3}\right) ,$$

where π_t stands for the period to period change in prices.

The model is complemented by three sets of equations characterizing the dynamics of the real interest rate, the foreign real interest rate and the real exchange rate.

The real interest rate must satisfy two equations. The Fisher equation 10, and an uncovered interest parity condition 11:

10 $$r_t = i_t - \pi^e_{t+1|t},$$

11 $$r_t - r^*_t = \left(\overline{r}_t - \overline{r}^*_t\right) + 4\left(q^e_{t+1|t} - q_t\right) + \varepsilon^r_t,$$

where r^*_t is the foreign real interest rate, $\overline{r}^*_t$ its neutral value at period t, and $q^e_{t+1|t}$ is the one period ahead expected value of the real exchange rate. ε^r_t is a shock that affects the UIP.

The neutral interest rate is assumed to follow an AR(1) process, this means that it is an exogenous factor for the model, nevertheless its value can be extracted from the model, since the relation between the neutral rate and other variables is well defined by IS curve 4, and the UIP condition 11. Since all equations operate simultaneously in the equilibrium, the value of the neutral rate depends implicitly on the foreign interest rate, the real exchange rate and the overall state of the economy.[3]

12 $$\overline{r}_t = \rho_r \overline{r}_{t-1} + \left(1 - \rho_r\right)\overline{r}_{ss} + \varepsilon^{\overline{r}}_t.$$

The real exchange rate gap is defined as the difference between its realized and its trend value:

13 $$\tilde{q}_t = q_t - \overline{q}_t,$$

its trend is assumed to follow a random walk:

14 $$\overline{q}_t = \overline{q}_{t-1} + \varepsilon^q_t$$

and the expected real exchange rate is assumed to be an average between the trend, and the lagged value of the exchange rate:

[3] The relation between the neutral interest rate and the potential output's growth rate $\left(g_t\right)$ is not included explicitly, as is done by Laubach and Williams (2003), Mesonnier and Renne (2007) and Echavarría et al. (2007). Nevertheless, an extra exercise was carried out modifying the definition of the neutral interest rate. The potential output's growth rate recovered was very stable and implied little changes over the neutral rate, with respect to the results presented in Section 5.

15 $$q^{e}_{t+1|t} = \varphi \overline{q}_t + (1-\varphi) q_{t-1} .$$

Finally, the nominal interest rate responds to a contemporaneous Taylor rule,[4] the rule's intercept is given by the neutral interest rate plus the inflation target, following Taylor(1993) and Woodford (2003a) and it is assumed that the foreign neutral interest rate and the foreign interest rate gap evolve exogenously following AR(1) processes:

16 $$i_t = \gamma_1 i_{t-1} + (1-\gamma_1)\left((\overline{r}_t + \overline{\pi}) + \gamma_2 (\pi_{4,t} - \overline{\pi}) + \gamma_3 \tilde{y}_t\right) + \varepsilon^i_t ,$$

17 $$\overline{r}^*_t = \rho_{r^*} \overline{r}^*_{t-1} + (1-\rho_{r^*}) \overline{r}^*_{ss} + \varepsilon^{\overline{r}^*}_t ,$$

18 $$r^*_t - \overline{r}^*_t = \kappa (r^*_{t-1} - \overline{r}^*_{t-1}) + \varepsilon^{r^*}_t .$$

All ε^j variables, with $j \in \{y, \pi, r, q, \overline{r}, \overline{r}^*, r^*\}$, are assumed to be i.i.d. Gaussian disturbances with mean zero and constant variance.

2.3 Hybrid Semi-structural Model

The second model is built on top of the adaptive expectations model and differs from it in the way inflation and real exchange rate expectations are formed, and in the dynamics of the nominal interest rate, for which it is now possible to assume a forward looking Taylor rule. Additionally a forward looking component is introduced into the is curve.

The IS curve 4 is modified and is given by:

19 $$\tilde{y}_t = \beta_1 \tilde{y}_{t-1} - \beta_2 (r_{t-1} - \overline{r}_{t-1}) + \beta_3 \tilde{q}_{t-1} + \beta_4 E_t \{\tilde{y}_{t+1}\} + z^y_t .$$

[4] As in Laubach and Williams (2003) and Mesonnier and Renne (2007) the equilibrium is well defined in the absence of a Taylor rule, and the nominal interest rate can be taken as an exogenous variable. The Taylor rule is included for comparison with the rational expectations models, where it plays a crucial role for equilibrium determinacy (see Taylor, 1999), and Woodford, 2003a).

Inflation expectations (Equation 8) are also modified and are now given by the average between expected and lagged annual inflation:

$$\pi^e_{t+1|t} = \lambda_1 E_t \left\{ \pi_{4,t+4} \right\} + \left(1 - \lambda_1\right) \pi_{4,t-1}. \tag{20}$$

Exchange rate expectations formulation is also modified, and is the average between expected and lagged exchange rate. The relative importance of each component is given by the parameter φ. The equation that characterizes the expectations is:

$$q^e_{t|t+1} = \varphi E_t \left\{ q_{t+1} \right\} + \left(1 - \varphi\right) q_{t-1}. \tag{21}$$

The Fisher equation 10 is defined in terms of the expected inflation corresponding to rational expectations:

$$r_t = i_t - E_t \left\{ \pi_{t+1} \right\}. \tag{22}$$

Finally, the Taylor rule is modified to include the four-periods expected value of inflation, taking into account the lagged effect of monetary policy:

$$i_t = \gamma_1 i_{t-1} + \left(1 - \gamma_1\right)\left(\left(\bar{r}_t + \bar{\pi}\right) + \gamma_2 E_t \left(\pi_{4,t+4} - \bar{\pi}\right) + \gamma_3 \tilde{y}_t\right) + \varepsilon^i_t. \tag{23}$$

2.4 Forward Looking Semi-structural Model

The last model can be represented as a special case of the hybrid model, restricted so that the IS curve (Equation 19), the inflation expectations (Equation 20), and the exchange rate expectations (Equation 21) are only forward looking. This means restricting the parameters so that $\beta_1 = 0$, $\lambda_1 = 1$ and $\varphi = 1$.

3. DATA

A set of five macroeconomic variables is used for the estimation and filtering process. All variables are used in quarterly frequency with a sample that ranges from the first quarter of 1994 to the last quarter of 2011, thus the sample has 72 observations.

The series used are the natural logarithm of the seasonally adjusted GDP, total CPI inflation (seasonally adjusted), and the nominal interest rate, taken as the average rate of the 90 days certificate of deposit (CDT). As for foreign variables, the real interest rate is taken as the 90 days certificate of deposit rate for the USA,[5] and the real exchange rate corresponds to the bilateral exchange rate between Colombia and the USA, computed with the average bilateral nominal exchange rate and the CPI indices for both countries (all items included).

Two things are worthwhile mentioning. The first is that, as in Mesonnier and Renne(2007), the real interest rate is computed in-model, in a way consistent with the models' inflation expectations. The second is that the Colombian economy experienced a disinflation period in the 2000s, with a decreasing inflation target. Since the models take the nominal series as stationary, we shall work with the domestic inflation and nominal interest rate series relative to the inflation target; this eliminates the trend from the series and makes them compatible with the models definitions. Two parallel exercises were conducted incorporating a time varying inflation target, assuming AR(1) and random walk dynamics; the results are robust to this changes.

4. PARAMETRIZATION

The parameters are divided in two sets. One is fixed and is composed mainly by those of the steady state, and the other one is to be estimated. The estimation is done by means of Bayesian techniques.

4.1 Fixed Parameters

The parameters that determine the long run values of the variables in the models are fixed according to the characteristics

5 The real rate is computed ex post with the US CPI inflation; the CPI is seasonally adjusted and all items are included.

of Colombian data. The long run rate of output growth is fixed at 4% in annual terms $(\overline{g}_{ss} = 0.04)$. The inflation target is set at 3% $(\overline{\pi} = 0.03)$ accordingly to the mid point of the long run target band for inflation of the Banco de la República. Since Colombia is a small open economy, its real interest rate is given in the long run by the foreign interest rate, hence the domestic and foreign real interest rates are set to 2.5% in the steady state $(\overline{r}_{ss} = \overline{r}^*_{ss} = 0.025)$. This fact along with the absence of drift in the equilibrium exchange rate process imply that there is no depreciation in steady state.

4.2 Estimation

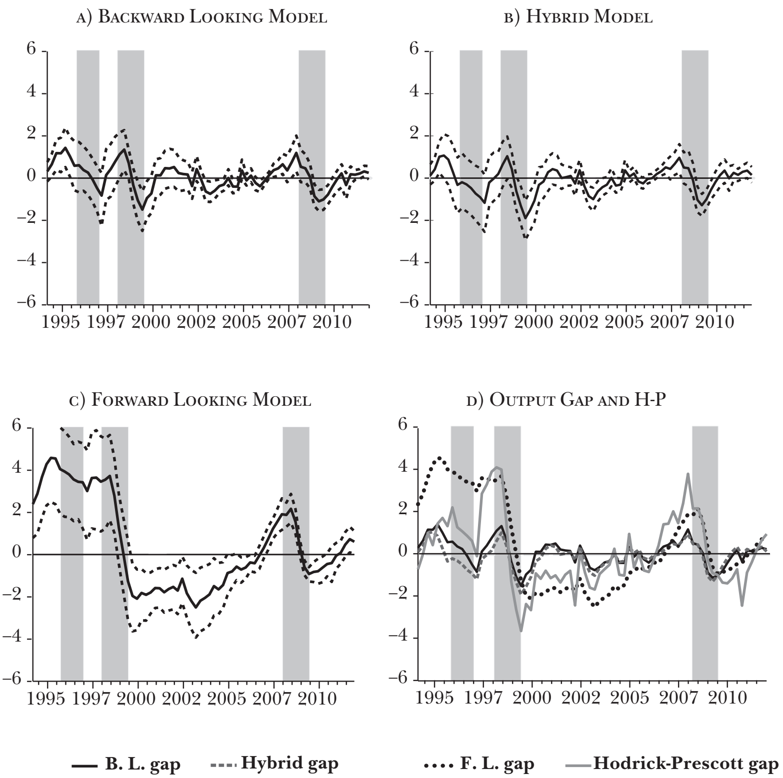
Parameters that are not fixed are estimated by means of Bayesian techniques, combining prior information with the model's likelihood function (computed with the Kalman filter). These techniques have been applied with great success to the estimation of DSGE models in the literature (e.g., Smets and Wouters, 2007), and, as noted in An and Schorfheide(2007), have many advantages when dealing with short time series and identification issues (common in semi-structural models), they also provide a natural benchmark for model comparison (the model's marginal likelihood).

Two chains of 100,000 draws are used when computing the parameters' posterior distributions. There are three types of prior distributions used. For bounded parameters (between zero and one) a beta distribution is used, the mean is set to the mid point of the interval. For unbounded parameters a gamma distribution is used, the mean is set to 0.3 in accordance to previous estimations of semi-structural models. Finally the shocks' variances are all associated with an inverse-gamma prior distribution. Appendix B summarizes the prior distributions used for the estimation of the models.

The results of the estimation procedure for each model are presented in Appendices C, D and E respectively. The estimation was made using the Dynare software (Adjemian et al., 2011).

Figure 1

OUTPUT GAP MEASURES



Output gap given by the backward looking, hybrid and forward looking models (HPD regions at 90%), and the cyclical component of output obtained from the Hodrick-Prescott filter with λ = 1,600. Grey areas correspond to peak-to-trough periods of the Colombian business cycle according to Alfonso et al. (2011). Series are all quarterly for the period 1994-2011. Calculations were made using Dynare.

5. THE OUTPUT GAP

After the estimation the parameters are set to their posterior mode values. Then each model is used to extract the output gap from the data. The proposed output gap measure is obtained with the Kalman smoother for variable $\tilde{y}$ in each model. Since the Hodrick-Prescott filter (henceforth HP filter) can be represented as a special case of the local linear trend model it is used as a benchmark for the results (see Harvey and Jaeger, 1993, and Canova, 2007). Figure 1d presents the results for this exercise. Panels 1a, 1b and 1c show the output gap obtained from each model with its respective higher posterior density (HPD) region at 90%. This region accounts for the uncertainty in the parameter estimates. Grey areas correspond to peak-to-trough periods of the Colombian business cycle according to Alfonso et al. (2011).

There is a clear difference between the ability of the forward looking model (Panel 1c) to capture the dynamics of the output gap, and the other two models. Even with an HPD at 90% the forward looking model is able to capture the boom experienced in Colombia in the 1990s, the subsequent recession and that affected most of the 2000s and the last cycle (2006-2007 boom and the international financial crisis of 2008).

Panel 1d presents the output gap measures and the Hodrick-Prescott filter for the Colombian GDP. Note that, although all three measures comove they are not equal, showing that the economic models have additional information when compared to the statistical filter.

The most notorious differences are in the 1994-1996, 2000-2004 and 2006-2009 periods. In the first period the forward looking model presents a higher (positive) output gap than the other models (joining the HP filter only until 1997). In the second period, the backward looking and hybrid models identify a closed output gap whereas the forward looking and the HP filter still show a negative cyclical component. In the second period the models, specially the backward looking model, fail to recognize a great increase in the output gap, as opposed to the forward looking model and the HP filter, that identify a strong positive cycle.

Besides the differences between the proposed measures for the output gap and the one given by the HP filter, there are also differences between those measures and the consensus among the experts. According to them, the gap should have been positive at the beginning of the sample (as in the forward looking model) and more negative at the 1998-1999 recession. The models fail to reproduce these facts because of two reasons. First, the Kalman filter is initialized at an arbitrary point, that does not necessarily reflect the true value of the states. In the previous exercise the filter was initialized as if the gap was equal to zero –its steady state value– in 1994Q1.[6] Second, the local linear trend model, on top of which the proposed models are built, understands the data in the 1998-1999 period as a change in output's trend –this means that the model is attributing part of the recession to a decrease in potential output, thus generating a *less negative* output gap. It is important to note that most of the models designed to extract output's cyclical component fail to recognize a strong negative output gap in the 1998-1999 period,[7] but, unlike most of them, the use of the Kalman filter allows us to incorporate additional information about the output gap, for the estimation and filtering process.[8]

Because of the above discussion a second exercise is carried out. The models are now estimated using the same database and prior distributions for the parameters, while allowed to observe the output gap level given by the experts for the first four observations of the sample and the fourth quarter of 1999 (Table 1). This information is subject to measurement error, whose variance is estimated along with all the other parameters. The results of the estimation are summarized in Appendices C.2, D.2 and E.2. All models turn out to assign little variance to the measurement error of the output gap additional information,

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6 In Figure 1 the output gap is not equal to zero at the first period because the gap measure is given by the Kalman filter smoother, which takes into account the whole sample for determining the gap value at each period. Only the forward looking model interpreted the data as to get the positive output gap at the beginning of the sample.

7 An exception to this is the measure proposed in Cobo (2004), based on the production function approach.

8 The methodology presented in Julio (2011) represents an exception to this, allowing the introduction of *priors* as linear restrictions on the Hodrick-Prescott filter.

Table 1

OUTPUT GAP PRIOR INFORMATION
(percentage)

Period	*Value*	*Period*	*Value*	*Period*	*Value*	*Period*	*Value*	*Period*	*Value*
1994Q1	1.35	1994Q2	1.62	1994Q3	2.03	1994Q4	2.38	1999Q4	–5.72

as reflected in the recovered output gap measure (Figure 2) and the posterior mode of the parameter (Tables 6, 8 and 10).

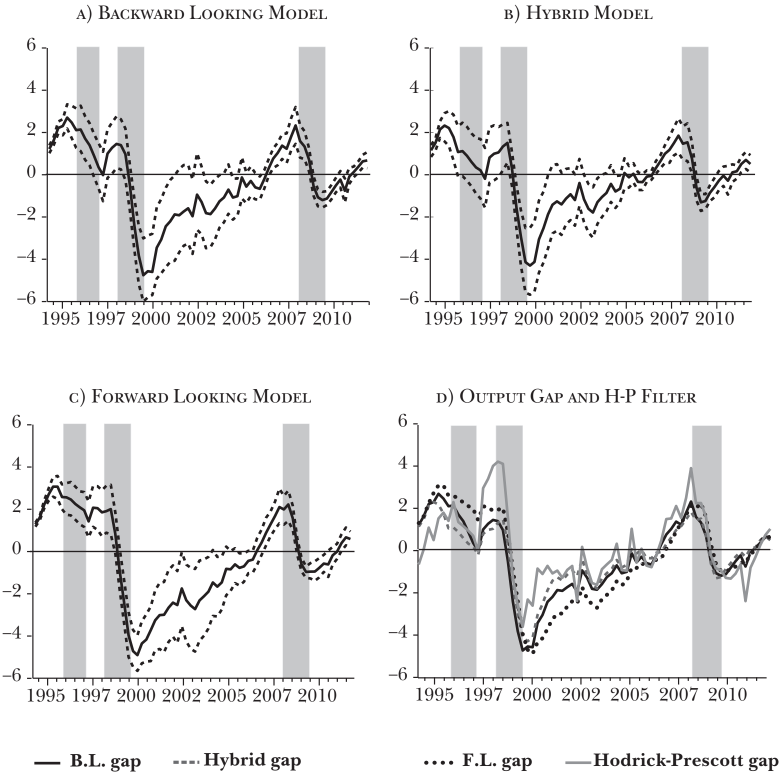
The output gap measures recovered from this exercise are able to recognize both a positive gap between 1994 and 1998, as well as a more negative and persistent gap following the 1998-1999 recession, up until the mid 2000s (although the HPD regions in panels 2a and 2b include zero after 2001). They also present a somewhat higher gap at the end of the sample and in the 2007-2008 period. As before there is a comovement between the three measures, with differences in the timing and magnitude of the cycles, because of the additional information given to the models the differences in the recovered output gap are now fewer. In order to assess the models goodness of fit, we use the marginal likelihood value. It is found that among the conditioned estimation, the forward looking model is the one with the higher marginal likelihood and the hybrid model is the worst. In the case of the non-conditioned estimation, the backward looking model is the one with the highest marginal likelihood and the worst is once again the hybrid model. The values are presented in the Appendix.

The gaps presented also match previous findings on the Colombian business cycle. As shown in Figure 3, all measures identify all the peaks and troughs presented by Alfonso et al. (2011), who use an accumulated diffusion index, computed with 24 Colombian series,[9] in order to obtain a chronology of the business cycle. Before the additional information was introduced only the forward looking matched this turning points (Panel 1c).

[9] The only variable in common between this exercise and the one of Alfonso et al. (2011) is the nominal interest rate.

Figure 2

Output Gap Measures - Prior Information



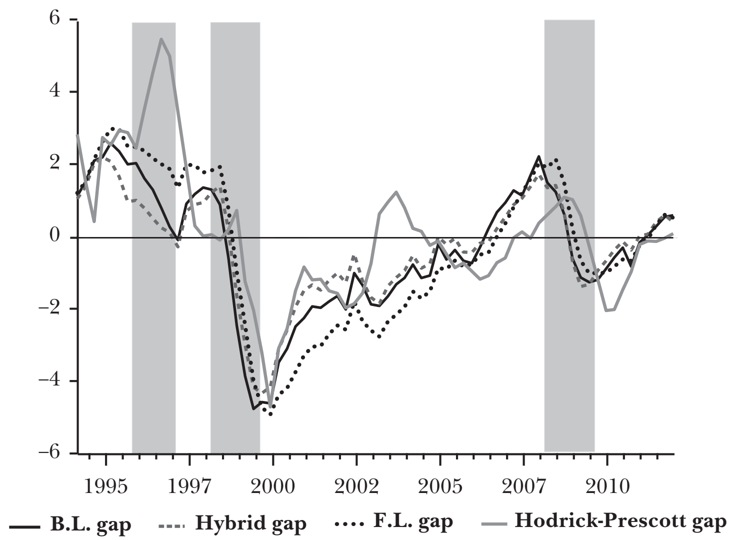
Output gap given by the backward looking, hybrid and forward looking models (HPD regions at 90%), and the cyclical component of output obtained from the Hodrick-Prescott filter with λ = 1,600. Grey areas correspond to peak-to-trough periods of the Colombian business cycle according to Alfonso et al. (2011). Series are all quarterly for the period 1994-2011. Calculations were made using Dynare.

Figure 3 also makes clear that there is a strong positive correlation between the output gap measures and the core inflation, defined as the CPI less food items inflation.[10] Moreover, the output gap precedes the movements in the core inflation

[10] Core inflation gap is defined as the current level of inflation less the target.

Figure 3

Output Gap Measures vs Core cpi Inflation



Output gap given by the backward looking, hybrid and forward looking models with prior information about the output gap level in 1994 and 1999Q4, and cpi less food items inflation relative to the inflation target. Grey areas correspond to peak-to-trough periods of the Colombian business cycle according to Alfonso et al. (2011). Series are all quarterly for the period 1994-2011. Calculations were made using Dynare.

to some extent. Note for example the inflation's peaks after the 1995, 1997 and 2007 peaks in the output gap, as well as the falls in inflation after the 1998 and 2009 falls in the output gap. This can also be seen when computing the correlation between the core inflation and the current and lagged values of the output gap (Table 2), the correlation is always above halve and is greater for the first and second lagged values than for the contemporaneous one (except in the forward looking model).

Finally, the output gap can be decomposed into the effects of the shocks by using the state space representation of the model (Canova, 2007). The historical decomposition for the output gap measures is computed and reported in Figure 4. The exercise consists in identifying which shocks affected the

Table 2

OUTPUT GAP AND CORE INFLATION GAP CORRELATION

Model	$corr(\tilde{y}_t, \pi_t)$	$corr(\tilde{y}_{t-1}, \pi_t)$	$corr(\tilde{y}_{t-2}, \pi_t)$	$corr(\tilde{y}_{t-4}, \pi_t)$	$corr(\tilde{y}_{t-5}, \pi_t)$
Backward looking	0.660	0.727	0.764	0.749	0.676
Hybrid	0.603	0.667	0.694	0.667	0.590
Forward looking	0.745	0.753	0.724	0.659	0.566

economy in the sample period using the observed macroeconomic series, along with the economic structure of the models. After the shocks have been identified it is possible to compute their individual impact over the output gap.

Since the identification and impact depend on the model's structure, the decomposition is different for the backward looking, hybrid and forward looking models. Nevertheless there are common features between them. The most important one is that the output gap is explained mostly by the effect of shocks to the IS curve (demand shocks). This is very useful if one wishes to interpret the output gap as a measure of demand pressures in the economy. Another common characteristic is the low and short-lived effect of the filter's initial values over the output gap, it can be seen that this effect is only determinant in the first period and that only lasts for approximately 12 periods. Another common feature is the effect of the Phillips curve shock (supply shocks) after the 1999 recession. Because of the large drop in inflation that followed the first quarters of 1999, the models identify a Phillips curve shock that helps to explain such drop, as a consequence positive pressures over the output gap were created.

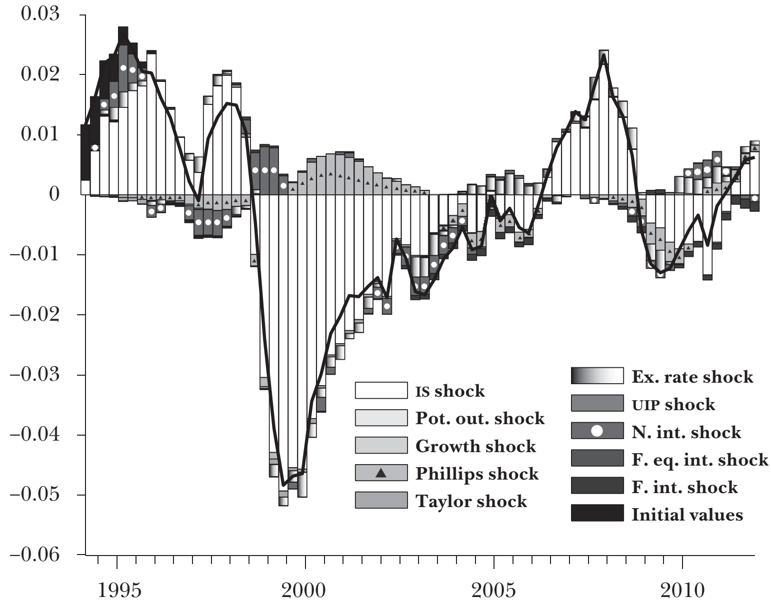
There are three other shocks that appear significant in the historical decomposition. The first is to the foreign interest rate, this shock is more relevant in Panels 4b and 4c and has a negative effect over the output gap for the 2000s' period. During this period the foreign interest rate was low and the models identify this as a negative shock, associated to a real appreciation of the exchange rate. Nevertheless there must be caution over this result, for the models are biased toward the negative effects of the shock, since they do not take into account the positive effects of appreciation and a cheaper debt over the aggregate demand.

The second shock is to the real exchange rate trend, it is expansive in 2004 and 2010, both periods of real exchange rate appreciation. The reason for this is that the models interpret these appreciations as changes in the real exchange rate trend. When the trend is lowered the exchange rate gap becomes

Figure 4a

OUTPUT GAP HISTORICAL DECOMPOSITION

BACKWARD LOOKING MODEL



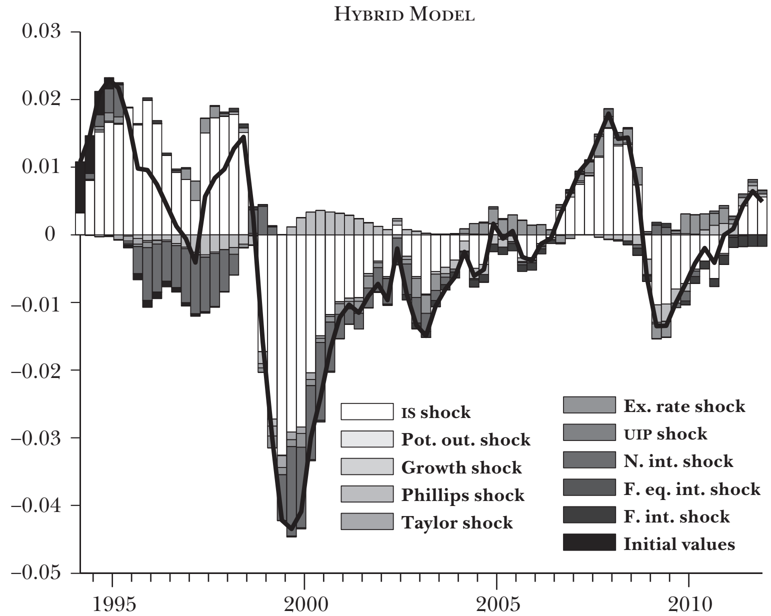
Output gap historical decomposition in shocks given by the adaptive and rational expectations models with prior information about the output gap level in 1994 and 1999Q4. The series are all of quarterly frequency for the period 1994-2011. Calculations were made using Dynare.

positive, hence increasing the output gap. However this effect is not of great magnitude, relative to the effect of other shocks.

The third shock is to the neutral interest rate. Note that for the models this variable is completely exogenous and only influenced by this shock. Because the models are able to extract both the level of the real interest rate and of the interest rate gap, the neutral rate of interest can be computed. The negative effect over the output gap of the neutral interest rate shock in the early 2000s is explained by a decrease in the neutral rate from the high levels of the late 1990s, which lowered the interest rate gap. More about the neutral rate is discussed in the following Section.

Figure 4b

OUTPUT GAP HISTORICAL DECOMPOSITION



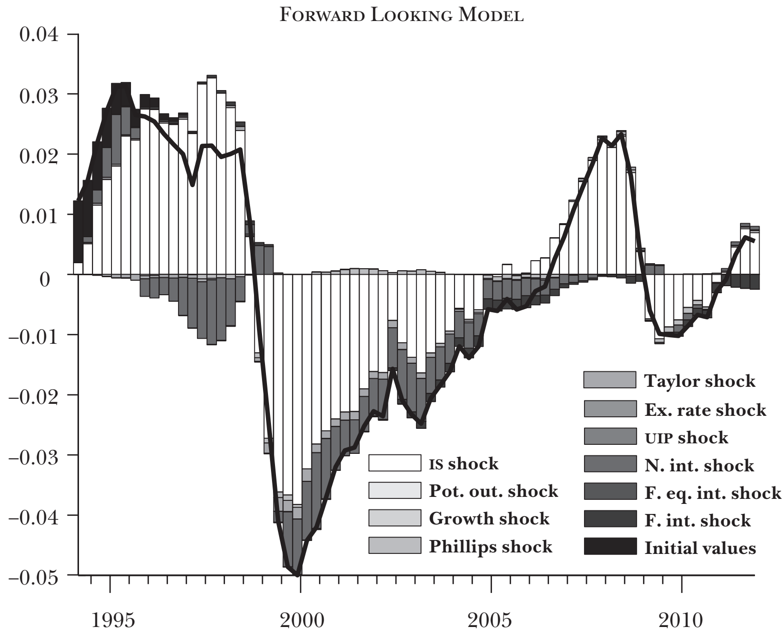
Output gap historical decomposition in shocks given by the adaptive and rational expectations models with prior information about the output gap level in 1994 and 1999Q4. The series are all of quarterly frequency for the period 1994-2011. Calculations were made using Dynare.

6. THE NEUTRAL INTEREST RATE

Before discussing the models' implications over the neutral interest rate, it is important to examine the behavior of the real interest rate. Recall that this variable is computed in-model, given the nominal interest rate and the inflation expectations, nevertheless all three models generate similar measures (Figure 5) that are also in line with the movements and level of the expost real interest rate. The period under consideration is characterized by high and volatile levels of the real interest rate before the 2000, followed by a more stable period with a lower interest rate level. This is clear from the mean and standard

Figure 4c

OUTPUT GAP HISTORICAL DECOMPOSITION



Output gap given by the backward looking, hybrid and forward looking models with prior information about the output gap level in 1994 and 1999Q4, and CPI less food items inflation relative to the inflation target. Grey areas correspond to peak-to-trough periods of the Colombian business cycle according to Alfonso et al. (2011). Series are all quarterly for the period 1994-2011. Calculations were made using Dynare.

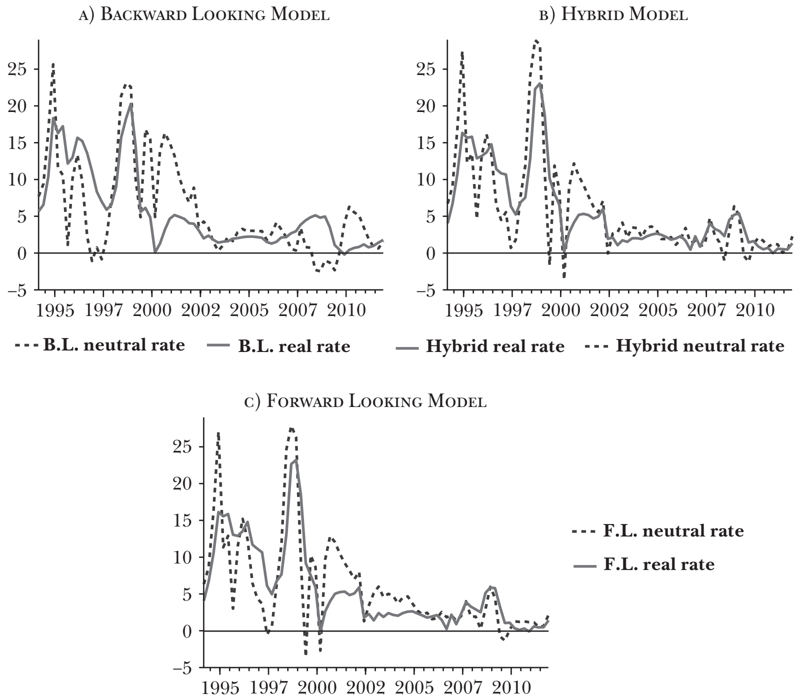
deviation of the real interest variable in all models, shown in the first two columns of Table 3.

The volatility; and subsequent stabilization, of the real interest rate is probably explained by changes in the Colombian monetary policy; we refer to Giraldo et al. (2011) and the references therein for a review of Colombia's recent monetary history. Overall there are no drastic changes in the real interest rate, save from the great increase that coincides with the 1998-1999 recession, which is explained by the large drop in inflation that followed the crisis (see Figure 4).

Turning to the neutral interest rate, Figure 5 presents the neutral and real interest rate that each model recovered from the data. Note that all measures of the neutral interest rate are even more volatile than the real interest rate measures (compare the standard deviations of both variables in the second and fourth columns of Table 3). The volatility of the real interest rate, although present only before the 2000, influences the neutral interest rate in the whole sample, generating a changing measure of neutrality for the last decade.

Figure 5

NEUTRAL INTEREST RATE



Neutral and real interest rate measures given by the backward looking, hybrid and forward looking models with prior information about the output gap level in 1994 and 1999Q4 (HPD regions at 90%). The series are all of quarterly frequency for the period 1994-2011. Calculations were made using Dynare.

All models imply that there was a positive interest rate gap before the 1999 recession and a negative gap afterward, with a slow convergence of the neutral rate to the levels that the real interest rate has presented after the crisis. Then, the interest rate gap turns positive in the 2007-2008 period, although considerably more (and sooner) in the backward looking model. At the end of the sample the interest rate gap becomes negative, again in a larger amount in the backward looking model.

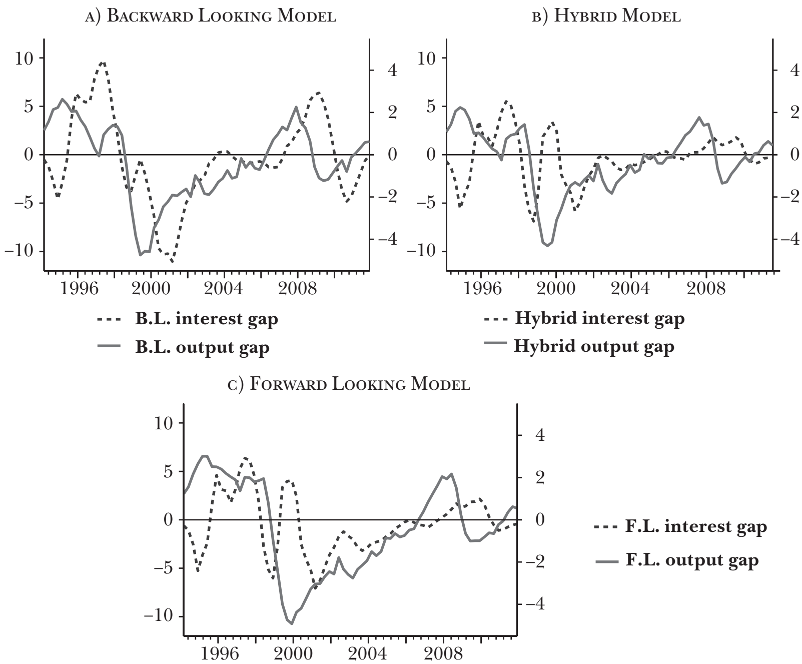
Note, from Figure 6, that the behavior of the interest rate gap is countercyclical almost everywhere. It exerts a negative pressure over the output gap while it was positive in the pre-1999 period, and has expansive effects afterward, up until the 2007-2008 period, in which the output gap is again positive. Finally, the interest rate gap has positive effects after 2008, when there is a drop in the output gap, associated to the international turbulence that followed the recent us financial crisis. The countercyclality of the interest rate gap is clearly interrupted in the hybrid and forward looking models between 1999 and 2001 (Panels 6b and 6c). In this period the interest rate gap turns positive while the output gap remains negative. This is attributed to a drop in the neutral interest rate (see Panels 5b and 5c), since this variable is exogenous for the model, this means that the model identifies the need of a positive interest gap in order to explain the drop in the output gap in those periods. This is reflected in the negative correlation between the output and interest rate gaps for the 1994-2000 period for the hybrid and forward looking models (Table 3).

Yet, it must be mentioned that the interest gap reaction is lagged with respect to the output gap movements,[11] this is clearer in Panel 6a for the backward looking model, and post-2006 period in Panels 6b and 6c, where the interest rate gap turns positive a year after the output gap does and then remains

[11] Recall that the interest rate gap presented in Figure 5 is smoothed with a fourth order moving average. This is done for clarity since the neutral rate measures are too volatile, and does not affect the findings.

Figure 6

NEUTRAL INTEREST GAP VS. OUTPUT GAP



Smoothed real interest rate gap and output gap given by the backward looking, hybrid and forward looking models with prior information about the output gap level in 1994 and 1999Q4. The real interest rate gap is smoothed with a fourth order moving average. The series are all of quarterly frequency for the period 1994-2011. Calculations were made using Dynare.

positive while the output gap fells in the 2008 financial crisis. In other words, given that the monetary authority can influence the real interest rate, the monetary policy, although countercyclical, has failed to anticipate the changes of the output gap, or at least to react strongly enough to them.

7. FINAL REMARKS

This document presents three new measures of the Colombian output gap and neutral interest rate. Both variables are crucial

Table 3

INTEREST RATE MOMENTS

	Real interest rate		*Neutral interest*		*Interest rate gap*		
	Mean	*Std*	*Mean*	*Std*	*Mean*	*Std*	$corr(\tilde{y}_t, \tilde{r}_t)$
			Backward looking model				
1994-2011	7.961	5.299	8.413	6.526	−0.451	5.293	0.484
1994-2000	14.056	4.889	13.000	7.792	1.056	6.696	0.343
2000-2011	4.914	1.505	6.119	4.303	−1.205	4.318	0.630
			Hybrid model				
1994-2011	8.103	5.507	8.548	6.609	-0.445	4.234	0.232
1994-2000	14.307	5.227	13.425	8.614	0.882	6.299	−0.106
2000-2011	5.001	1.720	6.110	3.386	−1.109	2.513	0.644
			Forward looking model				
1994-2011	8.086	5.486	8.433	6.859	−0.348	3.883	−0.077
1994-2000	14.352	5.114	14.304	8.475	0.047	6.024	−0.286
2000-2011	4.953	1.611	5.498	3.085	−0.545	2.213	0.399

for the conduct of monetary policy and their measurement is subject to a great deal of uncertainty. Because of this the results presented here are not to be taken as final, but as an extra input, useful for policy evaluation and academic research. The models deliver an output gap coherent with previous works for Colombia, as Echavarría et al. (2007), and is capable to identify all the turning points of the Colombian business cycle, as measured by Alfonso et al. (2011). The Colombian output gap begins with a positive, although variable, level from 1994 to 1997, when there is a large drop that starts with the 1998-1999 crisis, after this drop the output gap remains negative until 2006. The gap turns positive in the 2006-2008 period and then drops in 2009, after the international turmoil that followed the US financial crisis of 2008. Both models imply that the gap has recovered from its last drop and is positive since 2011, although still close to zero.

As for the neutral interest rate, the models are more heterogeneous in the results, but all imply a somewhat countercyclical behavior of the monetary policy during most of the sample period, except at the time of the 1999 recession. They also imply a delay between the movements of the output gap and those of the interest rate gap, specially the hybrid and forward looking models. This may correspond to a lack of anticipation of the monetary authority, or the need of stronger reaction to the economy's condition.

Finally, it is important to expand the methodology to account for model uncertainty to which the output and neutral interest rate measurement is subject to; this implies the use of more advanced techniques that go beyond the scope of this paper. It is also noted that the methodology presented relies in semi-structural models to take into account the relations between several macroeconomic aggregates, and there are still efforts to be done in order to compute a micro-founded measure of the output gap, and the natural interest rate, in the spirit of Woodford (2003a) and Christiano et al. (2010a,b). These new measures can potentially improve our understanding of the shocks that affect the economy, and the design of monetary policy.

Appendix

A. Equations

A.1 Adaptive Expectations Model

A.1 $$y_t = \tilde{y}_t + \overline{y}_t$$

A.2 $$\overline{y}_t = \overline{y}_{t-1} + g_t + \varepsilon_t^{\overline{y}}$$

A.3 $$g_t = (1-\tau)\overline{g}_{ss} + \tau g_{t-1} + \varepsilon_t^g$$

A.4 $$\tilde{y}_t = \beta_1 \tilde{y}_{t-1} - \beta_2 (r_{t-1} - \overline{r}_{t-1}) + \beta_3 \tilde{q}_{t-1} + z_t^y$$

A.5 $$\pi_t = \pi_{t+1|t}^e + \lambda_2 \tilde{y}_{t-1} + \lambda_3 (q_t - q_{t-1}) + z_t^\pi$$

A.6 $$\pi_{t+1|t}^e = \lambda_1 \overline{\pi}_t + (1-\lambda_1)\pi_{4,t-1}$$

A.7 $$\pi_{4,t} = \frac{1}{4}(\pi_t + \pi_{t-1} + \pi_{t-2} + \pi_{t-3})$$

A.8 $$i_t = \gamma_1 i_{t-1} + (1-\gamma_1)\left((\overline{r}_t + \overline{\pi}) + \gamma_2 (\pi_{4,t} - \overline{\pi}) + \gamma_3 \tilde{y}_t\right) + \varepsilon_t^i$$

A.9 $$r_t = i_t - \pi_{t+1|t}^e$$

A.10 $$r_t - r_t^* = 4\left(q_{t+1|t}^e - q_t\right) + \left(\overline{r}_t - \overline{r}_t^*\right) + \varepsilon_t^r$$

A.11 $$\overline{r}_t = \rho_r \overline{r}_{t-1} + (1-\rho_r)\overline{r}_{ss} + \varepsilon_t^{\overline{r}}$$

A.12 $$r_t^* = \overline{r}_t^* + \kappa\left(r_{t-1}^* - \overline{r}_{t-1}^*\right) + \varepsilon_t^{r^*}$$

A.13 $$\overline{r}_t^* = \rho_{r^*} \overline{r}_{t-1}^* + \left(1-\rho_{r^*}\right)\overline{r}_{ss}^* + \varepsilon_t^{\overline{r}^*}$$

A.14 $$q_t = \tilde{q}_t + \overline{q}_t$$

A.15 $$\overline{q}_t = \overline{q}_{t-1} + \varepsilon_t^q$$

A.16 $$q_{t+1|t}^e = \varphi \overline{q}_t + (1-\varphi) q_{t-1}$$

A.17 $$z_t^y = \rho_y z_{t-1}^y + \varepsilon_t^y$$

A.18 $$z_t^\pi = \rho_\pi z_{t-1}^\pi + \varepsilon_t^\pi$$

A.2 Rational Expectations Semi-structural Model

A.19 $$y_t = \tilde{y}_t + \overline{y}_t$$

A.20 $$\overline{y}_t = \overline{y}_{t-1} + g_t + \varepsilon_t^{\overline{y}}$$

A.21 $$g_t = (1-\tau)\overline{g}_{ss} + \tau g_{t-1} + \varepsilon_t^g$$

A.22 $$\tilde{y}_t = \beta_1 \tilde{y}_{t-1} - \beta_2 \left(r_{t-1} - \overline{r}_{t-1}\right) + \beta_3 \tilde{q}_{t-1} + \beta_4 E_t \left\{\tilde{y}_{t+1}\right\} + z_t^y$$

A.23 $$\pi_t = \pi_{t+1|t}^e + \lambda_2 \tilde{y}_{t-1} + \lambda_3 \left(q_t - q_{t-1}\right) + z_t^\pi$$

A.24 $$\pi_{t+1|t}^e = \lambda_1 E_t \left\{\pi_{4,t+4}\right\} + (1-\lambda_1)\pi_{4,t-1}$$

A.25 $$\pi_{4,t} = \frac{1}{4}\left(\pi_t + \pi_{t-1} + \pi_{t-2} + \pi_{t-3}\right)$$

A.26 $$i_t = \gamma_1 i_{t-1} + (1-\gamma_1)\left(\left(\overline{r}_t + \overline{\pi}\right) + \gamma_2 E_t \left(\pi_{4,t+4} - \overline{\pi}\right) + \gamma_3 \tilde{y}_t\right) + \varepsilon_t^i$$

A.27 $$r_t = i_t - E_t \left\{\pi_{t+1}\right\}$$

A.28 $$r_t - r_t^* = 4\left(q_{t+1|t}^e - q_t\right) + \left(\overline{r}_t - \overline{r}_t^*\right) + \varepsilon_t^r$$

A.29 $$\overline{r}_t = \rho_r \overline{r}_{t-1} + (1-\rho_r)\overline{r}_{ss} + \varepsilon_t^{\overline{r}}$$

A.30 $$r_t^* = \overline{r}_t^* + \kappa\left(r_{t-1}^* - \overline{r}_{t-1}^*\right) + \varepsilon_t^{r^*}$$

A.31 $$\overline{r}_t^* = \rho_{r^*} \overline{r}_{t-1}^* + \left(1 - \rho_{r^*}\right)\overline{r}_{ss}^* + \varepsilon_t^{\overline{r}^*}$$

A.32 $$q_t = \tilde{q}_t + \overline{q}_t$$

A.33 $$\overline{q}_t = \overline{q}_{t-1} + \varepsilon_t^q$$

A.34 $$q_t^e = \varphi E_t \left\{q_{t+1}\right\} + (1-\varphi) q_{t-1}$$

A.35 $$z_t^y = \rho_y z_{t-1}^y + \varepsilon_t^y$$

A.36 $$z_t^\pi = \rho_\pi z_{t-1}^\pi + \varepsilon_t^\pi$$

B. Prior Distributions

Table A.1

PRIOR DISTRIBUTIONS

Parameter	*Description*	*Distribution*	*Mean*	*Standard deviation*
σ_i	Shock i standard deviation	Inv. gamma	0.0125	∞
τ	Persistence of the growth process	Beta (0,1)	0.5	0.15
λ_1	Inflation expectations	Beta (0,1)	0.5	0.15

λ_2	Elasticity of inflation to output gap	Gamma	0.30	0.25
λ_3	Elasticity of inflation to depreciation	Gamma	0.30	0.25
β_1	Elasticity of output gap to its lag	Beta (0,1)	0.5	0.15
β_2	Elasticity of output gap to real interest gap	Gamma	0.30	0.25
β_3	Elasticity of output gap to exchange rate gap	Gamma	0.30	0.25
β_4	Elasticity of output gap to expectations	Gamma	0.30	0.25
φ	Exchange rate expectations	Beta (0,1)	0.5	0.15
κ	Persistence of foreign interest rate gap	Beta (0,1)	0.5	0.15
ρ_r	Persistence of natural interest rate	Beta (0,1)	0.5	0.15
ρ_{r^*}	Persistence of foreign natural interest rate	Beta (0,1)	0.5	0.15
ρ_y	Persistence of IS shock	Beta (0,1)	0.5	0.15
ρ_π	Persistence of Phillips curve shock	Beta (0,1)	0.5	0.15

C. Estimation Results – Backward Looking Model

C.1 Unconditioned Estimation

Table A.2

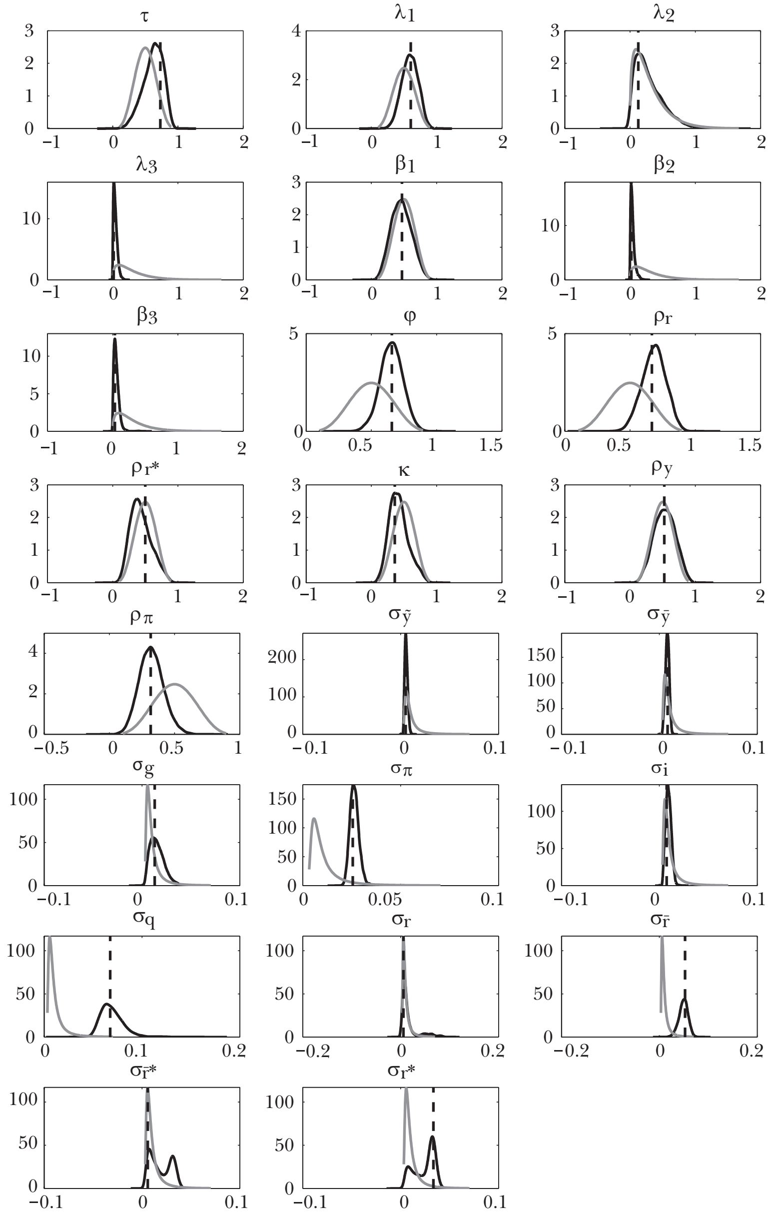
ESTIMATION RESULTS – BACKWARD LOOKING MODEL

		Prior		*Posterior*			*HPD 90%*	
Parameter		*Mean*	*SD*	*Mean*	*Mode*	*SD*	*Lower*	*Upper*
Persistence of the growth process	τ	0.50	0.15	0.62	0.73	0.13	0.37	0.86
Inflation expectations	λ_1	0.50	0.15	0.59	0.60	0.13	0.38	0.79
Elasticity of inflation to output gap	λ_2	0.30	0.25	0.29	0.13	0.19	0.00	0.59
Elasticity of inflation to depreciation	λ_3	0.30	0.25	0.04	0.01	0.02	0.00	0.08
Elasticity of output gap to its lag	β_1	0.50	0.15	0.46	0.47	0.19	0.20	0.71
Elasticity of output gap to real interest gap	β_2	0.30	0.25	0.04	0.02	0.03	0.00	0.08
Elasticity of output gap to exchange rate gap	β_3	0.30	0.25	0.06	0.03	0.04	0.00	0.11
Exchange rate expectations	φ	0.50	0.15	0.65	0.66	0.08	0.52	0.80
Persistence of natural interest rate	ρ_r	0.50	0.15	0.68	0.67	0.09	0.54	0.84
Persistence of foreign natural interest rate	ρ_{r^*}	0.50	0.15	0.43	0.50	0.18	0.18	0.69
Persistence of foreign interest rate gap	κ	0.50	0.15	0.42	0.36	0.09	0.19	0.67

Persistence of IS shock	ρ_y	0.50	0.15	0.53	0.52	0.19	0.28	0.80
Persistence of Phillips curve shock	ρ_π	0.50	0.15	0.32	0.32	0.09	0.16	0.47
Standard deviation of IS curve shock	σ_y	0.013	∞	0.006	0.005	0.002	0.003	0.008
Standard deviation of potential output shock	$\sigma_{\bar{y}}$	0.013	∞	0.008	0.008	0.002	0.005	0.011
Standard deviation of growth shock	σ_g	0.013	∞	0.016	0.013	0.006	0.004	0.026
Standard deviation of Phillips curve shock	σ_π	0.013	∞	0.026	0.026	0.002	0.023	0.030
Standard deviation of nominal interest rate shock	σ_i	0.013	∞	0.009	0.008	0.003	0.005	0.014
Standard deviation of potential exchange rate shock	σ_q	0.013	∞	0.069	0.068	0.010	0.052	0.086
Standard deviation of UIP shock	σ_r	0.013	∞	0.016	0.006	0.002	0.003	0.047
Standard deviation of natural real interest rate shock	$\sigma_{\bar{r}}$	0.013	∞	0.049	0.053	0.008	0.034	0.064
Standard deviation of foreign natural interest rate shock	$\sigma_{\bar{r}^*}$	0.013	∞	0.019	0.006	0.003	0.004	0.034
Standard deviation of foreign interest rate shock	σ_{r^*}	0.013	∞	0.024	0.034	0.003	0.006	0.037
Marginal likelihood	784.9973							

Figure 7

PRIOR & POSTERIOR: BACKWARD LOOKING MODEL



Prior and posterior density functions for the estimated parameters, prior functions are in gray and posteriors functions in black, the dashed vertical line indicates the parameter posterior mean. Calculations were made with Dynare.

C.2 Conditioned Estimation

Table A.3

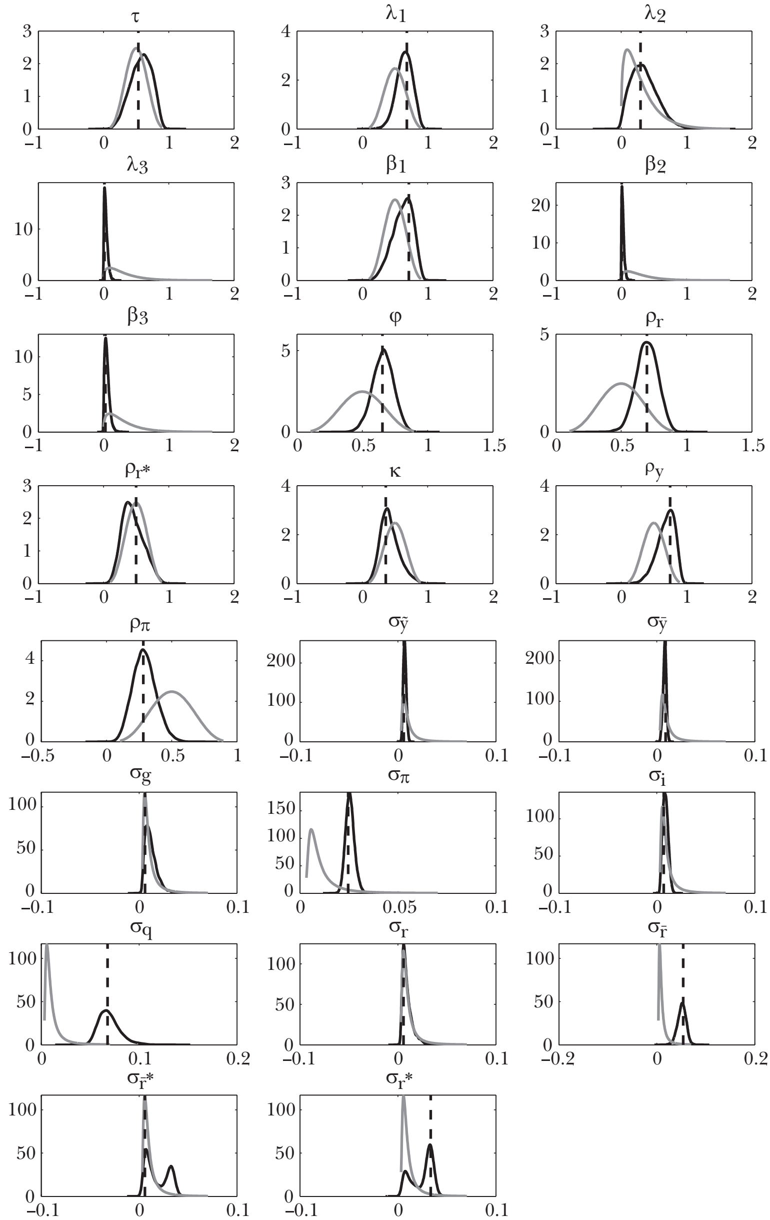
ESTIMATION RESULTS - BACKWARD LOOKING MODEL

Parameter		*Prior*		*Posterior*			*HPD 90%*	
		Mean	*SD*	*Mean*	*Mode*	*SD*	*Lower*	*Upper*
Persistence of the growth process	τ	0.5	0.15	0.57	0.53	0.20	0.32	0.84
Inflation expectations	λ_1	0.5	0.15	0.64	0.68	0.13	0.46	0.85
Elasticity of inflation to output gap	λ_2	0.3	0.25	0.35	0.30	0.20	0.03	0.65
Elasticity of inflation to depreciation	λ_3	0.3	0.25	0.04	0.01	0.02	0.00	0.07
Elasticity of output gap to its lag	β_1	0.5	0.15	0.61	0.71	0.14	0.37	0.86
Elasticity of output gap to real interest gap	β_2	0.3	0.25	0.03	0.01	0.01	0.00	0.05
Elasticity of output gap to exchange rate gap	β_3	0.3	0.25	0.05	0.03	0.03	0.00	0.10
Exchange rate expectations	φ	0.5	0.15	0.66	0.65	0.08	0.53	0.79
Persistence of natural interest rate	ρ_r	0.5	0.15	0.70	0.70	0.08	0.56	0.83
Persistence of foreign natural interest rate	ρ_{r^*}	0.5	0.15	0.45	0.50	0.18	0.18	0.70
Persistence of foreign interest rate gap	κ	0.5	0.15	0.42	0.36	0.09	0.19	0.66
Persistence of IS shock	ρ_y	0.5	0.15	0.68	0.75	0.12	0.47	0.89

Persistence of Phillips curve shock	ρ_{π}	0.5	0.15	0.29	0.28	0.09	0.15	0.43
Standard deviation of IS curve shock	σ_{y}	0.013	∞	0.007	0.006	0.001	0.005	0.009
Standard deviation of potential output shock	$\sigma_{\bar{y}}$	0.013	∞	0.008	0.009	0.001	0.005	0.011
Standard deviation of growth shock	σ_{g}	0.013	∞	0.012	0.006	0.003	0.003	0.021
Standard deviation of Phillips curve shock	σ_{π}	0.013	∞	0.026	0.025	0.002	0.022	0.029
Standard deviation of nominal interest rate shock	σ_{i}	0.013	∞	0.009	0.007	0.003	0.004	0.013
Standard deviation of potential exchange rate shock	σ_{q}	0.013	∞	0.069	0.068	0.011	0.052	0.086
Standard deviation of UIP shock	σ_{r}	0.013	∞	0.009	0.006	0.002	0.003	0.017
Standard deviation of natural real interest rate shock	$\sigma_{\bar{r}}$	0.013	∞	0.051	0.054	0.008	0.037	0.065
Standard deviation of foreign natural interest rate shock	$\sigma_{\bar{r}^*}$	0.013	∞	0.019	0.006	0.003	0.004	0.035
Standard deviation of foreign interest rate shock	σ_{r^*}	0.013	∞	0.025	0.034	0.003	0.005	0.037
Standard deviation of measurement error	σ	0.013	∞	0.009	0.005	0.002	0.003	0.017
Marginal likelihood		796.8164						

Figure 8

Prior & Posterior: Backward Looking Model



Prior and posterior density functions for the estimated parameters, prior functions are in gray and posteriors functions in black, the dashed vertical line indicates the parameter posterior mean. Calculations were made with Dynare.

D. Estimation Results - Hybrid Model

D.1 Unconditioned Estimation

Table A.4

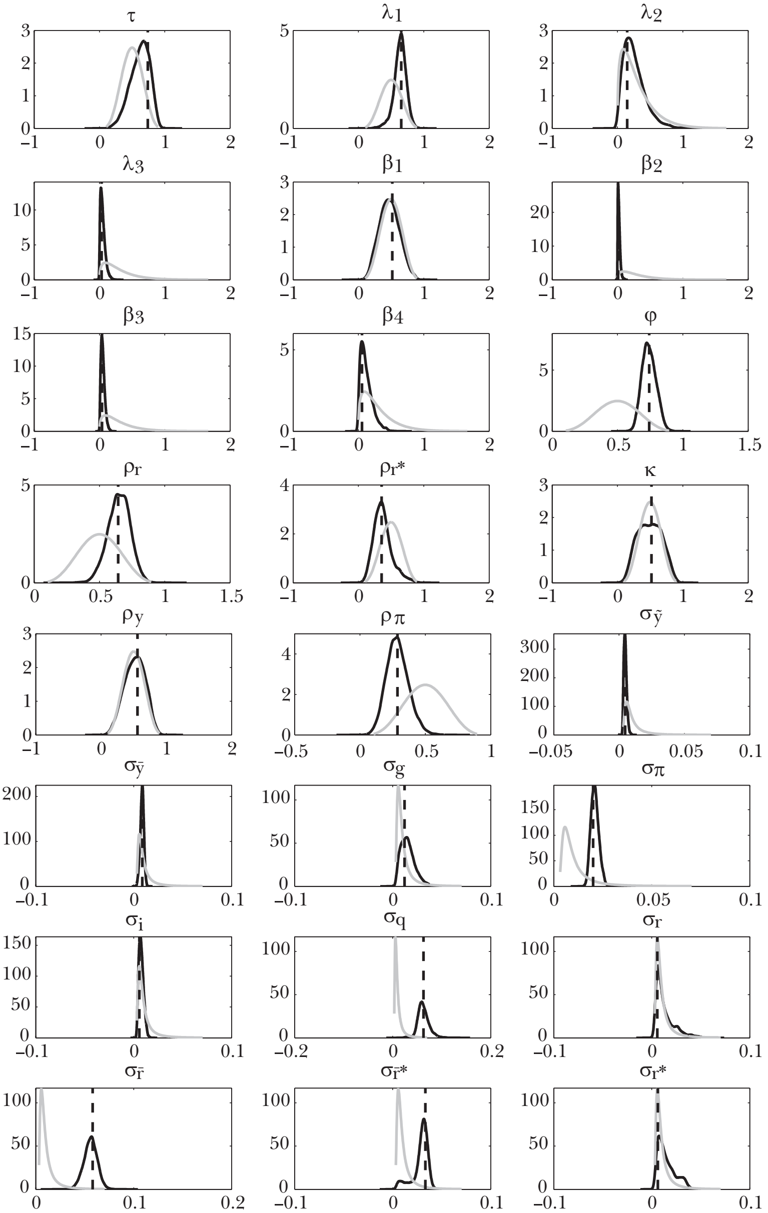
ESTIMATION RESULTS – HYBRID MODEL

Parameter		Prior		Posterior			HPD 90%	
		Mean	*SD*	*Mean*	*Mode*	*SD*	*Lower*	*Upper*
Persistence of the growth process	τ	0.5	0.15	0.62	0.74	0.13	0.39	0.85
Inflation expectations	λ_1	0.5	0.15	0.64	0.66	0.07	0.49	0.78
Elasticity of inflation to output gap	λ_2	0.3	0.25	0.26	0.15	0.15	0.01	0.48
Elasticity of inflation to depreciation	λ_3	0.3	0.25	0.05	0.03	0.04	0.00	0.10
Elasticity of output gap to its lag	β_1	0.5	0.15	0.47	0.52	0.20	0.22	0.71
Elasticity of output gap to real interest gap	β_2	0.3	0.25	0.12	0.05	0.07	0.00	0.25
Elasticity of output gap to exchange rate gap	β_3	0.3	0.25	0.02	0.01	0.01	0.00	0.05
Elasticity of output gap to expectations	β_4	0.3	0.25	0.05	0.04	0.04	0.01	0.10
Exchange rate expectations	φ	0.5	0.15	0.74	0.74	0.05	0.65	0.83
Persistence of natural interest rate	ρ_r	0.5	0.15	0.65	0.64	0.08	0.51	0.79
Persistence of foreign natural interest rate	ρ_{r^*}	0.5	0.15	0.37	0.36	0.09	0.14	0.58
Persistence of foreign interest rate gap	κ	0.5	0.15	0.49	0.52	0.19	0.20	0.78

Persistence of IS shock	ρ_y	0.5	0.15	0.52	0.56	0.22	0.26	0.77
Persistence of Phillips curve shock	ρ_π	0.5	0.15	0.29	0.29	0.09	0.15	0.42
Standard deviation of IS curve shock	σ_y	0.013	∞	0.005	0.005	0.001	0.003	0.007
Standard deviation of potential output shock	$\sigma_{\bar{y}}$	0.013	∞	0.009	0.009	0.002	0.005	0.011
Standard deviation of growth shock	σ_g	0.013	∞	0.015	0.012	0.006	0.004	0.026
Standard deviation of Phillips curve shock	σ_π	0.013	∞	0.021	0.02	0.002	0.018	0.024
Standard deviation of nominal interest rate shock	σ_i	0.013	∞	0.008	0.006	0.002	0.004	0.011
Standard deviation of potential exchange rate shock	σ_q	0.013	∞	0.063	0.063	0.010	0.046	0.080
Standard deviation of UIP shock	σ_r	0.013	∞	0.013	0.006	0.002	0.003	0.027
Standard deviation of natural real interest rate shock	$\sigma_{\bar{r}}$	0.013	∞	0.056	0.058	0.006	0.044	0.067
Standard deviation of foreign natural interest rate shock	$\sigma_{\bar{r}^*}$	0.013	∞	0.029	0.033	0.003	0.014	0.040
Standard deviation of foreign interest rate shock	σ_{r^*}	0.013	∞	0.015	0.006	0.003	0.003	0.030
Marginal likelihood	782.029							

Figure 9

PRIOR & POSTERIOR: HYBRID MODEL



Prior and posterior density functions for the estimated parameters, prior functions are in gray and posteriors functions in black, the dashed vertical line indicates the parameter posterior mean. Calculations were made with Dynare.

D.2 Conditioned Estimation

Table A.5

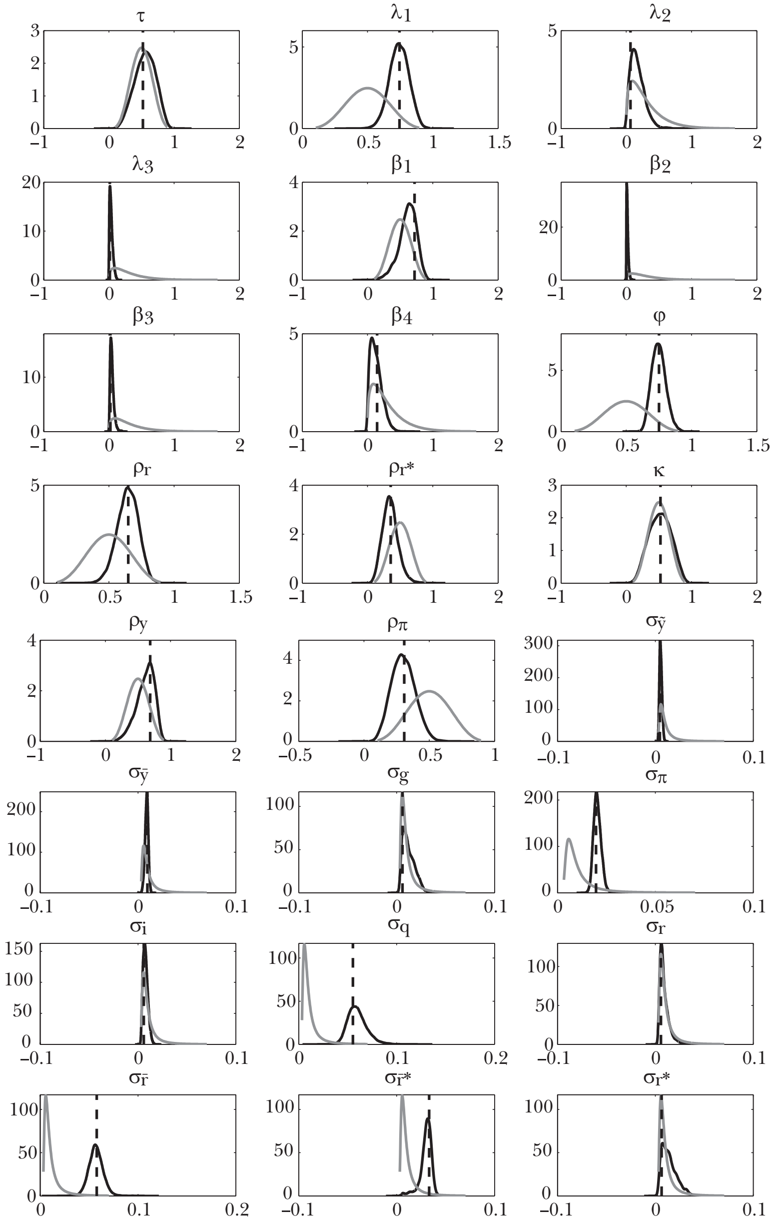
ESTIMATION RESULTS - HYBRID MODEL

Parameter		*Prior*		*Posterior*			*HPD 90%*	
		Mean	*SD*	*Mean*	*Mode*	*SD*	*Lower*	*Upper*
Persistence of the growth process	τ	0.5	0.15	0.55	0.52	0.19	0.30	0.81
Inflation expectations	λ_1	0.5	0.15	0.74	0.75	0.07	0.62	0.86
Elasticity of inflation to output gap	λ_2	0.3	0.25	0.17	0.06	0.07	0.01	0.32
Elasticity of inflation to depreciation	λ_3	0.3	0.25	0.03	0.01	0.02	0.00	0.07
Elasticity of output gap to its lag	β_1	0.5	0.15	0.61	0.72	0.10	0.40	0.83
Elasticity of output gap to real interest gap	β_2	0.3	0.25	0.13	0.15	0.13	0.00	0.26
Elasticity of output gap to exchange rate gap	β_3	0.3	0.25	0.02	0.01	0.01	0.00	0.04
Elasticity of output gap to expectations	β_4	0.3	0.25	0.05	0.02	0.02	0.01	0.09
Exchange rate expectations	φ	0.5	0.15	0.75	0.75	0.05	0.66	0.83
Persistence of natural interest rate	ρ_r	0.5	0.15	0.64	0.65	0.08	0.51	0.77
Persistence of foreign natural interest rate	ρ_{r^*}	0.5	0.15	0.35	0.35	0.09	0.15	0.53
Persistence of foreign interest rate gap	κ	0.5	0.15	0.52	0.52	0.19	0.24	0.78

Persistence of IS shock	ρ_y	0.5	0.15	0.61	0.69	0.14	0.39	0.82
Persistence of Phillips curve shock	ρ_π	0.5	0.15	0.30	0.31	0.09	0.15	0.44
Standard deviation IS curve shock	σ_y	0.013		0.006	0.005	0.001	0.003	0.008
Standard deviation of potential output shock	$\sigma_{\bar{y}}$	0.013		0.009	0.010	0.001	0.006	0.011
Standard deviation of growth shock	σ_g	0.013		0.012	0.006	0.003	0.004	0.022
Standard deviation of Phillips curve shock	σ_π	0.013		0.020	0.020	0.002	0.017	0.023
Standard deviation of nominal interest rate shock	σ_i	0.013		0.008	0.006	0.002	0.004	0.011
Standard deviation of potential exchange rate shock	σ_q	0.013		0.060	0.055	0.01	0.045	0.076
Standard deviation of UIP shock	σ_r	0.013		0.009	0.006	0.002	0.003	0.015
Standard deviation of natural real interest rate shock	$\sigma_{\bar{r}}$	0.013		0.057	0.058	0.006	0.045	0.068
Standard deviation of foreign natural interest rate shock	$\sigma_{\bar{r}^*}$	0.013		0.030	0.033	0.003	0.022	0.038
Standard deviation of foreign interest rate shock	σ_{r^*}	0.013		0.014	0.006	0.003	0.004	0.025
Standard deviation of measurement error	σ	0.013		0.010	0.005	0.002	0.003	0.018
Marginal likelihood	793.8896							

Figure 10

PRIOR & POSTERIOR: HYBRID MODEL



Prior and posterior density functions for the estimated parameters, prior functions are in gray and posteriors functions in black, the dashed vertical line indicates the parameter posterior mean. Calculations were made with Dynare.

E. Estimation Results - Forward Looking Model

E.1 Unconditioned Estimation

Table A.6

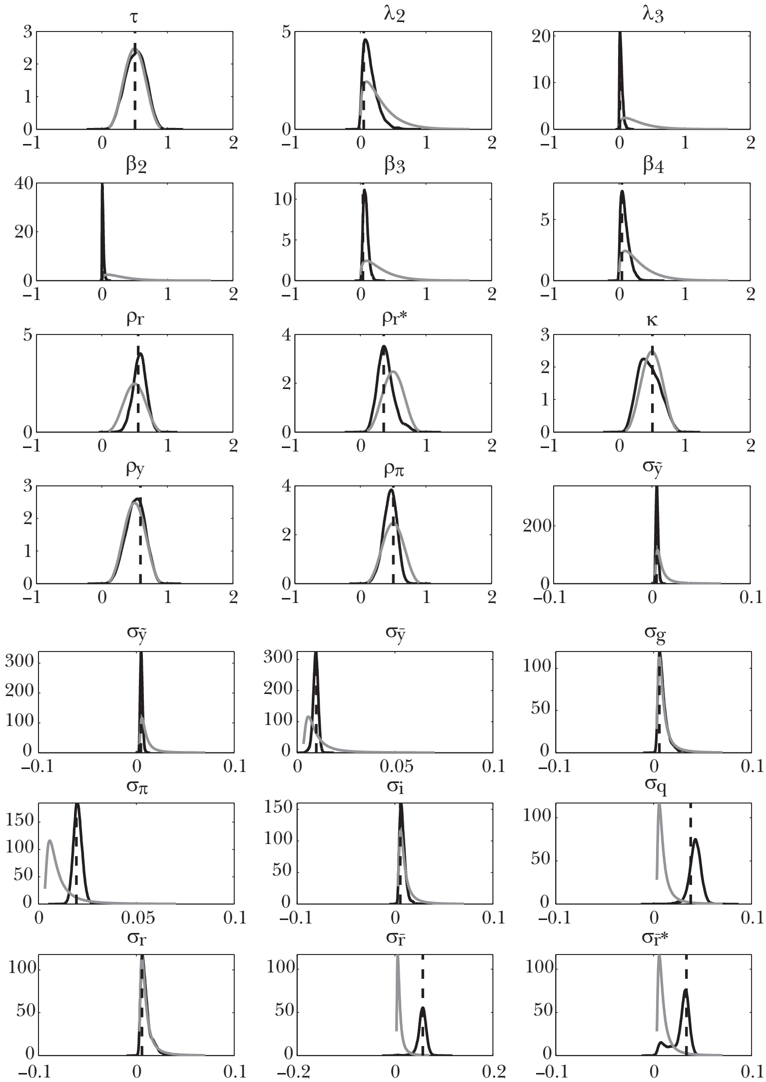
ESTIMATION RESULTS – FORWARD LOOKING MODEL

Parameter		*Prior*		*Posterior*			*HPD 90%*	
		Mean	*SD*	*Mean*	*Mode*	*SD*	*Lower*	*Upper*
Persistence of the growth process	τ	0.5	0.15	0.51	0.51	0.18	0.25	0.75
Elasticity of inflation to output gap	λ_2	0.3	0.25	0.15	0.05	0.05	0.00	0.30
Elasticity of inflation to depreciation	λ_3	0.3	0.25	0.03	0.01	0.02	0.00	0.06
Elasticity of output gap to real interest gap	β_2	0.3	0.25	0.09	0.04	0.06	0.00	0.18
Elasticity of output gap to exchange rate gap	β_3	0.3	0.25	0.02	0.01	0.01	0.00	0.04
Elasticity of output gap to expectations	β_4	0.3	0.25	0.08	0.04	0.03	0.02	0.14
Persistence of natural interest rate	ρ_r	0.5	0.15	0.57	0.55	0.10	0.41	0.73
Persistence of foreign natural interest rate	ρ_{r^*}	0.5	0.15	0.39	0.36	0.09	0.17	0.57
Persistence of foreign interest rate gap	κ	0.5	0.15	0.46	0.51	0.18	0.20	0.73
Persistence of IS shock	ρ_y	0.5	0.15	0.51	0.59	0.15	0.28	0.76

Persistence of Phillips curve shock	ρ_π	0.5	0.15	0.45	0.5	0.09	0.28	0.62
Standard deviation of IS curve shock	σ_y	0.013	∞	0.005	0.005	0.001	0.003	0.007
Standard deviation of potential output shock	$\sigma_{\bar{y}}$	0.013	∞	0.010	0.010	0.001	0.007	0.012
Standard deviation of growth shock	σ_g	0.013	∞	0.010	0.006	0.002	0.003	0.017
Standard deviation of Phillips curve shock	σ_π	0.013	∞	0.020	0.019	0.002	0.016	0.024
Standard deviation of nominal interest rate shock	σ_i	0.013	∞	0.008	0.005	0.002	0.004	0.012
Standard deviation of potential exchange rate shock	σ_q	0.013	∞	0.042	0.038	0.007	0.033	0.052
Standard deviation of UIP shock	σ_r	0.013	∞	0.010	0.006	0.002	0.003	0.017
Standard deviation of natural real interest rate shock	$\sigma_{\bar{r}}$	0.013	∞	0.056	0.057	0.006	0.043	0.069
Standard deviation of foreign natural interest rate shock	$\sigma_{\bar{r}^*}$	0.013	∞	0.028	0.033	0.003	0.008	0.039
Standard deviation of foreign interest rate shock	σ_{r^*}	0.013	∞	0.016	0.006	0.003	0.004	0.032
Marginal likelihood	782.7967							

Figure 11

PRIOR & POSTERIOR: FORWARD LOOKING MODEL



Prior and posterior density functions for the estimated parameters, prior functions are in gray and posteriors functions in black, the dashed vertical line indicates the parameter posterior mean. Calculations were made with Dynare.

E.2 Conditioned Estimation

Table A.7

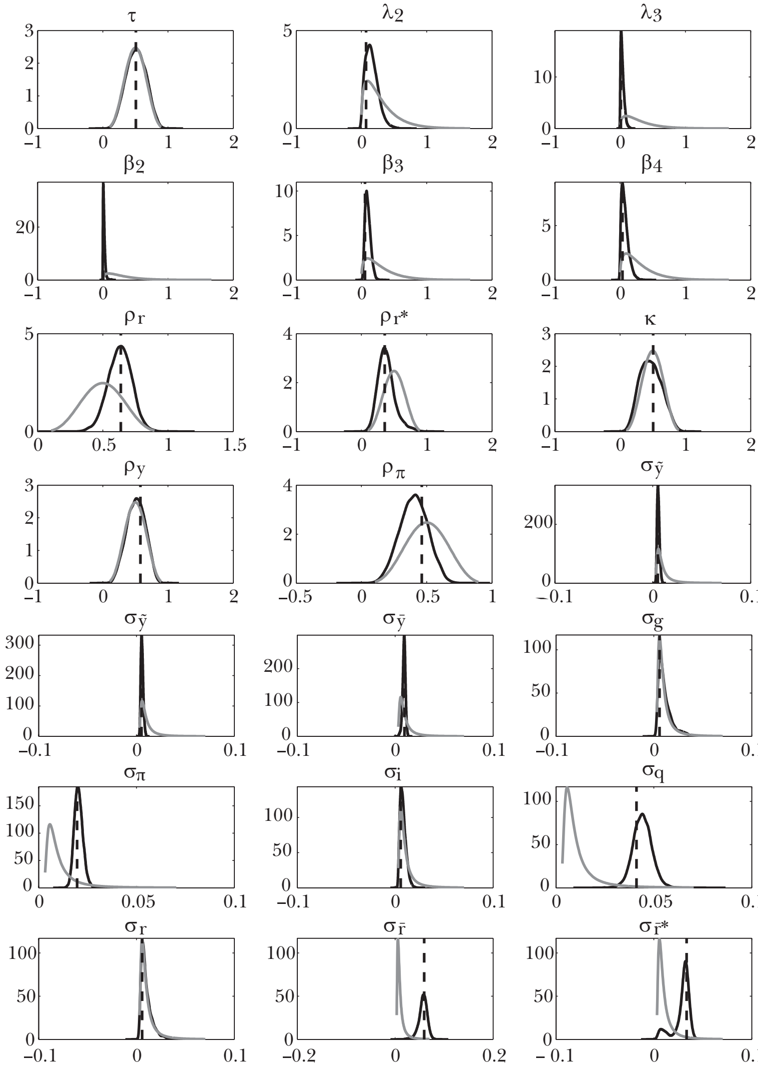
ESTIMATION RESULTS – FORWARD LOOKING MODEL

Parameter		Prior		Posterior			HPD 90%	
		Mean	*SD*	*Mean*	*Mode*	*SD*	*Lower*	*Upper*
Persistence of the growth process	τ	0.5	0.15	0.51	0.51	0.18	0.25	0.74
Elasticity of inflation to output gap	λ_2	0.3	0.25	0.16	0.07	0.07	0.01	0.29
Elasticity of inflation to depreciation	λ_3	0.3	0.25	0.04	0.01	0.02	0.00	0.07
Elasticity of output gap to real interest gap	β_2	0.3	0.25	0.07	0.04	0.05	0.00	0.15
Elasticity of output gap to exchange rate gap	β_3	0.3	0.25	0.02	0.01	0.01	0.00	0.04
Elasticity of output gap to expectations	β_4	0.3	0.25	0.10	0.05	0.03	0.03	0.16
Persistence of natural interest rate	ρ_r	0.5	0.15	0.63	0.64	0.08	0.48	0.78
Persistence of foreign natural interest rate	ρ_{r^*}	0.5	0.15	0.38	0.36	0.09	0.17	0.58
Persistence of foreign interest rate gap	κ	0.5	0.15	0.47	0.51	0.18	0.20	0.73
Persistence of IS shock	ρ_y	0.5	0.15	0.51	0.58	0.14	0.28	0.75
Persistence of Phillips curve shock	ρ_π	0.5	0.15	0.40	0.46	0.11	0.22	0.58

Standard deviation of IS curve shock	σ_y	0.013	∞	0.006	0.005	0.001	0.004	0.008
Standard deviation of potential output shock	$\sigma_{\bar{y}}$	0.013	∞	0.009	0.010	0.001	0.007	0.012
Standard deviation of growth shock	σ_g	0.013	∞	0.011	0.006	0.002	0.003	0.020
Standard deviation of Phillips curve shock	σ_π	0.013	∞	0.020	0.020	0.002	0.017	0.024
Standard deviation of nominal interest rate shock	σ_i	0.013	∞	0.008	0.006	0.002	0.004	0.013
Standard deviation of potential exchange rate shock	σ_q	0.013	∞	0.044	0.041	0.005	0.036	0.052
Standard deviation of UIP shock	σ_r	0.013	∞	0.010	0.006	0.002	0.003	0.018
Standard deviation of natural real interest rate shock	$\sigma_{\bar{r}}$	0.013	∞	0.057	0.059	0.006	0.043	0.070
Standard deviation of foreign natural interest rate shock	$\sigma_{\bar{r}^*}$	0.013	∞	0.029	0.033	0.003	0.012	0.040
Standard deviation of foreign interest rate shock	σ_{r^*}	0.013	∞	0.014	0.006	0.003	0.003	0.030
Standard deviation of measurement error	σ	0.013	∞	0.008	0.005	0.002	0.003	0.013
Marginal likelihood	796.9809							

Figure 12

PRIOR & POSTERIOR: FORWARD LOOKING MODEL



Prior and posterior density functions for the estimated parameters, prior functions are in gray and posteriors functions in black, the dashed vertical line indicates the parameter posterior mean. Calculations were made with Dynare.

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Josué Fernando Cortés Espada

Estimating the Exchange Rate Pass-through to Prices in Mexico

Abstract

This paper estimates the magnitude of the exchange rate pass-through to consumer prices in Mexico. Moreover, it analyzes if the pass-through dynamics have changed in recent years. In particular, it uses a methodology that generates results consistent with the hierarchy implicit in the CPI. The results suggest that the exchange rate pass-through to the general price level is low and not statistically significant. However, the pass-through is positive and significant for goods prices. Furthermore, the exchange rate pass-through declined over the 2000s and the depreciation observed in 2011 did not change this trajectory.

Keywords: depreciation, inflation, exchange rate pass-through, pass-through elasticity.

JEL Classification: E31, F31, F41

1. INTRODUCTION

During the last few decades a large number of emerging economies abandoned the exchange rate as nominal anchor in favor of an inflation targeting scheme with a free floating exchange rate. In addition, the number of economies with low and stable inflationary environments has

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increased recently. Under this context, literature studying the pass-through of exchange rate shocks to prices has shown that the benefits of a free floating regime become more evident once a stable inflationary process has been achieved. This is due to the fact that, as Taylor (2000) states, the magnitude of the exchange rate pass-through to prices depends on the volatility of the latter's inflationary process.

The objective of this paper is therefore to determine whether there is a pass-through of exchange rate movements to consumer price inflation in Mexico, and measure its magnitude. Special attention will also be placed on determining if the path of Mexico's consumer price index (CPI) inflation has been affected by the recent episodes of depreciation exhibited by the MXN/USD exchange rate. It particularly analyzes the depreciation recorded by said exchange rate during the second half of 2011, given the deteriorated international economic environment. Initially, economic analysts considered that the exchange rate adjustment would partly reverse within a relatively short time. Even though this reversal place, it took longer than was foreseen. In addition, at the end of 2011 the relative price of goods with respect to services began to increase as a consequence of the exchange rate adjustment, in line with Banco de México's forecast. However, the growth rate of goods prices was higher than anticipated.

The relevance of the topic in Mexico has led to a vast amount of literature that can be divided into two groups. First, the studies of Conesa (1998), González (1998), Garcés (1999), Goldfajn and Ribeiro da Costa (2000), Hausmann et al. (2000), Santaella (2002) and Schwartz et al. (2002), analyze the period of high inflation before the adoption of the inflation targeting scheme and show that there is a high degree of pass-through from exchange rate shocks to price variations. Second, there are the works of Baqueiro et al. (2003) and Capistrán et al. (2012), indicating that the hypothesis of Taylor (2000) would seem to apply to Mexico; i.e., after the change in inflation persistence documented by Chiquiar et al. (2010), the degree of pass-through from exchange rate movements to inflation has declined significantly.

Under such context, this paper uses a vector autoregressive (VAR) model similar to those employed in the literature on the topic. However, this research differs from previous works in five main aspects:

1) It employs an updated sample with information up to August 2012, allowing study of whether the results found by Capistrán et al. (2012) have changed and analysis of the recent episode of exchange rate depreciation that occurred in 2011.

2) Pass-through coefficients are calculated for the 16 main CPI aggregation groups. This allows determining which specific groups from the consumer price basket are affected by exchange rate fluctuations. Works such as that of Capistrán et al. (2012) analyzed the impact along the whole distribution chain, but did not carry out a disaggregation of the CPI. The main objective of this paper is to analyze the pass-through of exchange rate movements to consumer prices and it therefore does not study the impact along the whole distribution chain.

3) It uses the optimal aggregation method proposed by Hyndman et al. (2007) for the different CPI subindices. This methodology generates estimations that are consistent with the CPI's hierarchical structure. It also minimizes the distance between estimations made independently for each subindex and estimations obtained from the lowest aggregation groups. This is carried out by modifying the estimations of the lowest levels until this distance is minimized. Thus, estimations that use a wider group of information and that are consistent with the hierarchy are obtained. It is important to point out that this is first time the optimal aggregation method has been used to analyze the pass-through from exchange rate movements to inflation in the context of a VAR model.[1]

[1] In the case of Mexico, this method was applied by Capistrán et al. (2010) to aggregate forecasts of the consumer price indices.

4) It analyzes how the path of the pass-through coefficient of exchange rate movements has changed. Although in Capistrán et al. (2012) said trajectory was estimated through a bivariate regression between inflation and the exchange rate with rolling windows, this paper makes the estimation with a VAR model, also with the rolling window methodology. In this way it eliminates any possible bias caused by not including fluctuations in real activity, interest rates and other external variables.

5) The pass-through from the depreciation in mid-2011 is calculated. In particular, a counterfactual exercise is carried out to estimate the extent to which the shock suffered by the exchange rate in the second half of 2011 affected consumer prices in Mexico.

The results suggest that the pass-through coefficient of exchange rate shocks to consumer price inflation in Mexico is low and statistically not significant during the period June 2001-August 2012. However, said pass-through is positive and significant for goods prices due to the positive and significant pass-through to non-food merchandise prices. This is due to the fact that the prices of these groups are mostly determined in the international market. The latter is consistent with the fact only in these groups do exchange rate variations explain an important part of changes in their prices. It is also found that during the 2000s, the path of the exchange rate pass-through to the general price level shifted from positive and significant levels to statistically zero values. Moreover, the depreciation of the exchange rate in 2011 did not change this trajectory.

The rest of the paper is organized as follows: the second Section presents the VAR model employed for quantifying the pass-through of exchange rate movements to inflation, as well as the aggregation method for the differ rent CPI subindices. The impact of the exchange rate depreciation on consumer prices is addressed in the third Section. Finally, the fourth Section presents some final remarks.

2. METHODOLOGY

In order to quantify the magnitude of the pass-through from exchange rate shocks to consumer prices, this section presents a vector autoregressive model (VAR), similar to the one used in Capistrán et al. (2012), which will be used as the basis for the estimations in this research. Additionally, in order to ensure the results generated by said model respect the hierarchies and weights of the groups making up the CPI basket, the aggregation method developed by Hyndman et al. (2007) is employed.

2.1 Model

In order to analyze the pass-through of exchange rate fluctuations to consumer price inflation in Mexico a VAR model is estimated. This modeling strategy was introduced by Sims (1980) as an alternative to structural macroeconomic models, which generally resulted in large systems of equations requiring a large amount of restrictions for solving them. The importance of this type of models is that it allows study of the dynamics between a set of variables that are potentially endogenous, which is very common when analyzing macroeconomic series. In particular, this model allows analyzing the dynamics between shocks affecting the exchange rate and consumer price inflation, controlling for the behavior of other macroeconomic variables. For this reason, the works of Capistrán et al. (2012), Choudhri et al. (2005), Hahn (2003), McCarthy (2007) and Stulz (2007) opted for this technique for estimating exchange rate pass-through.

The analysis period employed for this estimation VAR model is from June 2001 to August 2012.[2] The selection of this starting point for the sample is due to two factors: First, as has been mentioned, Chiquiar et al. (2010) show that after 2001 inflation turned from being a stochastic trend process to a stationary

[2] The end of the period is determined by the availability of data from the global economic activity indicator (IGAE, for its Spanish acronym) at the time of developing this paper.

process; second, the study of Capistrán et al. (2012) shows that the pass-through coefficient underwent a change during the period January 1997-May 2001 as compared to that of June 2001-December 2010, therefore, given that the analysis will be based on the period where inflation has exhibited low and stable levels only the last time period, updated up to August 2012, will be employed. In this way it can also be studied whether the results obtained by said authors remain valid despite the depreciation that occurred in 2011.

The model includes a vector of endogenous variables: The global economic activity index *(IGAE)*; the 28-day Cetes interest rate (R); MXN/USD exchange rate *(TC)*, and the national consumer price index *(CPI)*. Additionally, the following exogenous variables are included: The US industrial production index *(PI)*, one-month US Treasury bonds interest rate *(R*)*, the US consumer price index *(CPI^{US})* and an international commodity price index *(P^{COM})*.[3] This selection of variables is included given that they typically, according to recent New Keynesian literature, characterize the conditions of balance in price-taking economies such as Mexico (i.e., small, open economies). The assumption of exogeneity implies that external variables affect domestic variables, but not vice versa, given that the model represents Mexico as a price-taking economy at the global level. As in the model employed by Capistrán et al. (2012), besides the Cetes and Treasury bill interest rates, which are defined in

[3] As in the study of Capistrán et al. (2012), each of the exogenous controls used are statistically significant for at least one of all the endogenous variables. In particular, the sample period June 2001-August 2012 for the model using the CPI yields the following: Just as economic activity in the USA affects that of Mexico, the Treasury bill interest rate also impacts the Cetes interest rate. In turn, changes in consumer prices abroad have a statistically significant impact on the IGAE and the exchange rate. Finally, international prices of commodities affect the exchange rate. The results of CPI disaggregations are similar, but present some peculiarities; for instance, US inflation have a statistically significant impact on the non-food goods price subindex.

percentage points, the other variables are presented by their annual change expressed in percentage. This allows the variables used in the calculation to be stationary during the study period. Furthermore, with this specification the roots of the characteristic polynomial of the model fulfill stationarity criteria set forth by Lütkepohl (2006, Chapter 2.1).

A recursive mechanism is used to identify the pass-through from exchange rate shocks to other endogenous variables, in particular, employing the Cholesky decomposition.[4] Through this mechanism a transformation of the variance-covariance matrix of the shocks is obtained from a lower triangular matrix. Thus, a shock in the first variable will be immediately passed on to the rest, while one in the last variable will impact the rest with a lag. Based on the aforementioned, the endogenous variables mentioned previously were placed in different orders, however, the results were robust to said variations and for this reason the same order used in Capistrán et al. (2012) is employed.

Thus, prices are placed after the exchange rate, allowing shocks to the latter to be immediately transmitted to the former. In turn, the interest rate is placed before both variables, implying that the monetary authority responds to exchange rate and inflationary shocks with a one-period lag. As in Capistrán et al. (2012), and following Peersman and Smets (2001), and Kim and Roubini (2000), the IGAE is placed first, indicating that the real activity reacts with a lag to interest rate shocks, while the exchange rate responds immediately to IGAE and interest rate shocks. This specification has also been used for analyzing the exchange rate pass-through to prices by Choudhri et al. (2005), Hahn (2003) and McCarthy (2007).

Based on the above, the model can be expressed as follows:

1 $$y_t = c + A(L)y_{t-1} + B\ (L)x_t + u_t\ ,$$

where:

[4] For details of the Cholesky decomposition see Hamilton (1994).

$$y_t = \left[\Delta_{12} \ln IGAE_t, R_t, \Delta_{12} \ln TC_t, \Delta_{12} \ln INPC_t \right],$$

$$x_t = \left[\Delta_{12} \ln PI_t, R_t^*, \Delta_{12} \ln IPC_t, \Delta_{12} \ln P_t^{com} \right].$$

A(L) and B(L) are matrix polynomials in the lag operator *L;* c is a vector of constants; u_t is a vector of residuals; and $\Delta_{12} \ln z_t$ represents the twelfth order logarithmic differences of variable z_t. Finally, it can be seen that the model to be estimated is in reduced form, meaning that no endogenous variable impacts the other immediately.

2.2 Aggregation of the Results

The VAR model explained in the previous section is used to estimate the pass-through of exchange rate movements to 16 superior aggregation groups of the CPI, i.e., an independent VAR is estimated for each of the following price indices:

- Headline index (I_G).
- Subindices: core (I_S) and non-core (I_N).
- Groups: goods (I_{SM}), services (I_{SS}), agricultural (I_{NA}), energy and government approved fares (I_{NE}).
- Subgroups: food, beverages and tobacco (I_{SMA}), non-food goods (I_{SMM}), housing (I_{SSV}), education (I_{SSE}), rest of services (I_{SSR}), fruits and vegetables (I_{NAF}), livestock (I_{NAP}), energy (I_{NEE}) and government approved fares (I_{NET}).

This method, consisting of estimating the pass-through to prices as if they were independent of each other, will hereafter be referred to as *direct estimation*. Once the 16 models have been estimated independently, the recursive method (Cholesky decomposition) is used to estimate the pass-through of exchange rate shocks to prices by means of impulse-response functions. However, the results obtained from the *direct estimation* method do not include the hierarchical relations among the 16 groups making up the CPI basket, which follow a *bottom-up* aggregation, i.e., superior aggregation groups are generated using the weighted averages of inferior groups. The latter implies that the results will not exhibit the consistency observed in the price indices.

In order to solve the above, the results generated by the *direct estimation* method are aggregated according to the procedure proposed by Hyndman et al. (2007), which will be referred to as *optimal combination*. This method combines the information of the aggregated and basic indices in line with the hierarchy of CPI groups. Besides, the estimators that present the minimum variance from the *direct estimation* are generated with certain assumptions. This aggregation mechanism was applied by Capistrán et al. (2010) for forecasting price indices in Mexico. However, as far as it is known, this is the first time they have been used to analyze the pass-through of exchange rate fluctuations to inflation in the context of a VAR model.

In order to coincide with the notation of Hyndman et al. (2007), the CPI is defined as aggregation level 0, the subindices as level 1, the groups as level 2 and finally the subgroups as level 3 in the aggregation of the CPI; as mentioned, these four aggregation levels include a total of 16 series. Data for period t for the series of level j are grouped in vector I_{jt}, in such way that vector $I_t = \left[I_{0t}, I_{1t}, I_{2t}, I_{3t}\right]$ represents the information in t of the 16 indices. Additionally, following Capistrán et al. (2010), a matrix P is defined that, unlike the matrix of zeros and ones used by Hyndman et al. (2007), is composed of 16 rows representing the relative weights of each of the level 3 subgroups within each of the indices I_t. Said matrix P is presented for the CPI weights based on the second fortnight of December 2012. It is worth mentioning that the weight matrix will remain constant in the exercises presented in the following section.[5]

[5] Although CPI weights changed in June 2002 and December 2010, such changes did not have a statistically significant impact on the estimations. Additionally, given that the analysis carried out in this paper takes place after the last change in the weights its results and conclusions are not affected by such updates.

$$I_t = \begin{bmatrix} I_G \\ I_S \\ I_N \\ I_{SM} \\ I_{SS} \\ I_{NA} \\ I_{NE} \\ I_{SMA} \\ I_{SMM} \\ I_{SSV} \\ I_{SSE} \\ I_{SSR} \\ I_{NAF} \\ I_{NAP} \\ I_{NEE} \\ I_{NET} \end{bmatrix} \quad P = \begin{bmatrix} 0.15 & 0.20 & 0.19 & 0.05 & 0.18 & 0.04 & 0.05 & 0.10 & 0.05 \\ 0.19 & 0.26 & 0.24 & 0.07 & 0.24 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.16 & 0.21 & 0.41 & 0.23 \\ 0.43 & 0.57 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.44 & 0.12 & 0.43 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.43 & 0.57 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.64 & 0.36 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Thus, it can be seen that with matrix *P* it is possible to obtain the aggregation of the 16 CPI indices using the *bottom-up* $\left(I_t^{BU}\right)$ method from the nine subgroups of level 3, i.e., $I_t^{BU} = PI_{3t}$. Furthermore, Hyndman et al. (2007) show that if $\hat{I}_t$ are independent estimations of the four aggregation levels, there is a matrix Q that produces lineal combinations of said estimations with which series $\tilde{I}_t$ are generated that fulfill the hierarchies implicit in calculating the CPI.

2 $$\tilde{I}_t = PQ\hat{I}_t$$

These authors also show that under the assumption that errors ε_{3t} existing between the inferior level independent estimations $\left(\widehat{I_{3t}}\right)$ and those generated by the previous formula $\left(\widetilde{I_{3t}}\right)$ fulfill the hierarchy implicit in matrix P, i.e., if the errors of all the aggregation levels, $\varepsilon_t = \left[\varepsilon_{0t}, \varepsilon_{1t}, \varepsilon_{2t}, \varepsilon_{3t}\right]$, fulfill the *bottom-up* aggregation, $\varepsilon_t = P\varepsilon_{3t}$, matrix $Q = (P'P)^{-1}P'$ generates combination $\left(\tilde{I}_t^*\right)$ that, besides fulfilling the hierarchy of the series, minimizes the variance with respect to the independent estimations $\left(\hat{I}_t\right)$.

3 $$\tilde{I}_t^* = P(P'P)^{-1} P'\hat{I}_t \cdot$$

Thus, the procedure of Hyndman et al. (2007) generates estimations from the information used for all aggregation levels and not only for inferior levels, meaning the group of data is broader than that used by the *bottom-up* method. The estimations will therefore be more efficient than those generated using the latter method given that it is limited within the space of possible combinations generated by matrix Q.

3. EXCHANGE RATE PASS-THROUGH TO PRICES

This section presents four exercises that allow for determining the magnitude of the pass-through from exchange rate shocks to consumer prices in Mexico, whether this has changed from December 2010 to date and its behavior during recent decades. It is important to mention that only the results for the headline index, core and non-core subindices, the groups of services and goods, and the disaggregation of the latter are shown, due to the nonsignificance exhibited by the other CPI[6] baskets.

3.1 Relation between the CPI and the Exchange Rate

The first point to analyze is whether there is in fact a correlation between CPI inflation and variations in the MXN/USD exchange rate. In this regard, it should be mentioned that the price formation process in the Mexican economy has changed significantly since 2001, when the inflation targeting scheme was adopted. Chiquiar et al. (2010) show that since then inflation turned from being a stochastic trend process to one that can be characterized as stationary. In addition to this, firms' price revision schemes changed from being mainly *state dependent* to predominantly *time dependent* (Cortés, Murillo and

[6] The results of the CPI groups which were not included are available from the author upon request.

Ramos-Francia, 2012).[7] In contrast, Gagnon (2007) estimates that for the period before the adoption of inflation targeting schemes the price formation process was mostly *state dependent*.

In this context, Figure 1 shows a change in the relation between the annual trajectory of CPI inflation and the annual change of the nominal exchange rate.[8] As can be seen, from 1976 to September 2012, both series are closely correlated (0.79). In fact, it can be observed that the depreciations in 1976-1977, 1982-1983, 1987-1988 and 1995 were accompanied by significant increases in headline inflation. However, since the adoption of inflation targeting schemes in 2001, the degree of correlation between inflation and depreciation declined (0.36). Thus, within the environment of low and stable inflation that has prevailed in Mexico during recent years, the exchange rate pass-through to prices seems to have been low. In particular, the depreciation between 2008 and 2009 had no significant impact on inflation, as opposed to the aforementioned devaluations. The model described in the previous section is estimated in order to quantify this impact.

3.2 Precise Estimation

Once the model is estimated, impulse-response functions are calculated to determine the pass-through of exchange rate shocks to inflation. In order to facilitate interpretation of the results generated from the methodology developed in the previous section, Figures 2 to 4 show the effect in terms of accumulated pass-through elasticities, which can be interpreted as

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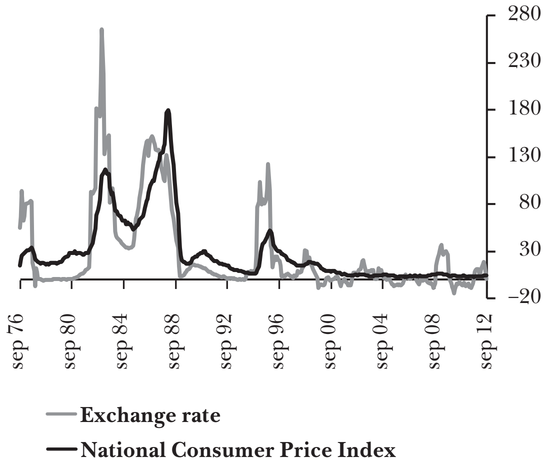
7 *Time dependent* price revision strategies are defined as those where revisions in order to realize possible price changes are carried out by the firm in pre-established periods, while in *state dependent* strategies prices are not revised in pre-established schedules, but rather depend on the circumstances faced by the firm at the macroeconomic level.

8 This Figure is an updated version of that presented in Capistrán et al. (2012). Its interpretation remains the same even with the sample up to 2012.

Figure 1

NATIONAL CONSUMER PRICE INDEX AND EXCHANGE RATE
(annual variation)



Sources: Banco de México and Inegi.

percentage changes in prices given a 1% depreciation of the exchange rate, i.e.:

4
$$PT_t = \frac{\Delta\% P_{t,t+\tau}}{\Delta\% TC_{t,t+\tau}},$$

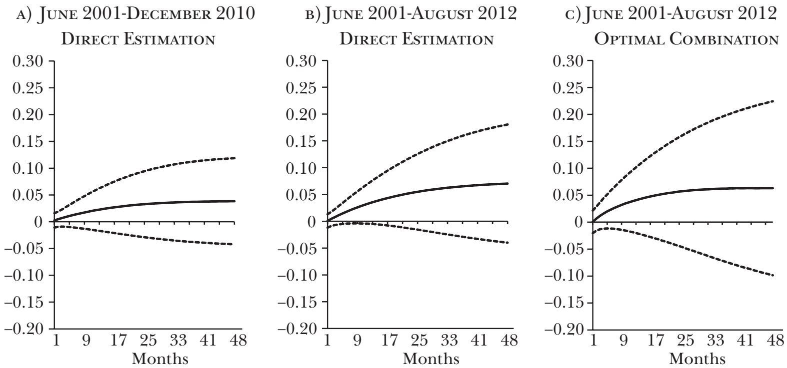
where $\Delta\% P_{t,t+\tau}$ is the percentage change of the price level τ periods after the shock, and $\Delta\% TC_{t,t+\tau}$ is the percentage change of the exchange rate in the same period. Thus, the vertical axis is measured in percentage points and the responses are presented for a 48-month horizon with 90% confidence intervals, a measure typically used in the literature. The standard errors of the elasticities are obtained from those generated for the impulse-response functions through ordinary least squares.

Figures 2a and 2b show the elasticities of the accumulated pass-through to the general price level using the *direct estimation* method for the period June 2001-December 2010 estimated by Capistrán et al. (2012) and for the period June 2001-August 2012, respectively. The results show that the accumulated pass-through elasticity increased slightly from December 2010 to

Figure 2

Impact of the Exchange Rate on the CPI[1]

(Accumulated pass-through elasticity)



Sources: Own calculations with information provided by Banco de México and Inegi.

[1] Doted lines are 90% confidence intervals.

August 2012. However, such differences are not statistically significant, given that, as can be seen, the impact is still statistically equal to zero. This shows that the exchange rate depreciation in 2011 did not significantly change said pass-through. In addition, Figure 2c shows the results obtained using the *optimal combination* method for the second study period. As can be seen, the pass-through elasticity of exchange rate movements to the general level of prices does not exhibit statistically significant differences after the estimation method is changed, implying that estimations for pass-through elasticities are robust to the method employed.[9]

The abovementioned results are shown in Table 1. As reported in Capistrán et al. (2012), in 2010 the elasticity of the exchange rate pass-through to general consumer prices was 0.02 one year after the shock and 0.04 four years after it. By

[9] As would be expected, given that the results generated by the *optimal combination* method have a minimum variance from the those obtained using the *direct estimation* method, the results from both methods for the remaining CPI levels also exhibit this robustness.

Table 1

ELASTICITY OF THE EXCHANGE RATE PASS-THROUGH TO THE CPI[1]
(accumulated pass-through elasticity)

	Months			
	12	*24*	*36*	*48*
June 2001 to December 2010	0.021	0.032	0.037	0.038
Direct estimation	(0.02)	(0.04)	(0.04)	(0.05)
June 2001 to August 2012	0.033	0.054	0.065	0.070
Direct estimation	(0.02)	(0.04)	(0.06)	(0.07)
June 2001 to August 2012	0.039	0.056	0.062	0.063
Optimal combination	(0.03)	(0.06)	(0.08)	(0.09)

Source: Own calculations with information provided by Banco de México and Inegi.
[1] Data in parenthesis represents standard errors.

updating this model with information up to August 2012, the pass-through elasticity is estimated to be 0.03, 12 months after the shock, and 0.07, 48 months after it, although such impact is not statistically significant. Finally with the optimal aggregation method of Hyndman et al. (2007) the pass-through coefficient is estimated to be 0.04 one year after the shock and reaches 0.06 four years after it.

As can be seen in Figure 2 and Table 1, the results of both estimation methods (*direct estimation* or *optimal combination*) are not statistically different. However, the *optimal combination* method satisfies the hierarchical structure of the CPI and yields estimates based on a broader group of information than the *bottom-up* method. In particular, it generates better estimates for the most inferior levels (due to the way it minimizes the distance with respect to direct estimates) by taking into consideration the trajectories that satisfy the hierarchies. This implies that all the groups of information used are combined to calculate all the estimates.

Table 2 shows the results for the different price subindices in the period June 2001-August 2012. In the case of core and non-core price indices, pass-through elasticity is found to be

0.02 and 0.10, respectively, one year after the shock, reaching 0.02 for the former and 0.13 for the latter after 48 months. In turn, the elasticity of the exchange rate pass-through to the goods price subindex is 0.07 twelve months after the shock and 0.17 after four years. In the case of the services price subindex, the pass-through is practically zero, both one year after the shock and in the long term. Additionally, regarding the food, beverages and tobacco and non-food merchandise price subindices, the elasticities of the exchange rate pass-through are approximately 0.05 and 0.09 after one year, reaching 0.13 and 0.19, respectively, after four years. It is important to point out that the estimation results indicate that only in the case of non-food merchandise inflation the exchange rate

Table 2

ELASTICITY OF THE EXCHANGE RATE PASS-THROUGH TO PRICE INDICES

(accumulated pass-through elasticity, June 2001-August 2012)

		Months			
		12	*24*	*36*	*48*
CPI	Elasticity	0.039	0.056	0.062	0.063
	Standard error	(0.03)	(0.06)	(0.08)	(0.09)
Core	Elasticity	0.017	0.023	0.025	0.025
	Standard error	(0.01)	(0.02)	(0.02)	(0.02)
Merchandise	Elasticity	0.071	0.125	0.153	0.166
	Standard error	(0.02)	(0.05)	(0.09)	(0.12)
Food	Elasticity	0.051	0.103	0.128	0.134
	Standard error	(0.03)	(0.07)	(0.12)	(0.16)
Non-food Merchandise	Elasticity	0.086	0.143	0.172	0.191
	Standard error	(0.02)	(0.04)	(0.06)	(0.08)
Services	Elasticity	0.002	0.000	−0.001	0.000
	Standard error	(0.01)	(0.02)	(0.02)	(0.02)
Non-core	Elasticity	0.095	0.122	0.130	0.131
	Standard error	(0.09)	(0.12)	(0.15)	(0.16)

Source: Own calculations with information provided by Banco de México and Inegi.

pass-through coefficient is statistically different from zero in the long term (Figure 3).

Up to this point it has been determined how an exchange rate shock affects prices. In order to complement said analysis, the decomposition of the variance in inflation used by McCarthy (2007) for the different CPI groups is presented. In particular, the contribution of exchange rate movements to changes in consumer prices during the period June 2001-August 2012 is studied. The results are shown in Figure 4 and support the findings above. It is found that, only in the case of goods and non-food merchandise, a significant part of their change is due to exchange rate movements, given that the latter's contribution is statistically not significant for the other groups.[10]

3.3 Dynamic Estimation

The results presented above provide a comprehensive, but precise, account of how consumer prices in Mexico were affected by exchange rate shocks during the period of low and stable inflation between June 2001 and August 2012. However, analyzing the behavior of the exchange rate pass-through when moving from a period of high inflation to one of relative stability might provide the analysis with a way to detect whether the results of the previous section are robust to the study period, and whether the exchange rate pass-through to prices has not begun to increase due to the recent depreciations.

A first study of this was carried out by Capistrán et al. (2012). Estimation of a rolling window linear regression of annual headline inflation on the annual depreciation rate of the exchange rate, a constant and a lag of inflation, provides evidence that the pass-through of exchange rate shocks to the general price level changed in 2001 from positive and significant levels to levels statistically equal to zero. This coincides with the change in inflation rate dynamics reported by Chiquiar et al.

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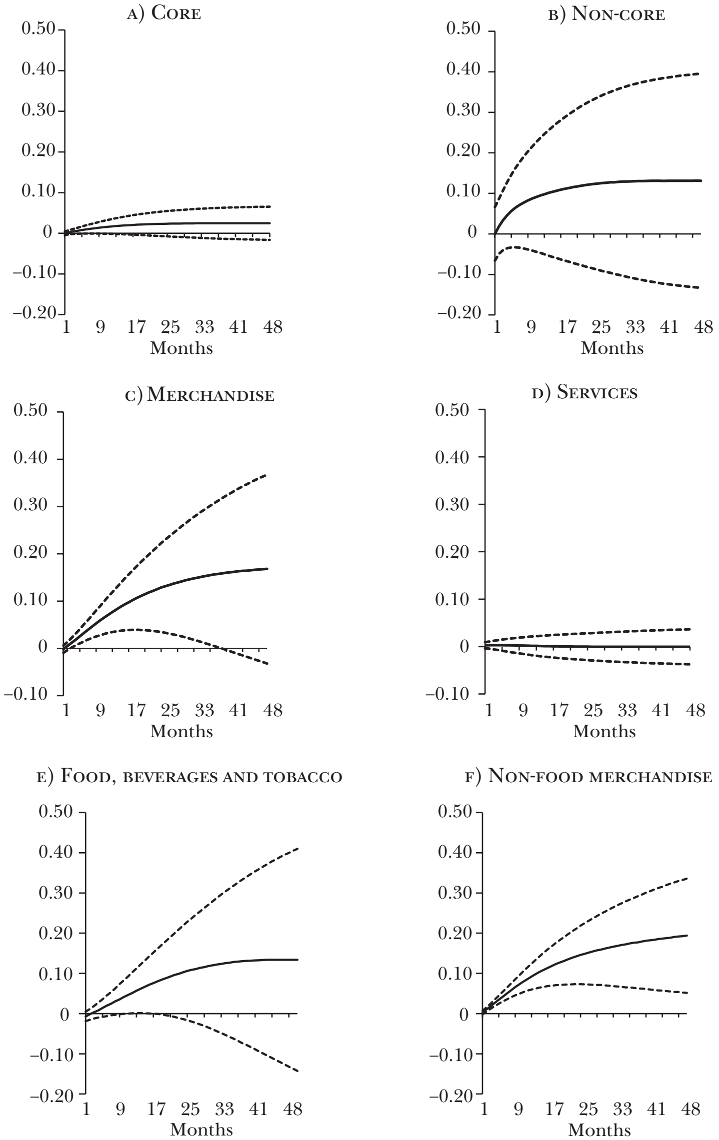
[10] Confidence intervals are obtained using Monte Carlo simulations with 50,000 repetitions.

Figure 3

EXCANGE RATE DEPRECIATION EFFECT TO PRICE INDICES[1]

(Accumulated pass-through elasticity, June 2001-August 2012)

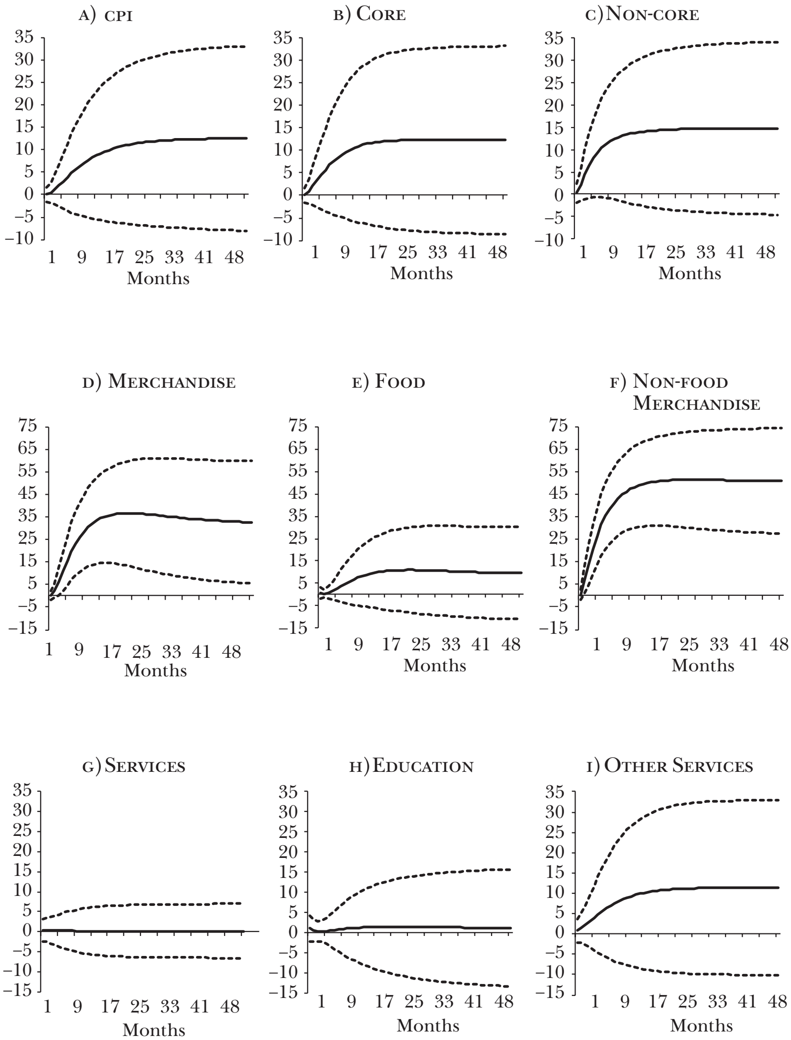


Sources: Own calculations with information provided by Banco de México and Inegi.
[1] Doted lines are 90% confidence intervals.

Figure 4

VARIANCE OF PRICES INFLATION EXPLAINED BY THE EXCHANGE RATE[1]

(Percentage, June 2001-August 2012)



Sources: Own calculations with information provided by Banco de México and Inegi.

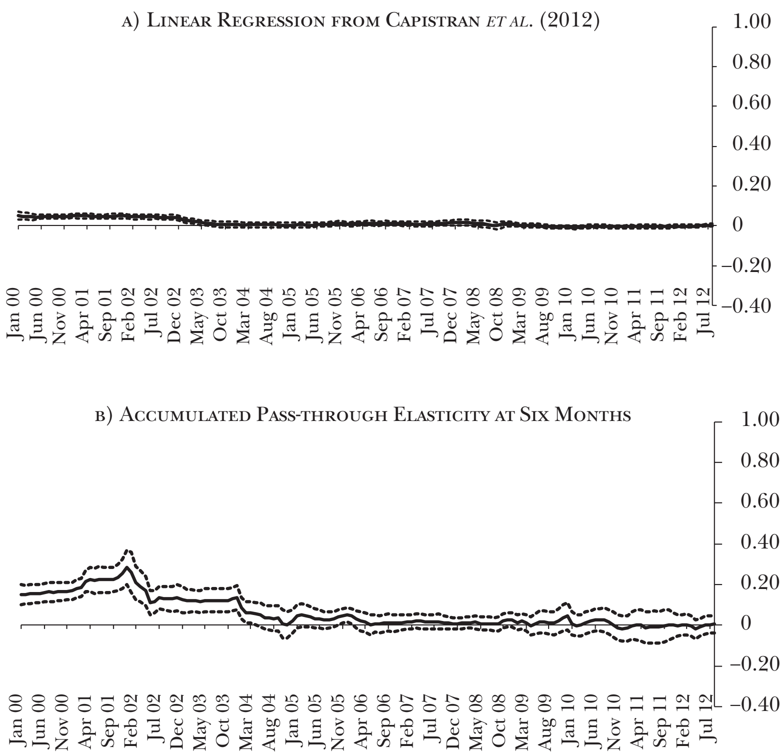
[1] Doted lines are 90% confidence intervals.

(2010). The results of said estimation were updated to August 2012 and are shown in Figure 5a.

Unlike Capistrán et al. (2012), this section estimates a VAR model with rolling windows using the group of variables described previously. The data sample includes the periods of stable and volatile inflation seen in recent decades, using data from 1994 to August 2012. Thus, the behavior of the pass-through coefficient is estimated, controlling for the possible bias generated by excluding changes in real activity, interest

Figure 5a

PASS-THROUGH OF EXCHANGE RATE TO CPI IN MEXICO[1]
(Accumulated pass-through elasticity, June 2001-August 2012)



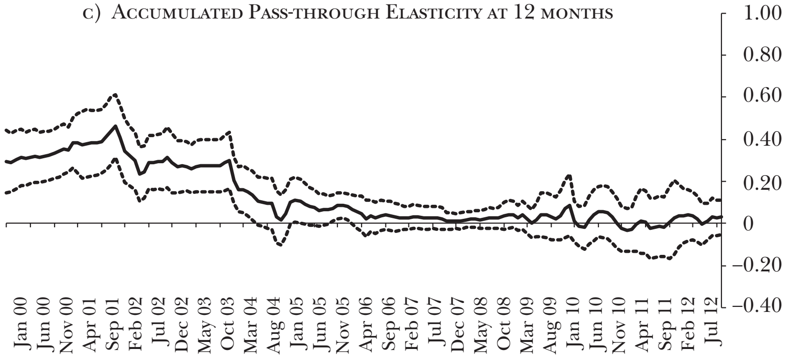
Sources: Own calculations with information provided by Banco de México and Inegi.
[1] Doted lines are 90% confidence intervals.

Figure 5b

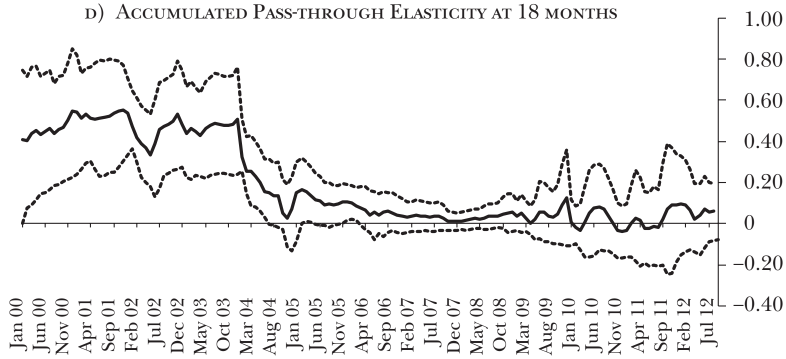
PASS-THROUGH OF EXCHANGE RATE TO CPI IN MEXICO [1]

(Accumulated pass-through elasticity, June 2001-August 2012)

c) ACCUMULATED PASS-THROUGH ELASTICITY AT 12 MONTHS



d) ACCUMULATED PASS-THROUGH ELASTICITY AT 18 MONTHS



Source: Own calculations with information provided by Banco de México and Inegi.
[1] Doted lines are 90% confidence intervals.

rates and the previously mentioned external macroeconomic variables. In addition to this, the *optimal combination* method is applied with six-year rolling windows. The calculations mentioned in the estimation are made for the first window from January 1994 to January 2000, then for February 1994 to February 2000, and so on, up until the window from August 2006 to August 2012.

This type of formula allows analysis of the pass-through coefficient, while controlling for the mentioned variables, on any time horizon and not just the immediate impact determined by the linear regression model. Based on this, Figures 5b to 5d present the estimates of said pass-through for horizons of 6, 12 and 18 months after the exchange rate shock.[11] It can be seen that, for any study horizon, at the start of the 2000s the pass-through changed from being at positive and statistically significant levels to levels statistically equal to zero.[12] It is also found that, despite the depreciation in the second half of 2011, the trajectory of the pass-through coefficient remained unchanged.

The above confirms that the pass-through coefficient of exchange rate movements to prices has undergone a change of trend as mentioned by Capistrán et al. (2012). However, unlike the bivariate regression carried out in that work, this model allows a better approximation of the magnitude and trajectory of said coefficient given that it controls for the interaction that exists with other macroeconomic variables. Additionally, the magnitude of the pass-through elasticity found for 6, 12 and 18 month horizons before 2001 are consistent with the results shown by Capistrán et al. (2012) for the period prior to the inflation targeting regime. The latter cannot be obtained through the aforementioned linear regression given that it only analyzes the immediate impact of the exchange rate on prices.[13]

Furthermore, when using the optimal aggregation method the results fulfill the hierarchy implicit in CPI calculations.[14] It

[11] Results for other time horizons exhibit the same behavior as those displayed in Figure 5.

[12] As can be seen, the change in the pass-through elasticity occurs around 2004, which is different from the date when the inflation targeting scheme was adopted. However, this shift is due to the fact that using rolling windows causes the change to be detected after it occurred because the windows also include data prior to the date of such change.

[13] In particular, Capistrán et al. (2012) find that for the period January 1997-May 2001 the pass-through elasticity was 0.16, 0.33 and 0.49 for horizons of 6, 12 and 18 months, respectively.

[14] To obtain the results with the *optimal combination* procedure it is necessary to apply precise estimation to the 16 most aggregated CPI indices. However, given that the results do not exhibit any large

also confirms the hypothesis of Taylor (2000), which indicates that in an environment of stable inflation derived from a credible monetary policy, firms are less inclined to pass through cost shocks to consumers given that their inflation expectations are well anchored.

3.4 Counterfactual Exercise

Finally, this section estimates the impact of the exchange rate depreciation observed since August 2011 on consumer prices in Mexico. In order to do this the methodology explained above is applied for the period June 2001-July 2011 with the aim of simulating the impact that would have occurred at the moment of the depreciation.

In particular, in mid-2011 the Mexican economy was affected by an exchange rate shock, as a reflection of the deterioration in the external economic environment that led to a depreciation of over 18% between July and December of that year. Consequently, the observed trajectory of the exchange rate was above that expected by analysts before the referred shock. To define the magnitude of the exchange rate shock that will be analyzed in this section, Figure 6 presents the average exchange rate from August 2011 to September 2012 (13.23 pesos per dollar) and the average trajectory expected in July 2011 (11.88 pesos).[15] As can be seen, the average exchange rate from August 2011 to September 2012 was 11.42% above the average level implied by economic analysts' expectations.

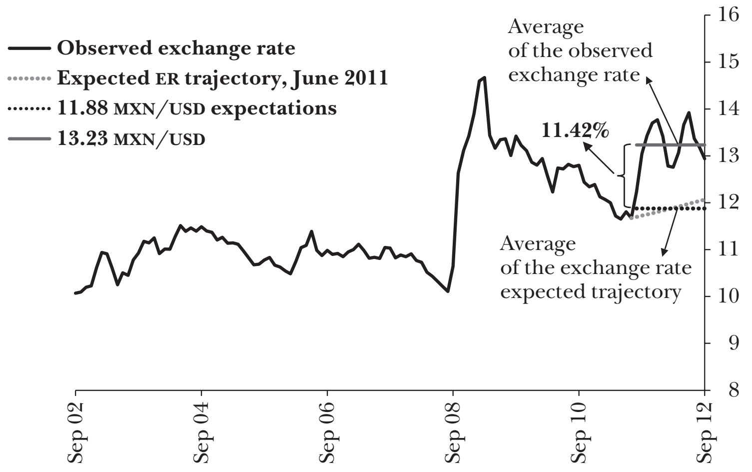
To determine the impact of this depreciation on headline inflation and its components, it will be assumed that the 11.42% shock occurred in August 2011. Thus, by calculating the pass-through elasticity for the mentioned period it is possible to

differences, only those of headline inflation are presented here.

[15] These estimations were taken from the Banamex Encuesta de Expectativas de Analistas de Mercados Financieros, according to which the expected exchange rate was 11.80 pesos per dollar at the end of 2011 and 12.15 pesos for 2012.

Figure 6

NOMINAL EXCHANGE RATE (MXN/USD)



Sources: Banco de México and Encuesta de Expectativas de Analistas de Mercados Financieros elaborated by Banamex, July 2011.

determine how many percentage points of the inflation of the different price subindices can be attributed to the shock in the months after it.

The obtained results show that the exchange rate depreciation in the second half of 2011 impacted annual headline inflation in September 2012 by 0.34 percentage points (Table 3). This means that 34 basis points from the annual CPI change, which was 4.77 per cent in September 2012, were due to the unexpected exchange rate adjustment. Regarding annual core and non-core inflation, the impact in September 2012 is estimated at 0.16 and 0.74 percentage points, respectively. In the case of annual goods and services core inflation, the impact is estimated at 0.82 and zero points that month. Finally, the effect of the shock on food, beverages and tobacco, and non-food merchandise inflation was 0.86 and 0.80 percentage points. Nevertheless, it is important to point out that, as for the period June 2001-August 2012, the impact of the exchange rate depreciation is only statistically significant for the goods

Table 3

IMPACT OF THE DEPRECIATION ON ANNUAL INFLATION
(percentage points)

		Dec. 2011	*Mar. 2012*	*Aug. 2012*	*Sep. 2012*
CPI	Observed inflation	3.82	3.73	4.57	4.77
	Shock	0.20	0.28	0.38	0.34
Core	Observed inflation	3.35	3.31	3.70	3.61
	Shock	0.09	0.13	0.18	0.16
Merchandise	Observed inflation	4.52	4.51	5.23	5.24
	Shock	0.32	0.53	0.86	0.82
Food	Observed inflation	7.32	6.63	6.81	6.91
	Shock	0.22	0.43	0.88	0.86
Non-food Merchandise	Observed inflation	2.39	2.89	4.01	3.96
	Shock	0.40	0.61	0.84	0.80
Services	Observed inflation	2.40	2.32	2.43	2.25
	Shock	0.05	0.04	0.00	−0.01
Non-core	Observed inflation	5.34	5.12	7.58	8.81
	Shock	0.50	0.68	0.89	0.74

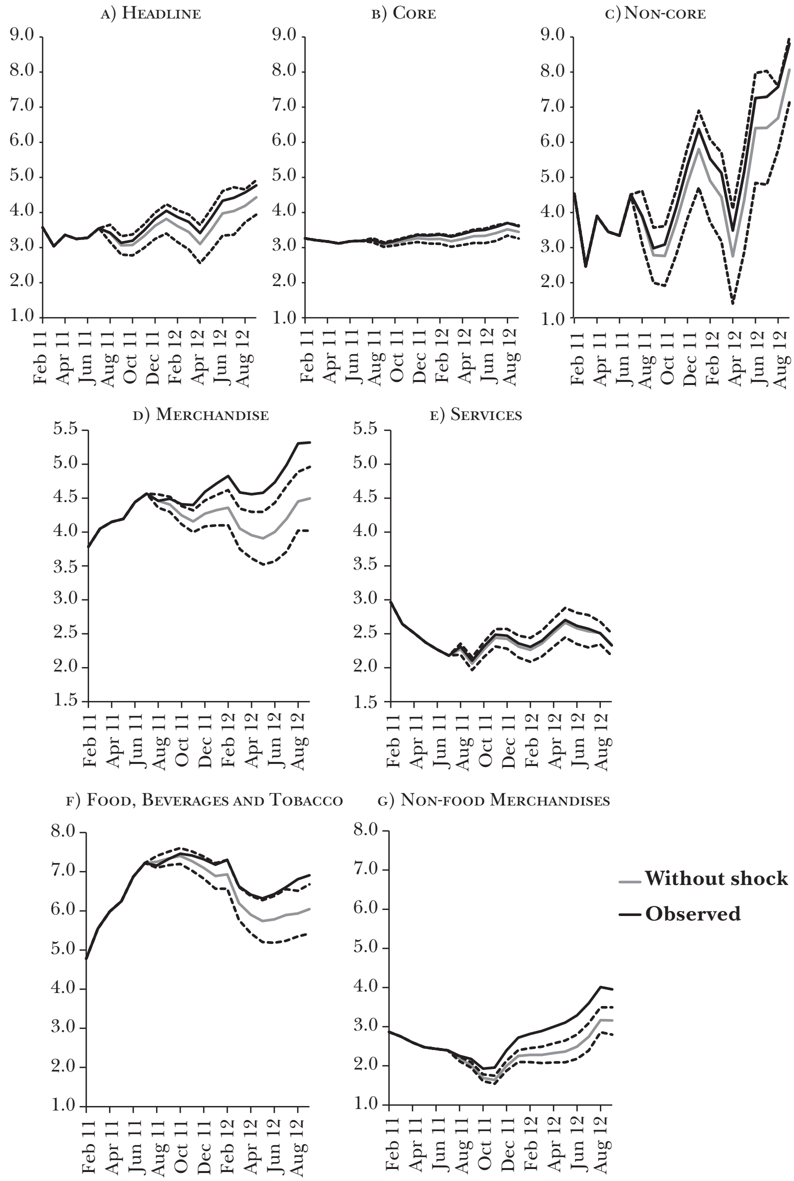
Source: Own calculations with information provided by Banco de México and Inegi.

price subindex, and in particular, for non-food merchandise (Figure 7).

In order to analyze the trajectories that would have been observed if the shock had not occurred, and under the mentioned assumptions, a counterfactual exercise is carried out that sheds more light on the previous results. The exercise consists of simulating the trajectories of the main CPI components in the absence of the exchange rate deprecation that occurred in August 2011. In order to do this, the impact of the shock was excluded from accumulated inflation after August 2011 and new indices were constructed that did not contain the effect of the shock. The aforementioned allows identification of the groups of goods and services from the CPI basket

Figure 7

IMPACT OF EXCHANGE RATE DEPRECIATION IN AUGUST 2011
PRICE INDICES[1] (annual variation)



Sources: Own calculations with information provided by Banco de México and Inegi.
[1] Doted lines are 90% confidence intervals.

on which the pass-through of exchange rate movements generate a significant impact.

Figure 7 shows observed inflations and the inflations simulated through the counterfactual exercise, as well as the confidence intervals around the counterfactual trajectories. The results are presented for the same price indices used in the above exercise. It can be observed that the impact on the two highest CPI aggregation levels is not significant (Figures 7a-7c). Additionally, within the core subindex it can be seen that exchange rate effect is generated in the goods group and not in that of services (Figures 7d-7e). Finally, and as mentioned, the pass-through to goods inflation is due to the change in prices of non-food merchandise (Figures 7f-7g).

4. FINAL REMARKS

In a large number of emerging economies inflation shifted from high and volatile levels to relatively stable conditions, which was accompanied by the adoption of inflation targeting schemes and abandonment of the exchange rate as nominal anchor. Thus, in line with economic theory, said economies have begun to enjoy the benefits of a free floating exchange rate regime, given that in an environment of low and stable inflation, and the presence of credible and efficient monetary policy, the pass-through of external cost shocks to consumers declines considerably.

This paper measured the pass-through of exchange rate movements to consumer prices in Mexico and analyzed whether the behavior of said pass-through has changed in recent years. It particularly studied the case of the exchange rate depreciation that occurred in the second half of 2011. A methodology that generates results consistent with the hierarchy implicit in the CPI was used for the aforementioned.

The results show that, for the period June 2001-August 2012, the coefficient of the exchange rate pass-through to headline inflation in Mexico was low and statistically not significant. However, said pass-through is found to be positive and significant for the group of goods as a result of the pass-through to prices of non-food merchandise, explained by the fact that these groups include tradable goods the prices of which are determined in international markets. These results coincide with the fact that exchange rate movements determine a significant part of price changes only for these groups. Additionally, at the start of the 2000s, the trajectory of the exchange rate pass-through to the general level of prices shifted from positive and significant levels to values statistically not different from zero, period coinciding with the change in inflation persistence. Furthermore, it is found that the depreciation of the exchange rate in 2011 did not change said trajectory.

This empirical work presents evidence on the relation between the exchange rate and consumer prices in Mexico, which can provide important elements and serve as a reference framework in different dimensions for structural and general equilibrium models. It also provides an analysis tool that can be used in the monetary policy decision-making process.

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Alberto Ortiz Bolaños

Credit Market Shocks, Monetary Policy, and Economic Fluctuations

Abstract

This paper uses a dynamic stochastic general equilibrium model with credit market imperfections to estimate the role of credit market shocks and monetary policy in US business cycles. The estimated model captures much of the historical narrative regarding the conduct of monetary policy and developments in financial markets that led to episodes of financial excess and distress over the last two decades. The estimation suggests that credit market shocks are an important factor behind economic fluctuations accounting for 15% of the variance in real output since 1985. In addition, we find that once credit market imperfections are considered, monetary policy is also an important force behind real output fluctuations explaining 12.5% of its variance.

Keywords: financial accelerator, monetary policy, DSGE models, Bayesian estimation.

JEL Classification: E32-E44.

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1. INTRODUCTION

The US financial crisis that started in 2008 was quickly followed by contractions in output, investment and employment indicating that financial factors could have real economic consequences. In response to the financial stress, the Federal Reserve Board reduced aggressively its policy interest rate implying monetary authorities' belief that they can partially offset negative credit market shocks. However, at the onset of the crisis there were scarce measurements of the real-financial linkages and none of the studies put together financial data and a model-based mechanism to provide insights. This paper fills this gap by providing evidence for the US economy using a Bayesian maximum likelihood methods to estimate an extended version of the Bernanke, Gertler, Gilchrist (1999) (henceforth BGG) financial accelerator model using real and financial data.

Among the evidence that suggested the existence of important linkages between financial conditions and macroeconomic outcomes Gilchrist, Yankov, and Zakrajsek (2008) (henceforth GYZ) show that corporate bond spreads have significant predictive power for economic activity.[1] Later, Gilchrist and Zakrajšek (2011) and Gilchrist and Zakrajšek (2012) included financial bond premium information into an otherwise standard macroeconomic vector autoregression (VAR) to examine the macroeconomic consequences of financial disturbances finding that credit market shocks have important effects on output, consumption, investment and working hours. Unfortunately, these analyses lacked of a structural macroeconomic model to distinguish between changes in credit supply and demand and that can account for general equilibrium feedback effects between developments in the financial and real sectors of the economy.

1 GYZ suggest that this predictive power likely reflects the information content of credit spreads for disruptions in financial markets or variations in the cost of default, two factors that would cause credit spreads to widen relative to expected default risk prior to an economic downturn.

Earlier work by Elekdag, Justiniano, and Tchakarov (2006), Tovar (2006), Christiano, Motto, and Rostagno (2007) (henceforth CMR), Christensen and Dib (2008), De Graeve (2008), and Queijo von Heideken (2008) sought to quantify these general equilibrium mechanisms by estimating dynamic stochastic general equilibrium (DSGE) models that incorporate credit market imperfections through the financial accelerator mechanism described in Carlstrom and Fuerst (1997) and BGG. Although details differ in terms of model estimation and shocks specification, all of these papers document an important role for financial factors in business cycles fluctuations. Queijo von Heideken (2008) for example, shows that the ability of a model with a rich array of real and nominal rigidities to fit both US and the euro area data improves significantly if one allows for the presence of a financial accelerator mechanism; and CMR demonstrates that shocks to the financial sector have played an important role in economic fluctuations over the past two decades, both in the United States and Europe. Queijo von Heideken (2008), however, estimate a structural model that is identified without reliance on financial data and that does not allow for shocks to the financial sector, whereas CMR, though allowing for a wide variety of shocks to the financial sector, do not estimate the parameters governing the strength of the financial accelerator mechanism.

This paper is the first to estimate simultaneously the key parameters of the financial accelerator mechanism along with the shocks to the financial sector using financial market data. An advantage of including financial factors in our model is that we can consider structural, as opposed to the criticized reduced-form, financial shocks and directly assess their importance as drivers of economic activity. The empirical exercise is conducted using US data from 1985 to 2008, the period of the so-called *great moderation*. We limit the sample to 2008 to avoid the zero-lower bound on interest rates that would complicate the identification of the monetary policy shocks using a Taylor-interest rate rule.

The model is a New Keynesian DSGE model with agency costs as in BGG. These credit market imperfections, caused by asymmetric information, would generate a link between the real and financial sectors of the economy. In the financial accelerator mechanism, originally proposed by Bernanke and Gertler (1989), that will be the mechanism adopted in this paper, borrower's financial position determine her cost of credit. Unexpected changes in borrower's financial position, caused by shocks that affect their expected returns, would change financial constraints and through the required financing it will impact investment activity. Therefore, this financial accelerator mechanism amplifies and propagates shocks to the economy.

Overall our estimations show that credit market shocks account for 15% of output fluctuations during the 1985Q1-2008Q2 period, exacerbating economic downturns and magnifying economic expansions. Meanwhile, monetary policy partially offset credit market shocks during the three periods of financial instability and economic downturn included in the sample and explains 12.5% of the variance in output. The impulse response functions of the estimated model show that financial shocks have important real effects as a 0.25% unexpected rise in the external finance premium causes a 0.73% decrease in output and a 2.8% decrease in investment. Meanwhile, a 0.44% unexpected reduction in the federal funds rate contributes to a 0.38% expansion in output and 1.42% increase in investment. The increase in output that comes with the expansionary monetary policy, by improving borrowers' financial positions, contributes to reduce the cost of external financing further contributing to the output expansion.

The outline of the paper is as follows. Section 2 presents empirical evidence of the effect of credit market shocks on economic activity using a VAR. Section 3 develops the DSGE model with agency costs that is used to describe a mechanism of how credit market conditions could affect economic activity. Section 4 discusses the estimation strategy and the empirical implementation. Section 5 contains the results. Section 6 concludes.

2. EVIDENCE OF THE EFFECT OF CREDIT MARKET SHOCKS ON ECONOMIC ACTIVITY

In this Section we present a standard macroeconomic VAR extended with data on credit risk premium to examine the effect of credit risk shocks on economic activity.

The VAR and the model presented in Section 3 are, both, estimated using the same data set. The variables included are quarterly data on growth rates of real output and investment, and levels of inflation, interest rates, and external finance premium.[2] As in Gilchrist and Zakrajšek (2011), following assumptions of contemporaneous effects, the VAR stacks the data in the following order: Growth rate of real investment, growth rate of real output, inflation, federal funds rate, and external finance premium. Figure 1, below, shows the effect of a credit risk premium shock. The innovations are expressed in percentage points and the mean and 90% confidence intervals are reported. In response to a 0.40% increase in the credit risk premium, output growth contracts 0.09%, while investment growth diminishes 0.50%. The direction of these responses is in line with empirical evidence reported in Gilchrist and Zakrajšek (2011) that documents the importance of credit market conditions for macroeconomic performance.

Even when this evidence shows us that credit market shocks have consequences for economic activity, without a structural

[2] Data comes from FRED II, except from the external finance premium measures. Output growth rates are computed as natural logarithm (ln) differences of the seasonal adjusted real gross domestic product. The same procedure applies for investment which is the seasonal adjusted total real business fixed investment. Inflation rates are detrended ln differences of the consumer price index multiplied by four to annualize. Nominal interest rates are reported in levels and correspond to the detrended effective federal funds rate. The external finance premium comes from Gilchrist, Ortiz, and Zakrajšek (2008) and consists of the first principal component of risk-premium measure computed using detailed information from bond prices on outstanding senior unsecured debt issued by a large panel of non-financial firms.

model we cannot discuss the transmission mechanism of financial shocks to the economy. There are different ways in which one could introduce a role for credit market imperfections and with this to generate a link between the real and financial sectors. Focusing on borrowing constraints one could consider costly enforcement, collateral constraints or costly state verification (CSV).

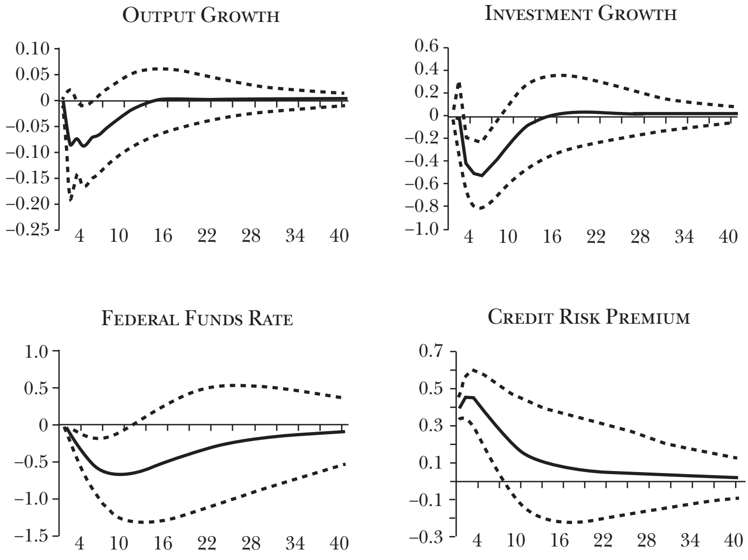
With costly enforcement, the credit market imperfection is associated to the inability to freely enforce contracts. In this paradigm, borrowers could decide to renege on debt and lenders anticipating this adverse behavior will limit the amount of credit. Despite its simplicity, this framework does not create default in equilibrium, nor changing external finance premium, neither a framework to analyze credit shocks.

Collateral could be used as a device to overcome costly enforcement, but if there are collateral constraints, the financial sector could still affect the real sector. A prominent work in this literature is Kiyotaki and Moore (1997) where there is loop between financial constraints and economic activity. In their model, assets play a dual role as factor of production and collateral. In this context, changes in the price of assets affect the value of collateral and with this credit access. With collateral constraints, the adjustment will mainly be in loanable quantities and not necessarily in the cost of credit, still a drawback for our identification strategy that needs changing cost of financing.

With CSV, the credit market imperfection is associated to asymmetric information. As first presented in Townsend (1979), and later adapted by Bernanke and Gertler (1989), one could consider a situation where borrowers have private information that lenders can only get by paying monitoring costs. This asymmetric information creates a role for the borrower's financial position and leads to the financial accelerator mechanism previously described. For our purposes, one advantage of this framework is that it allows for a changing external finance premium, which would be useful given that the identification of financial factors will be performed using financial data.

Figure 1

CREDIT MARKET SHOCKS, MONETARY POLICY, AND ECONOMIC FLUCTUATIONS



Note: The solid lines in each panel depict the mean impulse response function of each variable to one standard deviation external finance premium shock. The dashed lines give the 90% confidence intervals.

In the next section we develop a DSGE model with credit market imperfections under a CSV framework to describe the channels through which financial conditions affect economic outcomes. We will use the model to study the effects of financial shocks, as well as to analyze the role played by monetary policy in economic fluctuations.

3. MODEL

As stated in the introduction, the model is a monetary DSGE model with a financial accelerator mechanism as in BGG.[3] As

[3] The description of the core model follows Gilchrist and Saito

in BGG, we introduce money and price rigidities to study how credit market frictions may influence the transmission of monetary policy. Given that we are taking the model to the data we augment BGG original model with habits in consumption, investment growth adjustment costs, price indexation leading to a hybrid New Keynesian Phillips curve, and a monetary policy Taylor rule with an autoregressive component and that responds to contemporaneous inflation and output growth.

Christiano, Eichenbaum and Evans (2005), and Smets and Wouters (2007) show that these sources of inertia allow the model to better fit the data. However, we are aware that Chari, Kehoe and McGrattan (2009), when discussing the not readiness of New Keynesian models for policy analysis, criticizes the backward indexation and the autoregressive component of the Taylor-type monetary policy rule. Price indexation and the autoregressive component of interest rates are included to capture the persistence of inflation and the federal funds rates. In addition, the monetary policy rule that includes inflation and output tries to capture the dual mandate of the Federal Reserve System in effect since 1977. In the estimation we will use data to infer the macroeconomic degree of inflation and interest rate persistence. If these mechanisms generate counterfactuals movements of the variables, the estimation will try to cancel these features by producing small degrees of indexation and interest rate smoothing.

The introduction of habits creates a relation between the interest rate and the growth rate of consumption. By moving from levels to the growth rate of consumption, the model would generate a hump-shaped response of consumption when the economy is distorted by supply and demand shocks.[4] The investment growth adjustment costs imply that asset prices –the value of capital in place– increase during economic expansions in a way consistent to the behavior observed in the data.

(2006) that build on BGG (1999).

4 Dennis (2009) discusses in detail the introduction of consumption habits in New Keynesian business cycles models.

The model will also include five exogenous distortions: Discount factor, credit risk premium, government expenditure, neutral technology, and monetary policy. Out of these shocks, when analyzing the prototype New Keynesian model in Smets and Wouters (2007), Chari, Kehoe and McGrattan (2009) criticize the credit risk premium and the government expenditure shocks as non-structural.[5] A structural government expenditure shock would require a careful description of the fiscal-side together with an open-economy specification to avoid accounting net exports as government expenditure, something that is out of the scope of the current paper as this margin is not our main concern. However, as shown below, we do tackle directly the issue of having a structural risk premium shock that has a clear interpretation within our model with credit market imperfections.

The log-linearized version of the model is presented in Appendix 1.

3.1 Households

Households consume, hold money, save in the form of a one-period riskless bond whose nominal rate of return is known at the time of the purchase, and supply labor to the entrepreneurs who manage the production of wholesale goods.

Preferences are given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \zeta_{C,t} \left\{ \ln(C_t - bC_{t-1}) - \nu \frac{H_t^{1+\gamma}}{1+\gamma} + \xi \ln \frac{M_t}{P_t} \right\},$$

where C_t is consumption, H_t is hours worked, $\frac{M_t}{P_t}$ is real balances acquired in period t carried into period $t+1$, $\zeta_{c,t}$ is an exogenous shock to time t preferences, and γ, ν, and ξ are positive parameters capturing the inverse Frisch elasticity of labor supply, the relative preference for labor, and the relative

[5] Chari, Kehoe and McGrattan (2009) also criticize the shocks to wage markups and price markups in Smets and Wouters (2007) that are not included in the current paper.

preference for real money balances, respectively. Consumption preferences exhibit habit formation captured by b.

The budget constraint is given by

$$C_t = \frac{W_t}{P_t} H_t + \text{Profits}_t - T_t - \frac{M_t - M_{t-1}}{P_t} - \frac{B_{t+1} - R_t^n B_t}{P_t},$$

where W_t is the nominal wage for the household labor, Profits_t are the real dividends from ownership of retail firms, T_t is lump-sum taxes, B_{t+1} is a riskless bond held between period t and period $t+1$, and R_t^n is the nominal rate of return on the riskless bond held between period $t-1$ and period t.

The first-order conditions for the household's optimization problem include

1 $$\lambda_t = \frac{\zeta_{C,t}}{C_t - bC_{t-1}} - \beta b E_t \left[\frac{\zeta_{C,t+1}}{C_{t+1} - bC_t} \right],$$

2 $$\xi \frac{\zeta_{C,t}}{\frac{M_t}{P_t}} = -\lambda_t + \beta E_t \left[\lambda_{t+1} \frac{P_t}{P_{t+1}} \right],$$

3 $$\lambda_t E_t \left[\frac{P_{t+1}}{P_t} \right] = \beta E_t \left[\lambda_{t+1} R_{t+1}^n \right],$$

4 $$\lambda_t \frac{W_t}{P_t} = \zeta_{C,t} \nu H_t^{\gamma},$$

where λ_t is the multiplier on the budget constraint determined by Equation 1.

Equations 2 and 3 give the optimality conditions for real money balances and bond holdings, respectively. Equation 4 provides the optimality condition for labor supply. From these first order conditions we can appreciate that the exogenous shock to intertemporal preferences, $\zeta_{c,t}$, affects the marginal utility of consumption, the marginal utility of real money balances, and the marginal disutility of labor. Therefore, this intertemporal preference shock affects consumption and savings, different from the shock included in Smets and Wouters (2007) that also affects investment by generating a wedge between the interest rate controlled by the central bank and the return on assets held by the households. In our model, it will be credit market shocks the ones that will affect the investment decision.

3.2 Entrepreneurs

Entrepreneurs are introduced to generate the linkage between the real and financial sectors of the economy as their financing is affected by asymmetric information. There is a continuum of entrepreneurs that manage the production of wholesale goods. The production of wholesale goods uses capital constructed by capital producers and labor supplied by both households and entrepreneurs. Entrepreneurs purchase capital from capital goods producers, and finance the expenditures in capital with both entrepreneurial net worth (internal finance) and debt (external finance). We introduce financial market imperfections that make the cost of external funds depends on the entrepreneur's balance-sheet condition.

Entrepreneurs are risk neutral and discount the future at rate β. Given the high return to internal funds, they will postpone consumption indefinitely undoing capital misallocations. To capture the existing entry and exit of firms and to ensure that entrepreneurs do not accumulate enough funds to finance their expenditures on capital entirely with net worth, we assume that they have a finite lifetime. In particular, we assume that each entrepreneur survives until next period with probability η. New entrepreneurs enter to replace those who exit. To ensure that new entrepreneurs have some funds available when starting out, each entrepreneur is endowed with H_t^e units of labor that are supplied inelastically as a managerial input to the wholesale-good production at nominal entrepreneurial wage W_t^e. Here we are assuming the existence of an entrepreneurial labor market.

The entrepreneur starts any period t with capital, K_t, purchased from capital producers at the end of period $t-1$, and produces wholesale goods, Y_t, with labor and capital. Labor, L_t, is a composite of household labor H_t and entrepreneurial labor H_t^e, according to

$$L_t = H_t^{1-\Omega}(H_t^e)^{\Omega},$$

where Ω is the share of entrepreneurial labor in the total workforce.

The entrepreneur's project is subject to an idiosyncratic shock, ω_t, which affects both the production of wholesale goods and the effective quantity of capital held by the entrepreneur. We assume that ω_t is i.i.d. across entrepreneurs and time, satisfying $E_t[\omega_t]=1$ and with a normal distribution with standard deviation σ_ω. As this standard deviation increases, the agency costs problems become more severe. Below we will consider unexpected innovations to this standard deviation and we will call them credit risk premium shocks. The production of the wholesale goods is given by

5 $$Y_t = \omega_t(A_t L_t)^{\alpha} K_t^{1-\alpha},$$

where A_t is exogenous technology common to all the entrepreneurs and α is the share of labor in the production function. Let $P_{W,t}$ denote the nominal price of wholesale goods. Q_t is the price of capital relative to the aggregate price P_t to be defined later, and δ is the depreciation rate. The entrepreneur's real revenue in period t is the sum of the production revenues and the real value of the undepreciated capital given by

$$\omega_t\left(\frac{P_{W,t}}{P_t}(A_t H_t^{1-\Omega}(H_t^e)^{\Omega})^{\alpha} K_t^{1-\alpha} + Q_t(1-\delta)K_t\right).$$

In any period t, the entrepreneur chooses the demand for both household labor and entrepreneurial labor to maximize profits given capital acquired in the previous period. Below, when we derive the financial contract, we specify how capital is chosen, while the first-order conditions for labor inputs are

6 $$\alpha(1-\Omega)\frac{Y_t}{H_t}=\frac{W_t}{P_{W,t}},$$

and

7 $$\alpha\Omega\frac{Y_t}{H_t}=\frac{W_t^e}{P_{W,t}}.$$

At the end of period *t*, after the production of wholesale goods, the entrepreneur purchases capital K_{t+1} from capital producers at price Q_t. The capital is used as an input to the production of wholesale goods in period $t+1$. The entrepreneur finances the purchase of capital Q_tK_{t+1} partly with net worth N_{t+1} and partly by issuing nominal debt B_{t+1}, both determined at the end of period *t*, where debt in real terms is given by

$$\frac{B_{t+1}}{P_t}=Q_tK_{t+1}-N_{t+1}.$$

The entrepreneur's capital purchase decision depends on the expected rate of return on capital and the expected marginal cost of finance. By definition, the real rate of return on capital between period *t* and period $t+1$, R_{t+1}^k, depends on the marginal profit from the production of wholesale goods and the capital gain according to

8 $$R_{t+1}^k=\frac{\omega_{t+1}\left[\frac{P_{W,t+1}}{P_{t+1}}(1-\alpha)\frac{\bar{Y}_{t+1}}{K_{t+1}}+(1-\delta)Q_{t+1}\right]}{Q_t},$$

where $\bar{Y}_{t+1}$ is the average wholesale good production per entrepreneur $\left(Y_{t+1}=\omega_{t+1}\bar{Y}_{t+1}\right)$. Under our assumption of $E_t\omega_{t+1}=1$, the expected real rate of return on capital, $E_tR_{t+1}^k$, is given by

9 $$E_tR_{t+1}^k=E_t\left[\frac{\frac{P_{W,t+1}}{P_{t+1}}(1-\alpha)\frac{\bar{Y}_{t+1}}{K_{t+1}}+(1-\delta)Q_{t+1}}{Q_t}\right].$$

Equations 8 and 9 suggest that unexpected changes in asset prices are the main source of unexpected changes in the real rate of return on capital by looking at the difference between the realized rate of return on capital in period *t*, R_t^k, and the rate of return on capital anticipated in the previous period, $E_{t-1}R_t^k$, where the latter is the marginal cost of external funds between period $t-1$ and t.

As shown below, in the presence of financial market imperfections, the marginal cost of external funds depends on the entrepreneur's balance-sheet condition. As in BGG, we assume asymmetric information between borrowers (entrepreneurs) and lenders and a CSV. Specifically, the idiosyncratic shock to entrepreneurs, ω_{t+1}, is private information of the entrepreneur. To observe this, the lender must pay an auditing cost that is a fixed proportion μ of the realized gross return to capital held by the entrepreneur: $\mu R_{t+1}^k Q_t K_{t+1}$. The entrepreneur and the lender negotiate a financial contract that induces the entrepreneur to not misrepresent her earnings and minimizes the expected auditing costs incurred by the lender. We restrict attention to financial contracts that are negotiated one period at a time and offer lenders a payoff that is independent of aggregate risk. Under these assumptions, the optimal contract is a standard debt contract with costly bankruptcy: If the entrepreneur does not default, the lender receives a fixed payment independent of the realization of the idiosyncratic shock ω_{t+1}; and if the entrepreneur defaults, the lender audits and seizes whatever it finds.

Let $\overline{w}_{t+1}$ be the productivity cut-off value below which the entrepreneur defaults and the lender audits. Under the standard debt contract, a share $f(\overline{\omega}) \equiv \int_{\overline{\omega}}^{\infty} \omega\varphi(\omega)d\omega - \left[1-\varphi(\overline{\omega})\right]\overline{\omega}$ of the project's expected gross return, $E_t\left\{R_{(t+1)}^k Q_t K_{(t+1)}\right\}$, will go to the entrepreneur, and a share $g(\overline{\omega}) \equiv \left[1-\Phi(\overline{\omega})\right]\overline{\omega} + (1-\mu)\int_0^{\overline{\omega}} \omega\varphi(\omega)d\omega$ will go to the lender. To solve for the financial contract we can set the problem on the side of the entrepreneur, then the end-of-time-*t* contracting problem is given by

10 $$\max_{\kappa_t, \bar{\omega}_{t+1}} E_t \left\{ R^k_{t+1} \kappa_t f\left(\bar{\omega}_{t+1}\right) \right\}$$

subject to

11 $$E_t \left\{ R^k_{t+1} g\left(\bar{\omega}_{t+1}\right) \frac{\kappa_t}{\kappa_t - 1} \lambda_{t+1} \right\} \geq R^n_{t+1} E_t \left\{ \lambda_{t+1} \frac{P_t}{P_{t+1}} \right\},$$

where for convenience we express this problem in terms of leverage denoted by $\kappa_t \equiv \left(\frac{Q_t K_{t+1}}{N_{t+1}} \right)$ with N_{t+1} denoting next-period net worth. The left-hand side of expression 11 is the lender's expected return and the right-hand side is the expected required real return to participate in the contract. The optimality conditions for the productivity cut-off value, $\bar{\omega}_{t+1}$, the leverage ratio, κ_t, and the participation constraint are

12 $$E_t \left\{ R^k_{t+1} \kappa_t f'\left(\bar{\omega}_{t+1}\right) \right\} = \Xi_t E_t \left\{ R^k_{t+1} g'\left(\bar{\omega}_{t+1}\right) \frac{\kappa_t}{\kappa_t - 1} \lambda_{t+1} \right\},$$

13 $$E_t \left\{ R^k_{t+1} f\left(\bar{\omega}_{t+1}\right) \right\} = -\Xi_t \frac{1}{\left(\kappa_t - 1\right)^2} E_t \left\{ R^k_{t+1} g\left(\bar{\omega}_{t+1}\right) \lambda_{t+1} \right\},$$

14 $$E_t \left\{ R^k_{t+1} g\left(\bar{\omega}_{t+1}\right) \frac{\kappa_t}{\kappa_t - 1} \lambda_{t+1} \right\} = R^n_{t+1} E_t \left\{ \lambda_{t+1} \frac{P_t}{P_{t+1}} \right\},$$

where Ξ_t is the multiplier on the lender's participation constraint. Equation 12 equates the marginal cost of an increase in the productivity cut-off value, which lowers the marginal return to the entrepreneur, in the left-hand side, to the marginal benefit of a looser participation constraint of the lender. Equation 13 equates the marginal benefit of increasing leverage in terms of the expected total net return, in the left-hand-side, to the marginal cost of a tighter participation constraint. Equation 14 gives the participation constraint with equality that will hold given the risk neutrality of entrepreneurs. Using Equation 12 and Equation 14 we can express Equation 13 as

13' $$\frac{E_t\left\{R_{t+1}^k f\left(\bar{\omega}_{t+1}\right)\right\}}{R_{t+1}^n E_t\left\{\lambda_{t+1}\frac{P_t}{P_{t+1}}\right\}} = -\left[\frac{E_t\left\{R_{t+1}^k f'\left(\bar{\omega}_{t+1}\right)\right\}}{E_t\left\{R_{t+1}^k g'\left(\bar{\omega}_{t+1}\right)\lambda_{t+1}\right\}}\right]\frac{1}{\kappa_t}.$$

In equilibrium, the cost of external funds between period t and period $t+1$ is equated to the expected real rate of return on capital (9). Let s_t denote the borrowing external finance premium, given by the ratio of the entrepreneur's cost of external funds to the opportunity cost of internal funds, where the latter is equated to the cost of funds in the absence of financial market imperfections $E_t\left\{R_{t+1}^n \frac{P_t}{P_{t+1}}\right\}$. Then s_t is defined as

15 $$s_t = \frac{E_t\left\{R_{t+1}^k\right\}}{E_t\left\{R_{t+1}^n \frac{P_t}{P_{t+1}}\right\}}.$$

The agency problem presented above and partly summarized by Equation 13" implies that the cost of external funds depends on the financial position of the borrowers. In particular, the external finance premium increases when a smaller fraction of capital expenditures is financed by the entrepreneur's net worth:

16 $$s_t = s\left(\frac{Q_t K_{t+1}}{N_{t+1}}\right) = s\left(\kappa_t\right),$$

where $s(\cdot)$ is an increasing function for $\kappa > 1$. To derive the specific form of the function $s(\cdot)$, log-linearize equations 13' and 14 around the steady-state to get

13" $$E_t\left\{r_{t+1}^k\right\} - \left(r_{t+1}^n - E_t\left\{\pi_{t+1}\right\}\right) = \left(\Psi - \theta_f\right) E_t \bar{\omega}_{t+1} - \kappa_t$$

and

14' $$E_t\left\{r_{t+1}^k\right\} - \left(r_{t+1}^n - E_t\left\{\pi_{t+1}\right\}\right) = \left(\frac{1}{\kappa - 1}\right)\kappa_t - \theta_g E_t \bar{\omega}_{t+1},$$

where lower case letters, r_t^k, r_t^n, and, π_t denote log-deviations from their steady-state of the corresponding capital letter variables. In addition, using $\bar{\omega}$ to denote the steady-state productivity cut-off value, we have defined $F(\bar{\omega}_{t+1}) \equiv \frac{-f'(\bar{\omega}_{t+1})}{g'(\bar{\omega}_{t+1})}$,

$$\Psi \equiv \frac{\bar{\omega}F'(\bar{\omega})}{F(\bar{\omega})} > 0,\ \theta_g \equiv \frac{\bar{\omega}g'(\bar{\omega})}{g(\bar{\omega})}, \text{with } 0 < \theta_g < 1, \text{and } \theta_f \equiv \frac{\bar{\omega}f'(\bar{\omega})}{f(\bar{\omega})} < 0.$$

Solving 13" and 14' we have

17 $$E_t\bar{\omega}_{t+1} = \frac{\kappa}{\kappa-1}\frac{1}{\left(\Psi-\theta_f+\theta_g\right)}\kappa_t$$

and

18 $$E_t\left\{r_{t+1}^k\right\} - \left(r_{t+1}^n - E_t\left\{\pi_{t+1}\right\}\right) = \left[\frac{\left(\Psi-\theta_f+\theta_g\right)-\kappa\theta_g}{(\kappa-1)\left(\Psi-\theta_f+\theta_g\right)}\right]\kappa_t = \chi\kappa_t\,.$$

Equation 18 shows that the elasticity of the external finance premium with respect to leverage, captured by the term $\chi \equiv \left[\frac{\left(\Psi-\theta_f+\theta_g\right)-\kappa\theta_g}{(\kappa-1)\left(\Psi-\theta_f+\theta_g\right)}\right]$, depends on the primitive parameters of the CSV problem, including the bankruptcy cost parameter μ and the distribution of the idiosyncratic shock ω_t. However, this same expression shows that we can adopt the following simplified functional form for the determination of the external finance premium:

19 $$s_t = \frac{E_t\left\{R_{t+1}^k\right\}}{E_t\left\{R_{t+1}^n\frac{P_t}{P_{t+1}}\right\}} = \zeta_{s,t}\left(\frac{Q_tK_{t+1}}{N_{t+1}}\right)^{\chi},$$

where $\chi > 0$ is the elasticity of the external finance premium with respect to leverage, $\frac{Q_tK_{t+1}}{N_{t+1}}$, which is consistent with the micro-structured financial contract. In this expression we have added an exogenous shock to time t external finance premium, $\zeta_{s,t}$, which is fundamentally equivalent to a shock to the standard deviation of the distribution of the entrepreneurial productivity, σ_ω, that aggravates the credit market imperfections' problems. Therefore, within the context of the agency costs problem proposed in this model, and similar to CMR, this credit risk premium shock is structural and has a clear economic interpretation as opposed to the reduced-form shock included in Smets and Wouters (2007).

The aggregate net worth of entrepreneurs at the end of period t is the sum of the equity held by entrepreneurs who survive from period $t-1$ and the aggregate entrepreneurial wage, which consists of the wage earned by the entrepreneurs surviving from period $t-1$ and the wage earned by newly emerged entrepreneurs in period t according to

$$\begin{aligned} N_{t+1} &= \eta\left(R_t^k Q_{t-1} K_t - E_{t-1} R_t^k \frac{B_t}{P_{t-1}} \right) + \frac{W_t^e}{P_t} \\ &= \eta\left(R_t^k Q_{t-1} K_t - E_{t-1} R_t^k (Q_{t-1} K_t - N_t) \right) + \frac{W_t^e}{P_t}, \end{aligned} \tag{20}$$

where the second line used the relation $Q_{t-1} K_t = N_t + \dfrac{B_t}{P_{t-1}}$.

Equations 8, 9, 19 and 20 provide the financial accelerator mechanism. As already discussed, from Equations 8 and 9, unexpected changes in asset prices are the main source of changes in the ex post return to capital. In turn, Equation 20 suggests that these unexpected movements in the real rate of return on capital are the main source of changes in the entrepreneurial net worth, under the calibration that the entrepreneurial wage is small. Finally, Equation 18 implies that a change in leverage is the main source of changes in the external finance premium. Thus, movements in asset prices play a key role in the financial accelerator mechanism.

Entrepreneurs going out of business in period t consume the residual equity according to

21 $$C_t^e = (1-\eta)\left(R_t^k Q_{t-1} K_t - E_{t-1} R_t^k \frac{B_t}{P_{t-1}} \right),$$

where C_t^e is the aggregate consumption of the entrepreneurs who exit in period t.

Overall, the financial accelerator mechanism implies that an unexpected increase in asset prices increases the net worth of entrepreneurs and improves their balance-sheet conditions. This in turn reduces the external finance premium and increases the demand for capital by these entrepreneurs. In equilibrium, the price of capital increases further and capital producers increase the production of new capital. This additional increase in asset prices strengthens the mechanism just described. Thus, the countercyclical movement in the external finance premium implied by the financial market imperfections magnifies the effects of shocks to the economy.

3.3 Capital Producers

Capital producers are introduced to decentralize the capital accumulation process.[6] Capital producers use both final investment goods I_t and existing capital K_t to construct new capital K_{t+1}. They lease existing capital from the entrepreneurs. As in Christiano, Eichenbaum, and Evans (2005), capital production is subject to adjustment costs, which are assumed to be a function of investment growth $\frac{I_t}{I_{t-1}}$. The aggregate capital accumulation equation is given by

22 $$K_{t+1} = (1-\delta)K_t + I_t - \psi\left(\frac{I_t}{I_{t-1}}\right) I_t,$$

[6] In this version of the model, capital accumulation could equally be carried out directly by households without differences in the results. However, when introducing investment-specific technology shocks, together with preferences shocks, it could be advantageous to have a different agent in charge of the capital accumulation process to have a shock affecting the consumption Euler equation and a different shock affecting the investment Euler equation.

where $\psi(\cdot)$ is a function with the property that in steady state $\psi = \psi' = 0$, and $\psi'' > 0$. Below, in the estimation, we will use data to infer the value of ψ'', which has two contrasting effects as higher adjustment costs dampen the response of investment to aggregate shocks, but imply larger movements in the price of installed capital and with this bigger financial accelerator effects when agency costs are considered.[7]

Taking the relative price of capital Q_t as given, capital producers choose inputs I_t and K_t to maximize profits from the formation of new capital according to

$$E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t \left\{ Q_t \left[(1-\delta)K_t + I_t - \psi\left(\frac{I_t}{I_{t-1}}\right) I_t \right] - Q_t (1-\delta) K_t - P_t I_t \right\},$$

where λ_t is the multiplier on the household's budget constraint.

3.4 Retailers

Retailers are mainly introduced to generate price rigidities. There is a continuum of monopolistically competitive retailers of unit measure. Retailers buy wholesale goods from entrepreneurs in a competitive manner and then differentiate the product slightly at zero resource cost.

Let $Y_t(z)$ be the retail goods sold by retailer *z*, and let $P_t(z)$ be its nominal price. Final goods, Y_t, are the composite of individual retail goods

$$Y_t = \left[\int_0^1 Y_t(z)^{\frac{\varepsilon-1}{\varepsilon}} dz \right]^{\frac{\varepsilon}{\varepsilon-1}},$$

[7] As suggested by an anonymous referee, one can think of the introduction of the adjustment costs to investment growth as assuming that capital is a factor with semi-fixed supply, at least in the short run, and therefore all changes in demand will be fully reflected in prices.

where $\varepsilon > 0$ determines the elasticity of demand between varieties z. The corresponding price index, P_t, is given by

$$P_t = \left[\int_0^1 P_t(z)^{1-\varepsilon} dz \right]^{\frac{1}{1-\varepsilon}} .$$

Households, capital producers, and the government demand the final goods.

Each retailer faces an isoelastic demand curve given by

23 $$Y_t(z) = \left(\frac{P(z)}{P_t} \right)^{-\varepsilon} Y_t .$$

As in Calvo (1983), each retailer resets price with probability $(1-\theta)$, independently of the time elapsed since the last price adjustment. Thus, in each period, a fraction $(1-\theta)$ of retailers reset their prices, while the remaining fraction θ indexes its prices to past inflation $\Pi_{t-1} = \frac{P_{t-1}}{P_{t-2}}$ with a degree of persistence ρ_π. The real marginal cost to the retailers of producing a unit of retail goods is the price of wholesale goods relative to the price of final goods $\left(\frac{P_{W,t}}{P_t} \right)$. Each retailer takes the demand curve (23) and the price of wholesale goods as given and sets the retail price $P_t(z)$. All retailers given a chance to reset their prices in period t choose the same price P_t^* given by

24 $$P_t^* = \frac{\varepsilon}{\varepsilon - 1} \frac{E_t \sum_{i=0}^{\infty} \theta^i \Lambda_{t,i} P_{W,t+i} Y_{t+i} \left(\frac{1}{P_{i+1}} \right)^{1-\varepsilon}}{E_t \sum_{i=0}^{\infty} \theta^i \Lambda_{t,i} Y_{t+i} \left(\frac{1}{P_{i+1}} \right)^{1-\varepsilon}} ,$$

where $\Lambda_{t,i} = \frac{\beta^i \lambda_t}{\lambda_{t+i}}$ is the stochastic discount factor that the retailers take as given.

The aggregate price evolves according to

25 $$P_t = \left[\theta \left(\Pi_{t-1}^{\rho_\pi} P_{t-1} \right)^{1-\varepsilon} + (1-\theta)(P_t^*)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}.$$

Combining Equations 24 and 25 yields the canonical form of the new optimization-based Phillips curve that arises from an environment of time-dependent staggered price setting.

3.5 Aggregate Resource Constraint

The aggregate resource constraint for final goods is

26 $$Y_t = C_t + C_t^e + I_t + G_t + \mu \int_0^{\bar{\omega}} \omega dF(\omega) R_t^k Q_{t-1} K_t \ ,$$

where G_t is the government expenditures that we assume to be exogenous, while $\mu \int_0^{\bar{\omega}} \omega dF(\omega) R_t^k Q_{t-1} K_t$ corresponds to the aggregate monitoring costs.[8]

3.6 Government

Exogenous government expenditures G_t are financed by lump-sum taxes T_t and money creation according to

27 $$G_t = \frac{M_t - M_{t-1}}{P_t} + T_t \ .$$

The money stock is adjusted to support the interest rate rule specified below. Lump-sum taxes adjust to satisfy the government budget constraint.[9]

3.7 Monetary Policy

The monetary authority conducts monetary policy using the following interest rate rule

[8] In the numerical exercise we assume that actual resource costs to bankruptcy are small.

[9] As discussed before, given that the set-up of this economy is a closed-economy model, the government expenditure will capture the residual of aggregate demand including net exports.

28 $$\left(\frac{R_t^n}{R^n}\right)=\left[\frac{R_{t-1}^n}{R^n}\right]^{\rho_{r^n}}\left[\Pi_t^{\gamma_\pi}\left(\frac{Y_t-Y_{t-1}}{Y_{t-1}}\right)^{\gamma_y}\right]^{1-\rho_{r^n}}\zeta_{r^n,t},$$

where R^n is the steady-state nominal interest rate on the one-period bond, ρ_{r^n} captures the degree of interest-rate smoothing, $\Pi_t=\frac{P_t}{P_{t-1}}$ is inflation, γ_π is the weight on inflation, γ_y is the weight on output growth, and $\zeta_{r^n,t}$ is a monetary policy shock.

3.8 Shocks

It is assumed that the exogenous disturbances to the discount factor, financial distress, government spending, and technology obey autoregressive processes according to:

$$\ln(\zeta_{C,t})=\rho_{\zeta_C}\ln(\zeta_{C,t-1})+\varepsilon_t^{\zeta_C}$$

$$\ln(\zeta_{S,t})=\rho_{\zeta_S}\ln(\zeta_{S,t-1})+\varepsilon_t^{\zeta_S}$$

$$\ln(G_t)=\rho_g\ln(G_{t-1})+\varepsilon_t^g$$

$$\ln(A_t)=\rho_a\ln(A_{t-1})+\varepsilon_t^a$$

while the monetary policy shock is i.i.d.:

$$\zeta_{r^n,t}=\varepsilon_t^{r^n}.$$

All shocks $\left\{\varepsilon_t^{\zeta_C},\varepsilon_t^{\zeta_S},\varepsilon_t^g,\varepsilon_t^a,\varepsilon_t^{r^n}\right\}$ are assumed to be distributed normally with a zero mean and standard deviations $\left\{\sigma_{\zeta_c},\sigma_{\zeta_s},\sigma_g,\sigma_a,\sigma_{r^n}\right\}$, respectively.

4. ESTIMATION STRATEGY AND EMPIRICAL IMPLEMENTATION

The model presented is estimated using Bayesian methods.[10]

[10] A detailed description of the methods is found in An and Schorfheide (2007). Textbook treatments are available in Canova (2007)

This Section describes the methods and parameters used for estimation.

4.1 Bayesian Estimation of the DSGE Model

The object of interest is the vector of parameters

$$\varphi=\left\{b,\theta,\psi,\chi,\gamma_{\pi},\rho_{r^n},\rho_{\pi},\rho_{\zeta_c},\rho_{\zeta_s},\rho_g,\rho_a,\sigma_{r^{\pi}}\sigma_{\zeta_c},\sigma_{\zeta_s},\sigma_g,\sigma_a\right\}$$

Given a prior p(φ), the posterior density of the model parameters, φ , is given by

$$p\left(\varphi\,|\,Y^T\right)=\frac{L\left(\varphi\,|\,Y^T\right)p(\varphi)}{\int L\left(\varphi\,|\,Y^T\right)p(\varphi)d\varphi} \; ,$$

where $L\left(\varphi\,|\,Y^T\right)$ is the likelihood conditional on observed data $Y^T=\left\{Y_1,\ldots,Y_T\right\}$. In our case $Y_t=\left[\Delta y_t+a_t,\Delta i_t+a_t,4\pi_t,4R_t^n,4s_t\right]'$ for $t=1,\ldots,T$, where Δy_t+a_t is the growth rate of real output, Δi_t+a_t is the growth rate of real investment, $4\pi_t$ is annualized CPI inflation, $4R_t^n$ is annualized effective federal funds rate, and $4s_t$ is annualized external finance premium from Gilchrist, Ortiz, and Zakrajšek (2008).

The likelihood function is computed under the assumption of normally distributed disturbances by combining the state-space representation implied by the solution of the linear rational expectations model and the Kalman filter. Posterior draws are obtained using Markov Chain Monte Carlo methods. After obtaining an approximation to the mode of the posterior, a random walk Metropolis algorithm with 1,000,000 iterations is used to generate posterior draws. Point estimates and measures of uncertainty for φ are obtained from the generated values.

4.2 Parameters

In the quantitative analysis we fixed a subset of the parameters that determine the non-stochastic steady-state and that the

and Dejong and Dave (2007).

estimation cannot fully identify and concentrate in the estimation of parameters describing the monetary policy, habit formation, investment, price rigidities, the financial accelerator mechanism, and the exogenous processes. The calibrated parameters are presented in the next subsection, while the priors for the estimated parameters are presented in subsection 4.2.2.

4.2.1 Calibration

The calibrated parameter values are standard; the values on the financial contract come from BGG, while the technological and government values match US data. The mean technology growth rate, g_{ss}, is 0.00427, which imply that the steady-state technology growth, $A = e^{g_{ss}}$, is 1.00428, while the discount factor, β, is set at 0.99. These values imply an annual steady-state nominal interest rate, $4\left(R^n - 1\right) = 4\left(\frac{\beta}{A} - 1\right)$, of 5.77%. The steady-state capital return, R^K, is set at 1.0195 that implies a 2% annual external finance premium. In the production function, the share of labor, α, is 0.65, while the share of entrepreneurial labor, Ω^e, is 0.01. The elasticity of the marginal disutility of labor, $1+\gamma$, is 1.33. The capital depreciation rate, δ, is 0.025, while the steady state capital-net worth ratio, κ, is set at 2. The entrepreneur' survival rate, η, is set to 0.9728, the standard deviation of the entrepreneurial productivity distribution, σ_{ss}, is fix at 0.28, and the monitoring costs, μ, are set to 0.12, to be consistent with a quarterly default rate of 0.0075. The steady-state government expenditure-output ratio, $\frac{G}{Y}$, is 0.2, while the steady-state entrepreneurial consumption-output ratio, $\frac{C^e}{Y}$, is fixed at 0.01. The parameter controlling money demand, ξ, does not affect the dynamics of the model as the monetary authority will supply any amount of money required to implement the nominal interest rate determined by the policy rule. Table 1, below, summarizes these calibrated values.

4.2.2 Priors

There are five common prior distributions used in the literature of Bayesian DSGE estimation. Uniform distributions are used when the researcher wants to limit the range of the parameters, but does not want to take a stance on the mass of particular values. Normal distributions are used to center prior means without introducing skewness in the distribution. Beta distributions are used for most parameters whose range is in the [0, 1] interval as the autoregressive parameters. Gamma distributions are used for parameters restricted to be positive. Inverse gamma distributions are used for the standard deviation of shocks to allow a positive density at zero. In our case, as described below, priors were selected on the basis of previous estimations and available information. The information of the chosen priors is summarized in the third to fifth columns of Table 2. Appendix 2 shows the distributions for each parameter.

The habit parameter, b, is assumed to follow a beta distribution with prior mean of 0.7 and standard deviation of 0.1. The second derivative of adjustment cost function with respect to investment growth, ψ'', is assumed to follow a gamma distribution with prior mean of five and standard deviation of 0.5. The elasticity of the external financial premium with respect to changes in net worth, χ, is assumed to follow a beta distribution with prior mean of 0.06 and standard deviation of 0.03.

The parameters related to prices and monetary policies follow. The Calvo probability of not adjusting prices, θ, is assumed to follow a gamma distribution with prior mean of 0.7 and standard deviation of 0.1. The degree of price indexation, ρ_π, is assumed to follow a beta distribution with mean 0.3 and standard deviation 0.1. The autoregressive component of nominal interest rate, ρ_{r^n}, is assumed to follow a beta distribution with mean of 0.5 and standard deviation of 0.2, while the Taylor rule coefficients on inflation, γ_π, and output growth, γ_y, are assumed to follow a gamma distribution with mean of 1.5 and 0.5, respectively and a common standard deviation of 0.25.

Table 1

CALIBRATED PARAMETERS		
Coefficient	*Description*	*Value*
g_{ss}	Mean technology growth rate	0.00427
β	Discount rate	0.99
R^k_{ss}	Steady-state capital return	1.0195
α	Share of labor in production	0.65
Ω^e	Share of entrepreneurial labor	0.01
$1+\gamma$	Elasticity of marginal disutility of labor	1.33
κ	Steady-state capital-net worth ratio	2
η	Entreprenurial survival rate	0.9728
σ_{ss}	Standard deviation of entrepreneurial productivity distribution	0.028
μ	Monitoring costs	0.12
G/Y	Steady-state government expenditure-output ratio	0.2
C^e/Y	Steady-state entrepreneurial consumption-output ratio	0.01

All the autoregressive parameters associated to the shock processes are assumed to have a beta distribution. Preferences, ρ_{ς_c} , and credit market, ρ_{ζ_s} , innovations are assumed to have prior mean of 0.5 and standard deviation of 0.25, while government, ρ_g , and technology, ρ_a , have a prior mean of 0.9 and standard deviation of 0.1. The standard deviations of the shock processes, $\sigma_{\zeta_c}, \sigma_{\zeta_s}, \sigma_g, \sigma_a$, are assumed to have an inverse gamma distribution with prior mean of 1 and standard deviation of 4, the only exception is the mean of the standard deviation of the nominal interest rate innovation, σ_{r^n} which is set to 0.4.

5. RESULTS

In this section we present the estimation results, the Bayesian impulse-response functions, the historical shock decomposition, and the variance decomposition.

5.1 Estimation

Table 2, below, summarizes the estimation results. The estimated coefficients and their descriptions are presented in columns 1 and 2, the prior densities' distributions, means, and standard deviations are reported in the next three columns. The posterior mode and 90% confidence intervals are reported in columns 6 to 8 for the no financial accelerator case, and in the last three columns for the financial accelerator case. The marginal likelihoods are not comparable because the model without the financial accelerator does not use financial data.[11] Overall, the parameter estimates in the models with and without the financial accelerator mechanism are similar. The main differences are in the degree of price indexation, which is bigger in the model without the financial accelerator, and in the standard deviation of the preference shock which is smaller in the model without the financial accelerator.

The habit parameter estimate, b, is 0.918, slightly higher than in the model without the financial frictions at 0.898, suggesting that in the presence of credit market imperfections consumers try harder to smooth consumption. The second derivative of the adjustment cost function with respect to investment growth, ψ'', is 5.559, which is a smaller number than the one reported by CMR in a model that also has capital utilization rate, but higher than in the model without financial frictions at 4.551. Recall that higher adjustment costs dampen the response of investment but, through the changes in the price of installed capital, magnifies the financial accelerator. In the model with financial frictions, the elasticity of the external financial premium with respect to changes in net worth, χ, is estimated at 0.009, lower than previous estimates between 0.03 and 0.1.

[11] We have estimated the no financial accelerator model using financial data and including measurement errors to the external finance premium. In this case the Log data densities are comparable, and the model with a financial accelerator has a superior fit to the data as the model without this financial mechanism cannot reproduce the observed behavior of the external finance premium.

The parameters related to prices and monetary policies follow. The estimate of the Calvo probability of not adjusting prices, θ, is 0.929, also higher than in the model without financial frictions at 0.896. The estimate of the degree of price indexation, ρ_{π}, is 0.224, much lower than the 0.516 in the model without financial frictions. In the model with financial frictions the autoregressive component of nominal interest rate, ρ_{r^n}, is 0.939, while the Taylor rule coefficient on inflation, γ_{π}, is 1.264 and output growth, γ_y, is 0.236. In the model without financial frictions the estimates are 0.903, 1.237, and 0.252, respectively, what suggests that the different dynamics observed between the two models is not due to differences in monetary policy estimates.

In the model with financial frictions the autoregressive processes imply autoregressive coefficients of 0.788 for preferences ρ_{ζ_c}, 0.957 for government expenditure ρ_g, 0.980 for technology ρ_a, and 0.725 for credit market ρ_{ζ_s}. The shock processes have standard deviations of 0.121 for nominal interest rates σ_{r^n}, 4.834 for preferences σ_{ζ_c}, 2.704 for government expenditure σ_g, 0.320 for technology σ_a, and 2.353 for credit market σ_{ζ_s} innovations. In the model without financial frictions credit markets are not included, so the autoregressive coefficients for preferences, government expenditure, and technology are 0.767, 0.971, and 0.991, respectively. The standard deviations for nominal interest rates, preferences, government expenditure, and technology are 0.123, 3.592, 2.838, and 0.209, respectively.

5.2 Impulse-Response Functions

Figure 2 shows the impulse response functions of output, investment, and the external finance premium to one standard deviation in the monetary policy shock. Figure 3 shows the evolution of output, investment, and the federal funds rate to one standard deviation external finance premium shock. All the innovations are expressed in percentage points and the mean and 90% confidence intervals are reported. The

Table 2

PRIORS AND POSTERIOR ESTIMATES

					No financial accelerator model[a]			Financial accelerator model[b]		
Log data density					−593.9			−654.1		
			Prior		**Posteriors**[c]			**Posteriors**		
Coefficient	*Description*	*Prior density*[d]	*Prior mean*	*Prior standard deviation*	*Posterior mean*	*5%*	*95%*	*Posterior mean*	*5%*	*95%*
b	Consumption habit	B	0.70	0.10	0.90	0.87	0.93	0.92	0.91	0.92
θ	Calvo probability of not adjusting prices	G	0.70	0.10	0.90	0.88	0.91	0.93	0.92	0.94
ψ''	Investment adjustment costs	G	5.00	0.50	4.55	3.84	5.31	5.56	4.57	6.47
χ	Elasticity of external finance premium w.r.t. leverage	B	0.06	0.03	–	–	–	0.009	0.008	0.011
ρ_π	Degree of price indexation	B	0.30	0.10	0.52	0.34	0.67	0.22	0.11	0.34
γ_π	Taylor rule inflation	G	1.50	0.25	1.24	1.11	1.37	1.26	1.00	1.49
γ_y	Taylor rule output growth	G	0.50	0.25	0.25	0.07	0.43	0.24	0.08	0.38
ρ_{r^n}	Taylor rule smoothing	B	0.90	0.10	0.90	0.88	0.93	0.94	0.93	0.95
ρ_g	Government spending	B	0.90	0.10	0.97	0.94	1.00	0.96	0.92	1.00

ρ_a	Neutral technology growth	B	0.90	0.10	0.99	0.98	1.00	0.98	0.98	0.98
ρ_{ζ^c}	Intertemporal preference	B	0.50	0.25	0.77	0.70	0.85	0.79	0.76	0.81
ρ_{ζ^s}	External finance premium	B	0.50	0.25	–	–	–	0.73	0.71	0.76
Standard deviation of shocks		*Prior density*	*Prior mean*	*Prior standard deviation*	*Posterior mean*	*5%*	*95%*	*Posterior mean*	*5%*	*95%*
σ_{r^n}	Monetary policy	I	0.40	4.00	0.12	0.11	0.14	0.12	0.11	0.14
σ_g	Government spending	I	1.00	4.00	2.84	2.45	3.22	2.70	2.31	3.22
σ_a	Neutral technology growth	I	1.00	4.00	0.21	0.16	0.26	0.32	0.21	0.43
σ_{ζ^c}	Intertemporal preference	I	1.00	4.00	3.59	2.16	5.00	4.83	4.60	5.00
σ_{ζ^s}	External finance premium	I	1.00	4.00	–	–	–	2.35	1.83	2.83

Note: calibrated coefficients: mean technology growth $g_{ss} = 0.00427$, discount factor $\beta = 0.99$, labor share in production $\alpha = 0.65$, share of entrepreneurial labor $\Omega^e = 0.01$, marginal disutility of labor $\gamma = 0.33$, depreciation rate $\delta = 0.025$, steady-state government expenditure-to-output ratio $G/Y = 0.2$, and steady-state entrepreneurial consumption-to-output ratio $C^e/Y = 0.01$. For the financial accelerator model the following parameters are also calibrated: entrepreneurial survival rate $\eta = 0.98$, a steady-state risk premium $rp = 0.02/4$ and a steady-state leverage ratio $\kappa = 2$. [a] In the no financial accelerator model no financial data was used, there is no external finance premium shocks and the elasticity of risk premium, χ, is set to 0. [b] In the financial accelerator model the external finance premium data was used to identify the external finance premium shocks and the elasticity of risk premium, χ. [c] Posterior percentiles are from two chains of 1,000,000 draws generated using a random walk Metropolis algorithm. We discard the initial 500,000 and retain one every five subsequent draws. [d] B-beta, G-gamma, and I-inverted-gamma distribution.

black lines show the case of the financial accelerator, while the model without financial frictions is represented with the gray lines.

Before discussing the results it is important to remind that, under the financial accelerator environment, an expansion in output causes an increase in the value of assets in place and a rise in the entrepreneurial net worth. As entrepreneurs' net worth expands relative to their borrowing, the external finance premium falls, causing a further increase in both asset values and investment demand. These general equilibrium feedback effects, in turn, further amplify the financial accelerator mechanism. For the financial accelerator model, this mechanism is in effect for both financial and non-financial shocks.

Figure 2 shows that an unexpected expansionary monetary policy innovation generates hump-shaped expansions in output and investment, accompanied by inflationary pressures (not shown), and due to the mechanism described above, a decrease in the external finance premium. This last effect is the key transmission mechanism that explains why monetary policy could have additional stabilizing effects in the presence of credit market imperfections as exemplified by the additional response of output and investment.

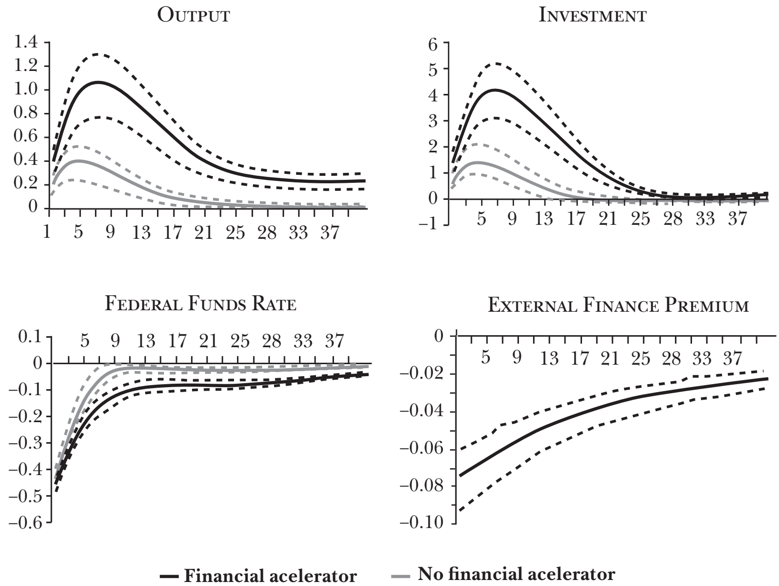
Figure 3 shows that an increase in the external finance premium by tightening credit market constraints contributes significantly to output and investment contractions, without alleviating inflationary pressures (not shown) through the supply-side costs of decreased capital accumulation, and creating constraints on monetary policy. These movements are in line with the empirical evidence of the VAR presented in Section 2.

The real effect of this mechanism is quantitatively large –a 0.25% rise in the external finance premium causes a 0.73% decrease in output and a 2.8% decrease in investment. These numbers are in the ball-park of the empirical evidence presented in Gilchrist and Zakrajšek (2012) that analyzes the economy's response to excess bond premium shocks.

For sake of completeness, we describe the responses of the

Figure 2

Model Responses to a Monetary Policy Shock



Note: The solid lines in each panel depict the mean impulse response function of each variable to one standard deviation monetary policy shock. The dashed lines give the 90% confidence intervals. The black lines in each panel depict the financial accelerator case. The gray lines depict the responses generated by the model without the financial accelerator.

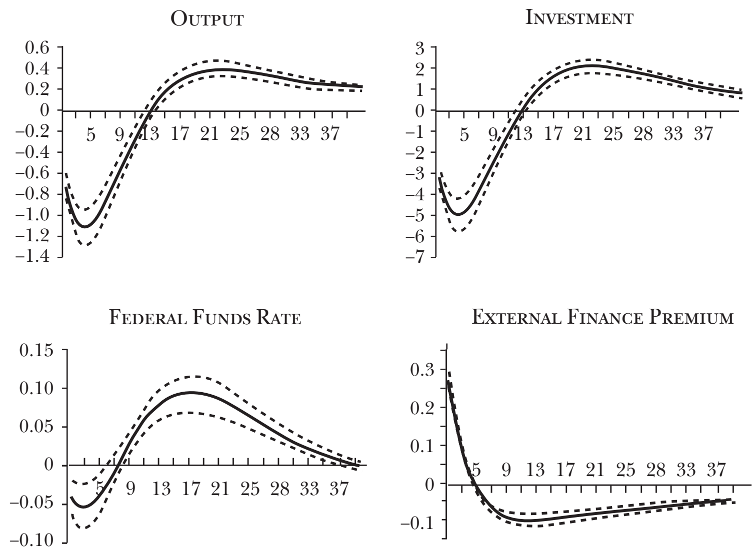
observable variables to the other three shocks: Government expenditure, technology and discount factor.[12]

A positive government expenditure shock causes an expansion in output and investment together with inflationary pressures that are faced with higher interest rates. In the financial accelerator model, the increase in the price of installed capital brought about by this demand driven expansion improves the entrepreneurs' financial position and eases the credit market conditions by lowering the external finance premium.

[12] The impulse-response figures are available upon request.

Figure 3

MODEL RESPONSES TO A CREDIT (EXTERNAL FINANCE) RISK PREMIUM SHOCK



Note: The solid lines in each panel depict the mean impulse response function of each variable to one standard deviation external finance premium shock. The dashed lines give the 90% confidence intervals. The black lines in each panel depict the financial accelerator case. Here there are no gray lines as the model without the financial accelerator does not have financial shocks.

A positive technology shock increases output and investment and lowers inflation at the time that interest rates drop. Again, in the financial accelerator model, credit conditions amplify the effect of the shock.

A positive discount factor shock increases consumption and in both models it has a positive initial response in output. However, the response of our model economy to discount factor shock has contrasting effects depending on the inclusion of a financial accelerator mechanism. Without the financial accelerator mechanism, the initial increase in output brought by the increase in consumption is quickly overturned by the drop in investment. When financial factors are considered, the improvement in credit market conditions is enough to keep investment strong. In both cases there are inflationary pressures and the federal funds rate is increased.

5.3 Shock Decomposition

To understand the implications of the model for the conduct of monetary policy and to evaluate the importance of financial market frictions in determining business cycle outcomes, we calculate the portion of the movement in the observed data that can be attributed to each shock. Figure 4 presents the contribution of each shock, monetary policy, government expenditure, technology, taste (discount factor), and external finance credit (credit risk) premium, to explain the observed behavior of demeaned output growth in the financial accelerator case. In Appendix 3, we present the graphs for the other four observable variables in the financial accelerator case.

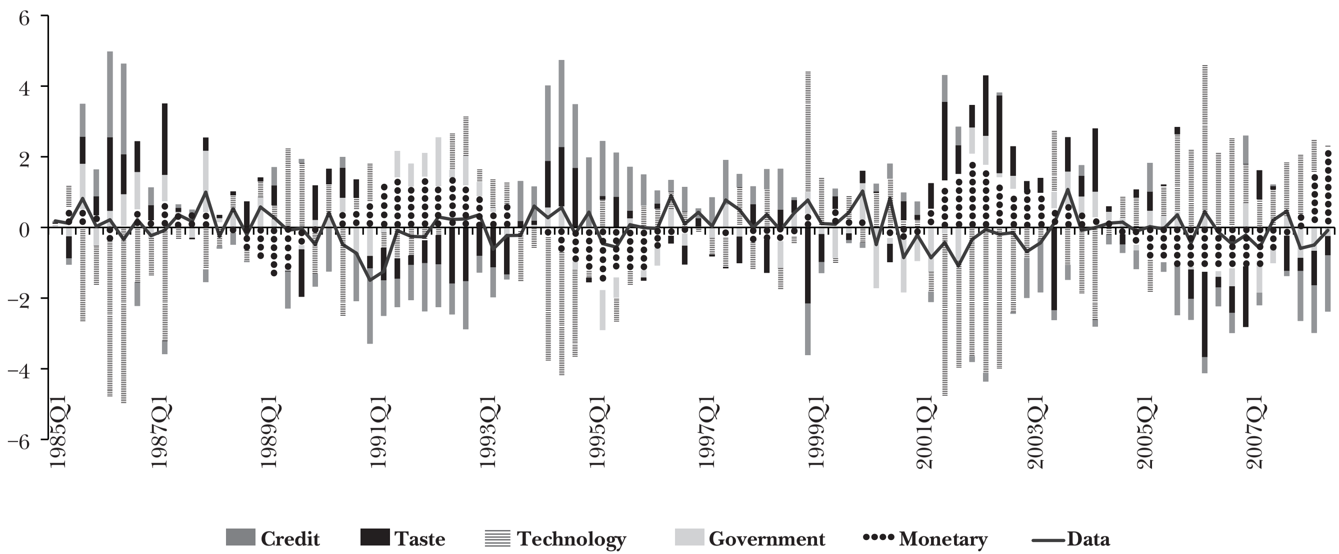
This figure shows the preponderance of technology innovations as engine of economic fluctuations and the relatively small role attributed to government shocks.[13] This historical shock decomposition also shows that there are clear episodes when monetary policy and financial disturbances were important in the determination of the economic fluctuations.

To gain more intuition, now we concentrate on the portion of the movement in the observable variables that can be credited to monetary policy and credit market innovations. Figure 5 shows the historical decomposition of monetary policy shocks in the cases with and without the financial accelerator, while Figure 6 focuses on the financial shocks.

[13] McGrattan and Prescott (2010) point out the important role that intangible capital played during the output expansion in the 1990s. Extending the current model with intangible investment and non-neutral technology change with respect to producing intangible investment goods would be a natural extension to verify the robustness of the presented shock decomposition, especially given the negative contributions of technology during part of the 1990s.

Figure 4

Historical Shock Decomposition of Output Growth in the Financial Accelerator Model



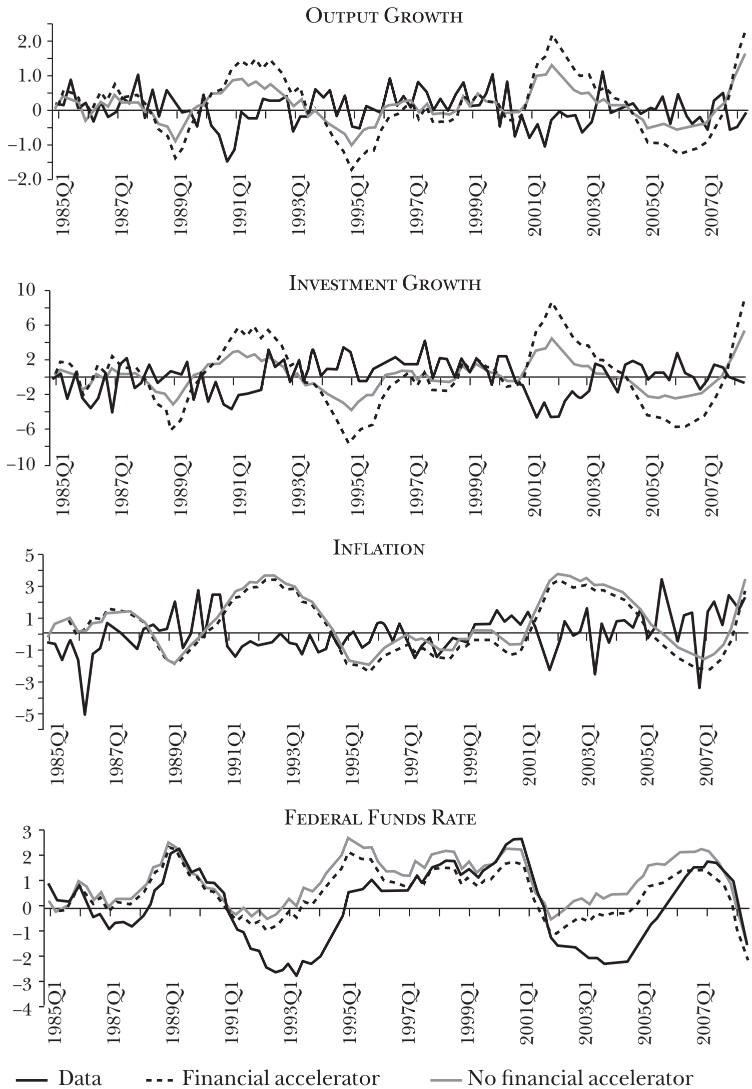
Note: This figure presents the historical shock decomposition of demeaned output growth computed using the estimated model. The solid line depicts the behavior of this variable expressed in percentage point deviations from steady state. Each of the bars associated with each quarter, present the contribution of each shock to the observed behavior. The sum of the five shocks adds to the data.

Figure 5 shows that the effect of monetary policy shocks on the economy accords well with the historical record regarding the conduct of monetary policy since the mid-1980s. Monetary policy was tight in the late 1980s prior to the onset of the 1990-1991 recession but was eased substantially during the economic downturn of the early 1990s. According to our estimates, tight monetary policy also contributed to the slowdown in business investment and output during the 1994-1995 period. The stance of monetary policy was roughly neutral up to the collapse of the stock market in early 2000, and according to our estimates, policy was eased significantly during the 2001 recession. Monetary policy was again relatively tight during the housing boom of the 2005-2007 period. The rapid sequence of cuts in the federal funds rate during 2007 also appears as a significant easing of monetary conditions that has supported the expansion in investment and output during that period. An appealing feature of this model is that the monetary transmission mechanism works in part through its impact on balance sheet conditions –that is, the external finance premium is strongly countercyclical in response to monetary policy shocks.

Figure 6 shows that the estimated effects of financial disturbances and their impact on the real economy also accord well with historical perceptions of the likely effects of tight credit conditions on economic activity. According to our estimates, the economy showed signs of financial distress at the onset of the 1990-1991 recession, and adverse financial conditions remained a drag on the real economy throughout the jobless recovery of the early 1990s. Indeed, between 1989 and 1993, shocks to the financial sector caused the external finance premium to rise by 150 basis points, an increase that led to an extended period of subpar economic performance. Credit market conditions improved markedly during the second half of the 1990s, a period during which the external finance premium fell about 250 basis points. The premium moved higher after the bursting of the dot-com bubble, and financial conditions deteriorated further at the onset of the collapse in the housing sector in 2005. The

Figure 5-a

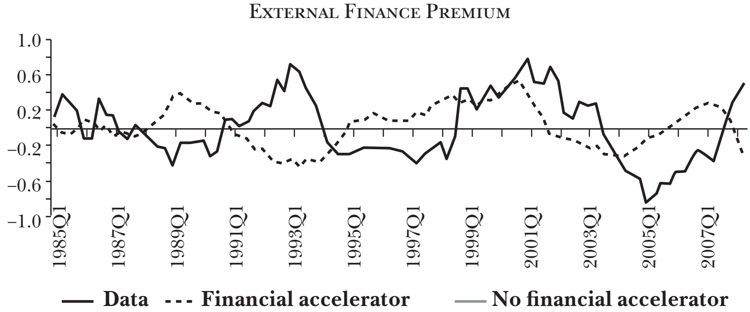
Historical Decomposition of Monetary Policy Shocks



Note: The solid black line in each panel depicts the behavior of actual variables expressed in percentage point deviations from steady state. The dotted line in each panel depicts the estimated effect of monetary policy shocks under the financial accelerator model. The solid gray line in each panel depicts the estimated effect of monetary policy shocks in the model without the financial accelerator.

Figure 5-b

HISTORICAL DECOMPOSITION OF MONETARY POLICY SHOCKS



model also captures the current financial crisis as a shock to the financial sector, manifested as a 75 basis point jump in the external finance premium that has led to a sharp slowdown in the growth of investment and output during the last four quarters.

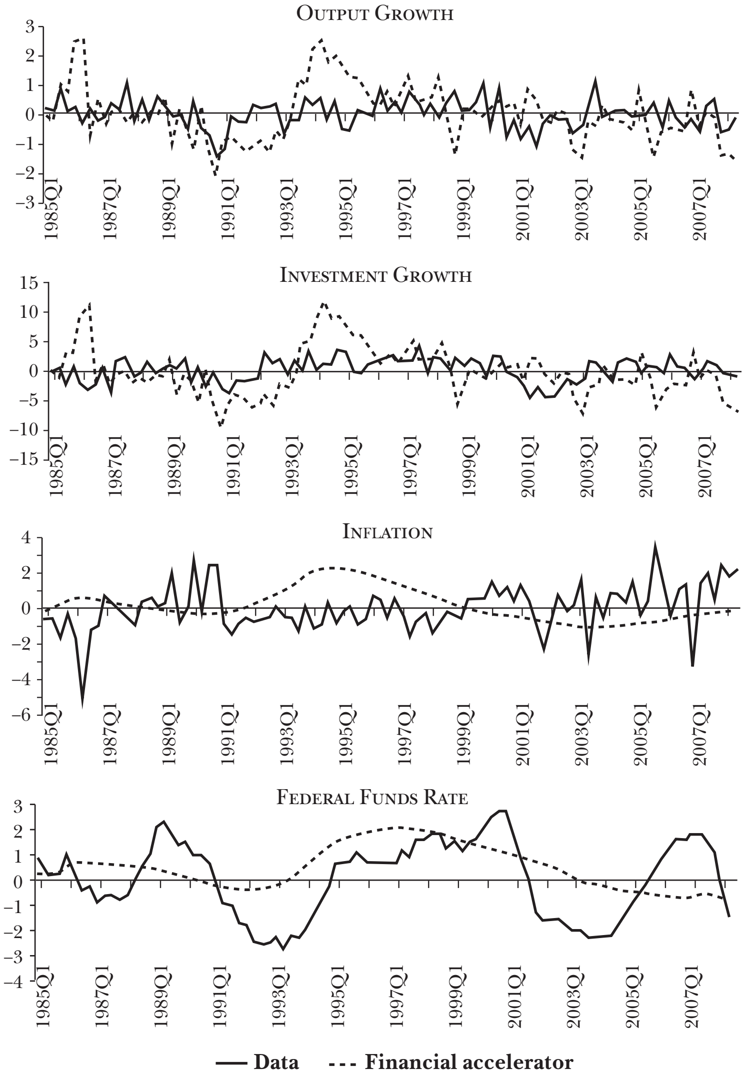
In summary, this relatively simple model of the financial accelerator –when estimated using both real and financial market data– does remarkably well at capturing much of the historical narrative regarding the conduct of monetary policy and developments in financial markets that led to the episodes of financial excess and distress over the last two decades. As shown during the three episodes when credit market innovations were dragging output growth, monetary policy partially offset these effects.

5.4 Variance Decomposition

Table 3 summarizes the asymptotic variance decomposition for the models with and without financial factors. In both cases technology innovations are the main force explaining the fluctuation in output, investment, inflation, and nominal interest rates. In the case of the external finance premium the variance is mostly explained by shocks to preferences with 50% and financial shocks (external finance premium) with 34.8%, while technology only accounts for 11.1% of its variance.

Figure 6-a

HISTORICAL DECOMPOSITION OF FINANCIAL SHOCKS



Note: The solid black line in each panel depicts the behavior of actual variables expressed in percentage point deviations from steady state. The dotted line in each panel depicts the estimated effect of monetary policy shocks under the financial accelerator model. Here there is no solid gray line as in the model without the financial accelerator there are no financial shocks.

Figure 6-b

HISTORICAL DECOMPOSITION OF FINANCIAL SHOCKS

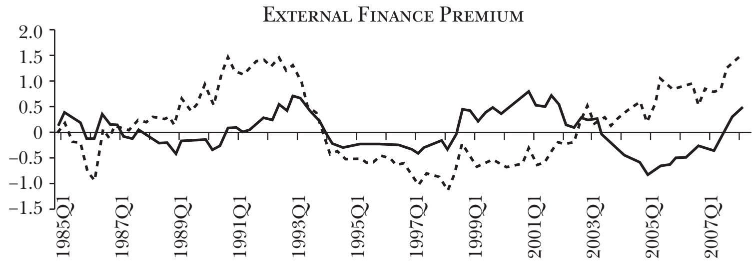


Table 3

ASYMPTOTIC VARIANCE DECOMPOSITION OF THE MODEL WITHOUT FINANCIAL FACTORS AND OF THE MODEL WITH FINANCIAL FACTORS

Shock/Variable	*Output*	*Investment*	*Inflation*	*Interest rate*	*External finance premium*
Monetary	18.5/12.5	26.1/17.1	10.6/7.1	10.4/9.6	–/3.8
Government	27.3/6.5	1.2/0.5	0.4/0.6	1.5/2.3	–/0.6
Technology	44.7/51.3	44.6/53.0	64.0/52.0	66.9/42.2	–/11.1
Discount factor	9.5/14.7	28.0/6.9	25.0/38.1	21.2/37.6	–/49.7
External finance premium	–/15.1	–/22.5	–/2.1	–/8.4	–/34.8

Note: The table reports the percentage of the variance of each variable (reported in columns) that is explained by each of the shocks (reported in rows). Each cell shows two numbers separated by a slash. The first number corresponds to the share in the model without financial factors and the second number is the share in the model with these factors included.

In the version with financial factors, monetary innovations explain 12.5% of the output variance, while credit market innovations explain 15.1%.[14] Meanwhile, in the case of investment,

[14] Using the same measure of the external finance premium, but a factor-augmented vector autoregression specification instead of

monetary policy explains 17.1%, while credit market innovations account for 22.5%. In the model without financial factors, government expenditure shocks (a residual in the aggregate resource constraint) capture most of the portion that is really explained by financial factors, while in the case of investment the discount factor does it.

6. CONCLUSIONS

Using macroeconomic and financial data in an estimated DSGE model with financial frictions, this paper shows that financial market frictions have been important in US business cycles amplifying real and nominal disturbances in the economy. The estimated model shows that financial shocks have important real effects as a 0.25% rise in the external finance premium causes a 0.73% decrease in output and a 2.8% decrease in investment. A 0.44% unexpected reduction in the federal funds rate contributes to a 0.38% expansion in output and 1.42% increase in investment. In the presence of credit market imperfections the increase in output that comes with the expansionary monetary policy, by improving borrowers' financial positions, contributes to reduce the cost of external financing further contributing to the output expansion. We provide evidence that disturbances originated in the financial sector have significant real consequences for output and investment activity accounting for 12.5% and 17.1% of their respective variances since 1985. We also observed that monetary policy was effective partially offsetting adverse shocks that originated in the financial market during the three most recent recessions.

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the DSGE model presented here, Gilchrist, Yankov, and Zakrajsek (2008) find that shocks emanating from the corporate bond market account for about 20% of the variance of industrial production at the two- to four-year horizon.

Appendices

Appendix 1. Log Linearized Model

The log-linearized version of the model is presented below. As in BGG (1999) the model is presented in terms of four blocks of equations: *1)* aggregate demand; *2)* aggregate supply; *3)* evolution of state variables; and *4)* monetary policy rule and shock processes. All lower case variable denote log-deviations from steady-state, while variables without a time subscript represent steady-state variables.

Aggregate Demand

Resource constraint:

A.1
$$y_t = \frac{C}{Y}c_t + \frac{C^e}{Y}c_t^e + \frac{1}{Y}i_t + \frac{G}{Y}g_t + \varphi_t$$

Marginal utility in the case of internal habit:

A.2
$$\lambda_t = \frac{1}{b^2\beta - bA(1+\beta) + A^2}[-\left(b^2\beta + A^2\right)c_t + bAc_{t-1} + + bA\beta E_t\left\{c_{t+1}\right\} - bAa_t + bA\beta E_t\left\{a_{t+1}\right\}]$$

Consumption-savings:

A.3
$$\lambda_t = E_t\{\lambda_{t+1}\} - r_{t+1}^n - E_t\{\pi_{t+1}\} - E_t\{a_{t+1}\} - \zeta_{c,t}$$

Entrepreneurial consumption:

A.4
$$r_t^e = n_{t+1}$$

Definition of the external finance premium:

A.5
$$s_t = E_t\left\{r_{t+1}^k\right\} - \left(r_{t+1}^n - E_t\left\{\pi_{t+1}\right\}\right) + \zeta_{s,t}$$

Determination of the external finance premium:

A.6 $$s_t = \chi\left(q_t - k_{t+1} + n_{t+1}\right)$$

Expected real rate of return on capital:

A.7 $$E_t\left\{R_{t+1}^K\right\} = \frac{(1-\alpha)\frac{\varepsilon-1}{\varepsilon}\frac{Y}{K}A}{(1-\alpha)\frac{\varepsilon-1}{\varepsilon}\frac{Y}{K}A+(1-\delta)}\left(E_t\left\{y_{t+1}\right\} - k_{t+1} + E_t\left\{a_{t+1}\right\} + \right.$$
$$\left. + E_t\left\{mc_{t+1}\right\}\right) + \frac{(1-\delta)}{(1-\alpha)\frac{\varepsilon-1}{\varepsilon}\frac{Y}{K}A+(1-\delta)}E_t\left\{q_{t+1}\right\} - q_t$$

Relation between price of capital q_t and investment adjustment cost as a function of growth rate of I_t:

A.8 $$q_t = (1+\beta)\psi A^2 i_t - \psi A^2 i_{t-1} - \beta\psi A^2 E_t\left\{i_{t+1}\right\} +$$
$$+\psi A^2 a_t - \beta\psi A^2 E_t\left\{a_{t+1}\right\}$$

Aggregate Supply

Aggregate supply of final goods:

A.9 $$y_t = \alpha\Omega h_t + (1-\alpha)k_t - (1-\alpha)a_t$$

Labor market equilibrium:

A.10 $$y_t - h_t + mc_t + \lambda_t = \gamma h_t$$

Phillips curve:

A.11 $$\pi_t = \frac{1}{1+\beta\rho_\pi}\frac{(1-\theta)(1-\beta\theta)}{\theta}mc_t + \frac{\beta}{1+\beta\rho_\pi}E_t\left\{\pi_{t+1}\right\} + \frac{\rho_\pi}{1+\beta\rho_\pi}\pi_{t-1}$$

Evolution of State Variables

Capital accumulation:

A.12 $$k_{t+1} = \left(1 - \frac{1-\delta}{A}\right)i_t + \frac{1-\delta}{A}(k_t - a_t)$$

Evolution of net worth:

A.13 $$n_{t+1} = n_t + \frac{K}{N} r_t^k - \left(\frac{K}{N} - 1 \right) E_{t-1} r_t^k + \alpha (1 - \Omega) \frac{Y}{N} \frac{\varepsilon - 1}{\varepsilon} \left(y_t + mc_t \right) - a_t$$

or using the definition of the external finance premium $E_{t-1}\left\{ r_t^k \right\} = s_{t-1} + \left(r_t^n + E_{t-1} \pi_t \right)$.

A.14 $$n_{t+1} = n_t + \frac{K}{N} r_t^k - \left(\frac{K}{N} - 1 \right) \left[s_{t-1} + \left(r_t^n + E_{t-1} \pi_t \right) \right] + \\ + \alpha (1 - \Omega) \frac{Y}{N} \frac{\varepsilon - 1}{\varepsilon} \left(y_t + mc_t \right) - a_t$$

Monetary Policy Rule and Shock Processes

The monetary policy rule follows:

A.15 $$r_t^n = \rho_{r^n} r_{t-1}^n + \left(1 - \rho_{r^n} \right) \left[\gamma_\pi \pi_t + \gamma_y \left(y_t - y_{t-1} + a_t \right) \right] + \varepsilon_t^{r^n}$$

It is assumed that the exogenous disturbances to government spending, technology, discount factor, and financial distress obey autoregressive processes:

A.16 $$g_t = \rho_g g_{t-1} + \varepsilon_t^g$$

A.17 $$a_t = \rho_a a_{t-1} + \varepsilon_t^a$$

A.18 $$\zeta_{c,t} = \rho_{\zeta_c} \zeta_{c,t-1} + \varepsilon_t^{\zeta_c}$$

A.19 $$\zeta_{s,t} = \rho_{\zeta_s} \zeta_{s,t-1} + \varepsilon_t^{\zeta_s}$$

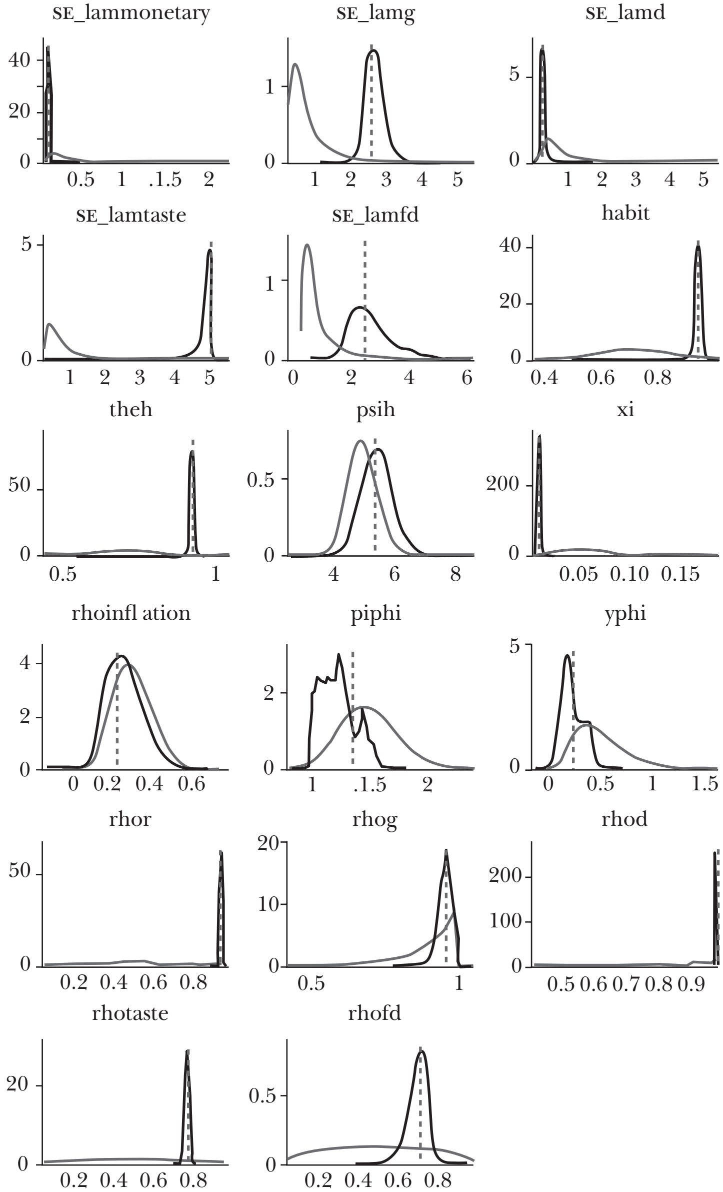
while the monetary policy shock is i.i.d.:

A.20 $$\zeta_{r^n,t} = \varepsilon_t^{r^n}$$

Appendix 2. Prior and Posterior Distributions

Figure A.1

ESTIMATED PARAMETERS' PRIOR AND POSTERIOR DISTRIBUTIONS



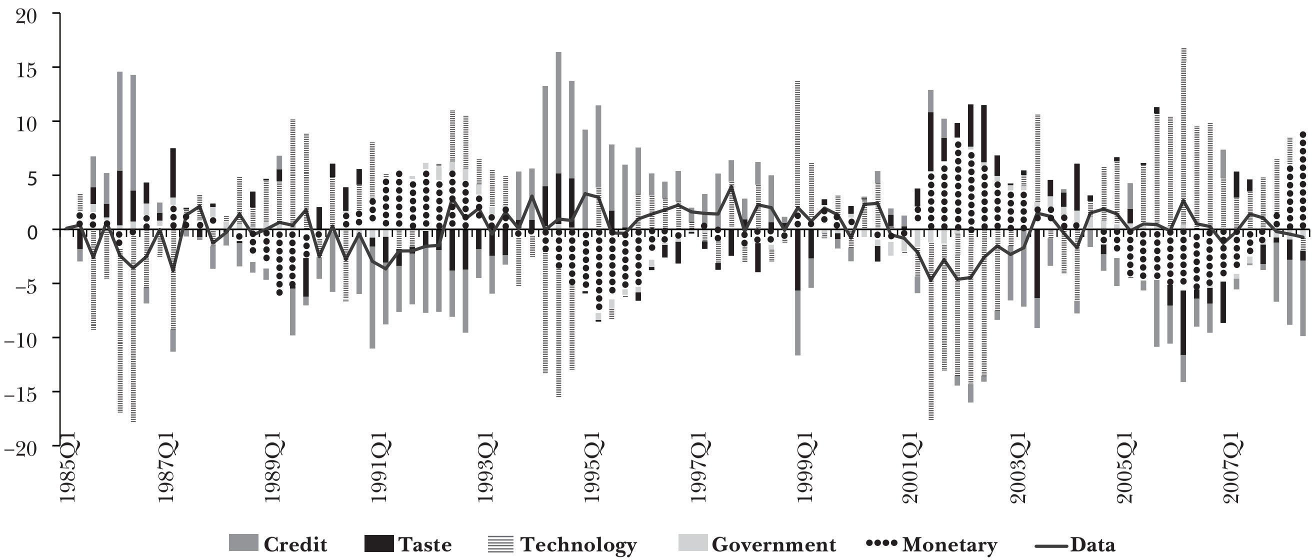
Note: The figure presentes the prior (grey) and posterior (black) distributions for the parameters estimates, along with the posterior mode (vertical line).

Appendix 3. Shock Decomposition

Figures A.2 to A.5 report the contribution of each shock to the observed data for the financial accelerator case. For example, Figure A.2 shows the contribution of monetary policy, government expenditure, technology, taste (discount factor), and credit (external finance premium) shocks to explain demeaned investment growth. Figures A.3 to A.5 report the results for stationary CPI inflation, stationary effective federal funds rate, and stationary external finance premium, respectively, where as specified in the text all variables are demeaned using the sample mean.

Figure A.2

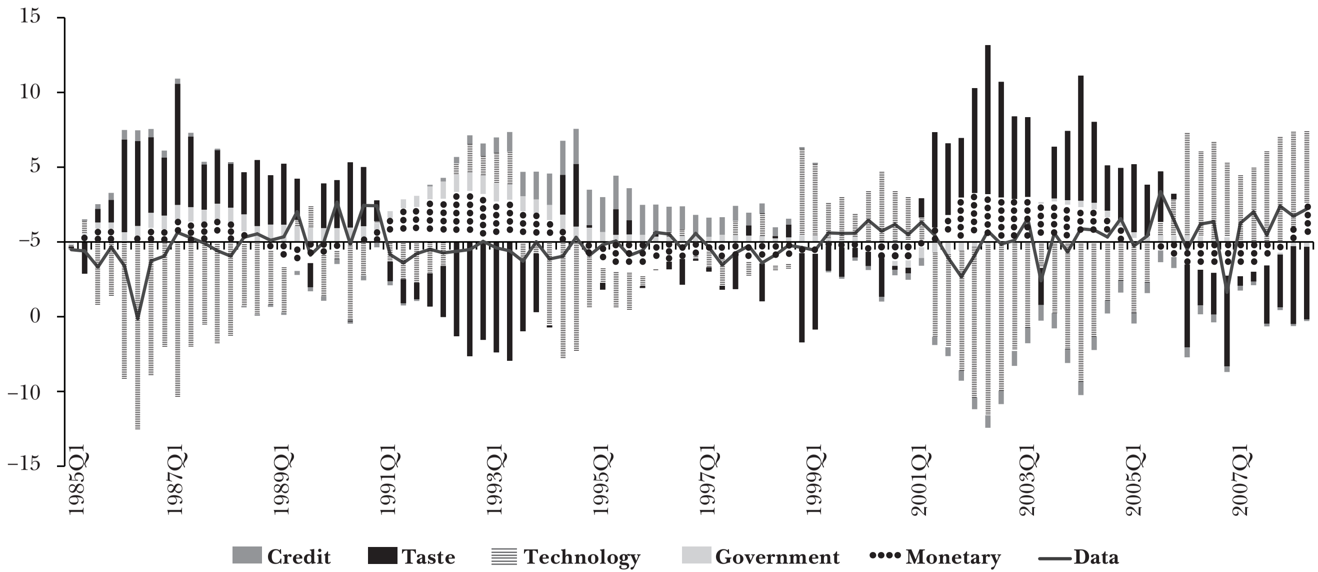
INVESTMENT GROWTH



Note: This figure presents the historical shock decomposition of investment growth computed using the estimated model. The solid line depicts the behavior of this variable expressed in percentage point deviations from steady state. Each of the bars associated with each quarter presents the contribution of each shock to the observed behavior. The sum of the five shocks adds to the data.

Figure A.3

Stationary CPI inflation



Note: This figure presents the historical shock decomposition of stationary CPI inflation computed using the estimated model. The solid line depicts the behavior of this variable expressed in percentage point deviations from steady state. Each of the bars associated with each quarter presents the contribution of each shock to the observed behavior. The sum of the five shocks adds to the data.

Figure A.4

Stationary Federal Funds

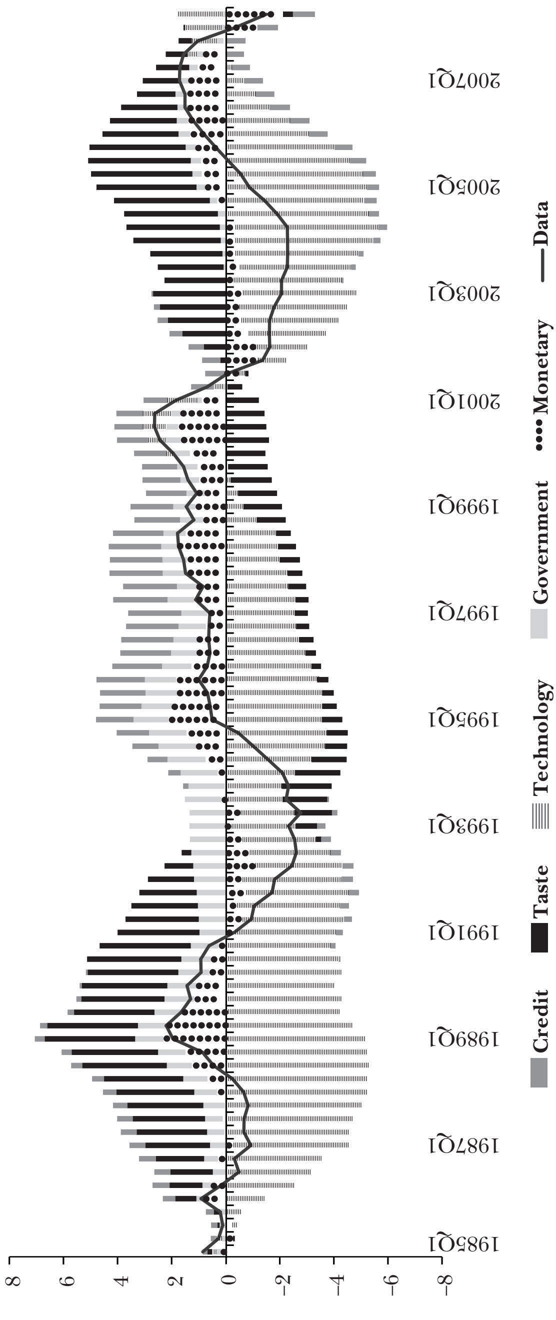
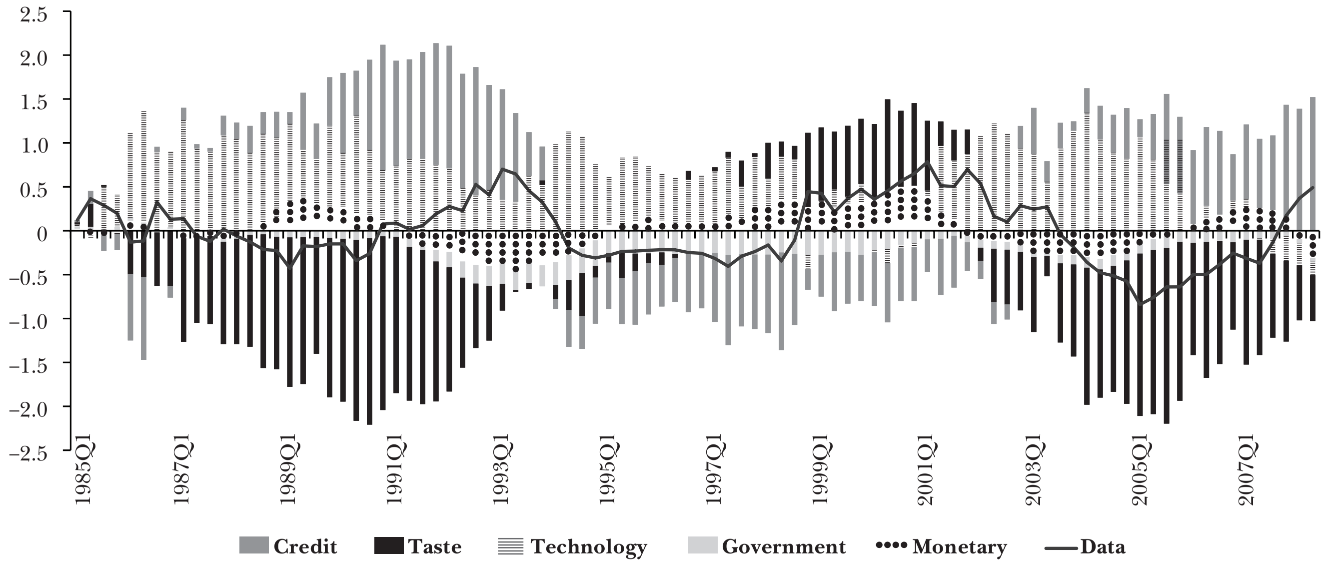


Figure A.5

Stationary Risk Spread



Note: This figure presents the historical shock decomposition of stationary credit risk spread computed using the estimated model. The solid line depicts the behavior of this variable expressed in percentage point deviations from steady state. Each of the bars associated with each quarter presents the contribution of each shock to the observed behavior. The sum of the five shocks adds to the data.

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Assessing the Impact of Nonperforming Loans on Economic Growth in The Bahamas

Abstract

This paper examines the extent to which economic output and other variables affect nonperforming loans in The Bahamas utilizing a vector error correction (VEC) model. It also seeks to determine if there is a feedback response from nonperforming loans to economic growth. Data utilized in the study spanned the period September 2002 to December 2011. The main findings reveal that growth in economic activity tends to lead to a reduction in nonperforming loans, and there is additionally a small but significant feedback effect from nonperforming loans to output.

Keywords: nonperforming loans; Chow-Lin procedure; impulse-response functions.

JEL Classification: G21

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1. INTRODUCTION

Since the start of the global economic recession in late 2007, commercial banks' credit quality indicators in the Caribbean have deteriorated significantly, due to the rise in unemployment rates, challenging business conditions and to some extent the significant increase in credit by consumers to support their expenditures prior to the recession.

The challenges faced by The Bahamas and the rest of the Caribbean are by no means unique; however, the rapid rise in nonperforming loans (NPLS), which have in some cases risen from around 5% of total loans in 2008 to over 10% by the end of 2011, based on IMF estimates,[1] are amongst some of the highest in the world. As The Bahamas continues to recover from recession, it is therefore prudent to attempt to determine the potential impact of elevated levels of arrears and NPLS on economic growth over time and whether there exist a feedback effect, as strong evidence of a negative relation could result in lower levels of growth going forward and increased vulnerabilities to external shocks. This has implications for economic policy making and forecasting. Based on studies, such as Espinoza and Prasad (2010) and Klein (2013), we expect that there is a negative relation between gross domestic product (GDP) and NPLS.

This paper therefore seeks to determine, not simply the extent to which economic activity and other variables affects NPLS in The Bahamas, but if there is also a feedback response from NPLS to economic growth, using an econometric framework. To the authors' knowledge, this is the first of this type of study conducted for The Bahamas.

The remainder of the paper is organized as follows: Section 2 reviews the literature relating to the factors, which either affect or are impacted by the rise in NPLS in the banking sector. Section 3 provides a review of trends in arrears and NPLS for The Bahamas since 2002. Section 4 presents the econometric

[1] See IMF's *Regional Economic Outlook*, "Western Hemisphere: Rebuilding Strength and Flexibility," April 2012, p. 26.

models utilized in the study and analyses the results and Section 5 concludes the study.

2. LITERATURE REVIEW

Over the past decade, there have been several papers produced which have tried to determine the causes of NPLS, especially as it relates to bank specific factors. There have also been studies that attempt to determine the relation between NPLS and other macroeconomic variables such as economic growth, and the extent to which NPLS affect real GDP.

Amador, Gómez-González, and Pabón (2013) studied the relation between abnormal loan growth and banks' risk taking behavior, using information on individual Colombian banks' balance sheets between June 1990 and March 2011. They used data from sixty-four financial institutions, provided by Colombia's Financial Superintendence and they tested the abnormal loan growth on banks' survival probability using information on individual banks' characteristics during the financial crisis of the late 1990s. In addition, they tested the effect of abnormal loan growth on banks' financial health (solvency, nonperforming loans and profitability), using cross-sectional time-series data on Colombian financial institutions between 1990 and 2011.

Their results show that abnormal loan growth during a sustained period led to reductions in banks' capital ratios and to increases in the ratio of nonperforming loans to total loans. The authors also show that sustained abnormal loan growth was one of the most significant variables in explaining observed differences in the process of bank failure during the Colombian financial crisis of the late 1990s.

In their 2009 study, Khemraj and Pasha aimed to analyze the responsiveness of NPLS to macroeconomic and bank specific factors in Guyana using regression analysis. They used a fixed effect panel model to ascertain the causes of NPLS in the Guyanese banking sector. As well, they utilized data from six commercial banks in Guyana over the period of 1994-2004, and estimated the model using pooled least squares. The macroeconomic factors that were included in their model were: real GDP growth, inflation, and the real effective exchange rate. The bank specific factors used in this study were the real interest rate, bank size, annual growth in loans, and the ratio of loans to total assets. The results of their correlation analysis show that NPLS and the loans to assets ratio are positively related, implying that banks which take greater risks tend to have a greater amount of NPLS. The authors analysis also show that GDP growth and growth in NPLS are negatively related and that the size of the bank may not be relevant in terms of mitigating credit risk, as larger banks did not have significantly lower NPLS. However, contrary to other studies, their results also indicated a "negative association between inflation and the ratio of NPLS to total loans".

In a similar study, Espinoza and Prasad analyzed the extent to which macroeconomic factors affected NPLS of various banks within the Gulf Cooperative Council (GCC) countries and endeavored to ascertain the causes of overall NPLS in the GCC banking sector. They used a dynamic panel of data retrieved from the database Bankwise™, and ran panel vector autoregressive (VAR) models to determine the factors that affected the growth in NPLS in the GCC banking system. The authors tested bank specific factors[2] as well as macroeconomic factors such as non-oil real GDP.

Their studies found that the NPL ratio of the banks deteriorated as interest rates rose and non-oil economic growth slowed, and the size of the banks played a role, as the larger banks as well as those with fewer expenses had less NPLS. They also found that a prior period of high credit growth could lead to increased NPLS in the future. In terms of the feedback effects, the authors noted that there is a strong but short-lived feedback effect from NPLS to economic growth.

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[2] Bank specific factors tested were the capital adequacy ratio, the expenses/asset ratio, the cost/income ratio, the return on equity, size (of the banks), the lagged net interest margin, and lagged credit growth (deflated by the CPI).

Fofack (2005) also investigated NPLS in sub-Saharan Africa in the 1990s, and focused on determining if increases in NPLS were the major causes of bank failures. In his paper, the author utilized a standard definition of NPLS across the various countries within the Communauté Financière Africaine (CFA)[3] and non-CFA countries separately and compared the two sets of results.[4] His research revealed that financial costs were higher in non-CFA countries, as CFA costs fell over the 1996-2002 period, after the devaluation of the franc. He also examined the determinants of NPLS using correlation and causality analysis with a number of macroeconomic variables such as GDP per capita, inflation, interest rates, changes in the real exchange rate, interest rate spread and broad money supply (M2); as well as bank specific factors, such as return on assets and equity, net interest margins and net income, and interbank loans. The results of this analysis illustrate that real exchange rate appreciation and NPLS are positively related; however, the relation is not clearly defined for the non-CFA countries.

Fofack then conducted a Granger test to determine which, if any variables used in his study led to increases in NPLS. He used a sample of regional countries and found that inflation, real interest rates, and GDP growth per capita Granger cause NPLS in most of the countries. However, his study also found that in some countries the level of inflation and interest rates were not significant determinants of NPLS, and in those countries, the Granger test revealed dual causality between GDP growth and rising NPLS. The author used a pseudo panel regression model to predict the potential impact that changes in banking sector variables and macroeconomic factors might

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[3] The CFA region comprises countries in the West African Economic and Monetary Union as well as countries in the Economic and Monetary Community of Central Africa. Although, the currencies are different in both regions.

[4] The CFA franc is under a fixed exchange rate regime, formerly pegged to the French franc (now to the euro) and guaranteed by the French Treasury.

have on the banking sector.[5] The results of the model show that GDP per capita, real interest rates, broad money supply (M2) and changes in real effective exchange rate were significant for the entire panel of countries, while other macroeconomic and bank specific variables were significant for a subset of the countries. In terms of bank stability, growth in NPLS was found to be a major cause of bank failures due to their high costs and the banks' lack of capital to withstand the effects of higher NPLS.

Dash and Kabras' (2010) study aimed at determining the causes of NPLS in India using regression analysis. The macroeconomic factors used in the model were the growth in real GDP, annual inflation, and the real effective exchange rate, as well as bank specific variables, including the real interest rate, bank size, annual growth in loans and the ratio of loans to total assets. Using a panel data set consisting of firm level data for six commercial banks operating through 1998-2008, the authors performed a correlation analysis which showed a strong negative relation between NPLS and real GDP growth, as well as a strong positive relation between NPLS and the loan to asset ratio. It also showed the ratio between NPLS and real interest rates and NPLS to total loans to be weak.

The results of their fixed effect regression model revealed that banks which take more risks are likely to have higher NPLS, the size of the bank is not important as a determinant of NPLS, and GDP growth is negatively related to NPLS. Their studies also indicated a negative relation between credit growth and NPLS, contrary to other literature, and their results showed mixed results between inflation and NPLS. Further, the real effective exchange rate exhibited a strong positive relation with NPLS, and loan delinquencies were higher for banks, which increase their real interest rates.

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5 The variables used were: equity (% of total assets), return on assets, net interest, net income (% of total revenue), interbank loans (% of assets), equity (% of liquid assets), growth rate of real GDP, M2 (% of M2), inflation, domestic credit provided by banks (% of GDP), domestic credit to the private sector (% of GDP), real interest rate, change in real effective exchange rate, and GDP per capita.

De Bock and Demyanets (2012) focused on examining how credit growth and asset quality in emerging markets (EMs) are affected by both domestic and external factors. The authors used variables that could possibly influence banks' asset quality indicators, such as GDP growth, terms of trade, the exchange rate, capital flows, equity prices, and interest rates. Using a combination of dynamic panel and structural panel VAR models for 25 EMs during the 1996-2010 period, the authors analyzed the effects on the real economy when credit contracts or banks' balance sheets deteriorate.

The results of their dynamic panel regressions show that important determinants of loan quality are portfolio and bank flows, economic growth, terms of trade, and exchange rate appreciation, which all are negatively related with the aggregate NPL ratio, while credit growth was found to be positively related with the NPL ratio, contrary to previous studies. The results of their structural panel VAR show that worsening growth prospects, a depreciating exchange rate, weaker terms of trade and a decrease in debt-creating capital inflows will potentially decrease private sector credit and worsen banks' asset quality indicators. Moreover, the authors also found that an increase in NPLS leads to less economic activity and that credit contracts when the exchange rate tends to depreciate.

Badar and Javid (2013) carried out a study with the purpose of examining the long run relation between macroeconomic variables and NPLS; examining the short run impact of macroeconomic forces on NPLS; and facilitating monetary and fiscal regulators to cover up the gaps and to make right decisions by sharing empirical results of the study. The authors used five macroeconomic variables in their study to examine the impact on NPLS: inflation, interest rate, gross domestic product, exchange rate and money supply. They carried out a bivariate and multivariate cointegration analysis, as well as a Granger causality test, before carrying out a vector error correction (VEC) model. Their results showed that a long run relation between macroeconomic forces and nonperforming loans exists, and the Johansen multivariate cointegration test confirmed it; similarly, the bivariate cointegration confirms a long run relation exists between nonperforming loans with money supply and interest rates. Weak short run dynamics were found between NPLS, inflation and exchange rate by the VEC model.

Similarly, Klein aimed to evaluate the determinants of NPLS in Central, Eastern and South Eastern Europe (CESEE) economies by looking at both bank-level data and macroeconomic indicators over 1998-2011. The author also aimed to evaluate the feedback effects from the banking sector to the real economy through a panel VAR analysis in order to assess how the recent increase in NPLS in the CESEE region is likely to affect economic activity in the period ahead. The panel VAR included five variables: NPLS, real GDP growth, unemployment rate, the change in credit-to-GDP ratio and inflation.

The author's results confirmed that the level of NPLS tends to increase when unemployment rises, exchange rate depreciates, and inflation is high. The results also suggest that higher euro area's GDP growth results in lower NPLS. As it relates to bank-level factors, the author found that higher quality of the bank's management, as measured by the previous period's profitability, leads to lower NPLS, while moral hazard incentives, such as low equity, tend to worsen NPLS. In addition, excessive risk taking (measured by loans-to-assets ratio and the growth rate of bank's loans) was found to contribute to higher NPLS in the subsequent periods.

While examining the feedback effects between the banking system and economic activity the author found that NPLS were responsive to macroeconomic conditions, such as GDP growth, and that there are feedback effects from the banking system to the real economy. To be specific, Klein's estimations suggest that an increase in NPLS has a significant impact on credit (as a share of GDP), real GDP growth, unemployment, and inflation in the periods ahead.

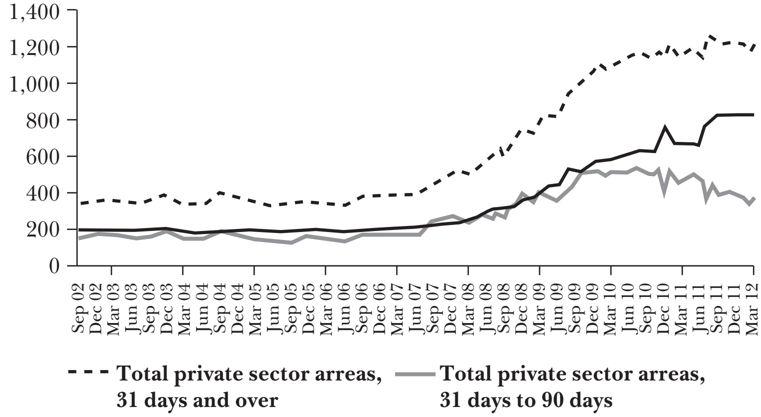
3. ANALYSIS OF ARREARS

For the purpose of the study, we utilized quarterly data for The

Figure 1

Total Private Sector Arrears

(millions of dollars)



Source: The Central Bank of The Bahamas.

Bahamas, which spanned the period September 2002 –the earliest date at which a consistent quarterly asset quality series is available– until March 2012.

As Figure 1 shows, from September 2002 to June 2007, arrears[6] in the Bahamian banking system remained relatively stable in the $330 million and $370 million range, with modest changes occurring due to seasonal factors –mainly the trends in the tourism sector. However, it breached the $450 million mark in June 2007, due in part to the surge in credit to the private sector, which occurred in the previous three years, which accompanied the general improvement in economic conditions as well as the lifting of the Central Bank's credit restrictions in August 2004. As an example, credit to the private sector rose by an average of 12.8 % between 2005 and 2007, compared to a mean increase of 3.6% in the prior three-year period. This increase in credit was fueled in part by a significant improvement

[6] Defined as loans which are greater than 30 days past due.

in business conditions, as economic output rose by an average of 2.5% over the three-year period, due to growth in the tourism sector and projects such as Atlantis Phase III. In addition, employment conditions improved, as the jobless rate averaged 8.6% between 2005 and 2007, vis-à-vis 10.0% in the prior three years, which allowed more customers to qualify for various types of loans from these lending institutions.

Between June 2007 and December 2009, arrears climbed steadily, reflecting the rapid deterioration of economic and employment conditions –particularly in the tourism and foreign investment sectors–, which resulted from the global financial crisis and subsequent recession. The Bahamas' real GDP growth slowed from 2.5% in 2006 to 1.4% in 2007, and fell by 2.3% in 2008 and 4.9% in 2009.[7] Additionally, the unemployment rate almost doubled from 7.6% in 2006 to 14.2% by 2009. As a result, a significant number of borrowers were unable to meet their debt payments, due to the fact that they were either laid off or worked reduced hours –as occurred in the lodging sector– and in the case of firms, there was a significant contraction in their revenues, due to reduced business activity.[8] Therefore, from 2007 to 2009, arrears rose by an average of 40% per annum, despite banks' attempts to engage in various types of debt restructuring programs.

Over the 2010 to 11 period, the rate of growth in arrears slowed considerably to 5.3%, as economic conditions appeared to stabilize, with real GDP rising marginally by 0.2% in 2010 and by 1.1% in 2011; however, the level of output remained significantly below the pre-recession period.[9]

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7 Based on estimates from the Bahamas Department of Statistics as at end-April 2012.

8 There is also some anecdotal evidence to suggest that some consumers were also adversely affected, because they had obtained other forms of credit in addition to the facilities offered by commercial banks; however, comprehensive information on non-bank lending and arrears is not readily available.

9 Table 1 (Appendix A) provides details on some of the key credit quality indications in the banking system from 2002 to 2011.

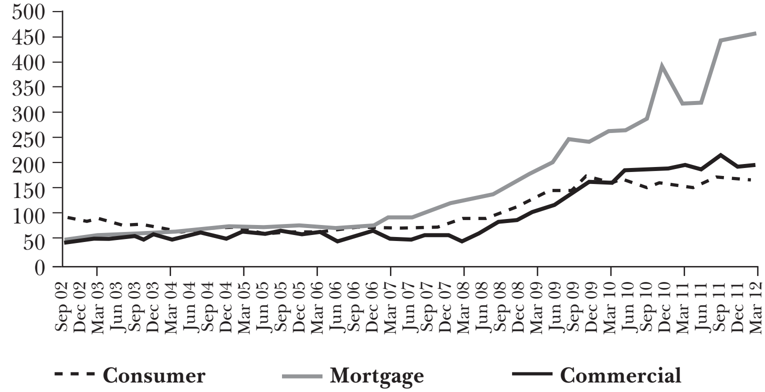
A disaggregation of arrears by average age revealed major increases in both the short term (loans 31 to 90 days in arrears) and the NPL segment (91 days and over). Trends in the short-term category tended to follow changes in total arrears over the 2002 to 2009 period, however, since December 2009, short-term arrears have trended downwards, as NPLS have driven the increase in arrears over the two-year period.

A breakdown of the NPL components (Figure 2) shows that the majority of the increase in this category was due to growth in the mortgage segment, which has consistently comprised the bulk of NPLS since March 2005. Indeed, between 2007 and 2009, mortgages accounted for a mean of 44.3% of total private sector NPLS and rose by an average of 39.8% per annum. Similarly, the consumer component –which represented 31.1% of NPLS over the period– rose by an average of 34.3% each year, while commercial NPLS, at 24.6% of the total, rose more rapidly by 48.6% per annum over the three-year period.

Despite the signs of stabilization in the economy, mortgage NPLS have continued to increase at a relatively moderate rate, rising by 62.6% in 2010 and 14.8% in 2011, or an average of 38.7% per annum. Commercial NPLS, which surpassed the

Figure 2

PRIVATE SECTOR NONPERFORMED LOANS BY CATEGORY
(millions of dollars)



Source: The Central Bank of The Bahamas.

consumer segment to become the second largest category in June 2010, recorded a slowdown in the rate of growth to 11.3% over the two-year period, while the consumer segment fell by an average of 1.9%. Over the review period, mortgage NPLS accounted for almost half (49.5%) of the total, followed by the commercial and consumer segments with shares of 27.3% and 23.2%, respectively.

4. ECONOMETRIC ANALYSIS

4.1 Data

In order to investigate the effect which economic growth has on nonperforming loans in The Bahamas, the factors that influence nonperforming loans must first be determined. In this initial step, we used several macroeconomic variables in the model, which served as indicators of economic activity and interest rates in the country. Variables included were:[10] real GDP in The Bahamas (*real_GPD*); United States real GDP (*real_GPD_US*); air arrivals (*air_arrivals*), which served as a proxy for tourism sector output;[11] foreign direct investment (*FDI*); the weighted average loan rate (*WAIR_BAH*); and inflation (*INF_BAH*). Additionally, we used credit to the private sector (*P_credit*) to represent consumer demand (Table A.2, Appendix A, shows all of the variables and the expended sign of their coefficients). The dependent variable used in the regression analysis was total private sector NPLS (*P_NPL*).[12] The quarterly data was obtained from various sources including: The Central Bank of The Bahamas' *Quarterly Statistical Digest* and unpublished databases, while the information for United States real GDP was

[10] Based on the work of Khemraj and Pasha (2009), Espinoza and Prasad (2010), and Fofack (2005).

[11] Since the majority of the high value-added stopover tourists are air visitors, it seemed prudent to use this indicator as a proxy for tourism output.

[12] All of the variables are in nominal terms with the exception of the real GDP variables.

obtained from the Bureau of Economic Analysis.[13] The timeframe was limited to 2002Q3 to 2011Q4, because data on commercial banks' credit quality indicators was only compiled on a consistent aggregate basis from 2002. Table A.3 (Appendix A) provides some descriptive statistics for the variables used in the model.

4.2 Results: Real GDP

The real GDP series (*real_GPD*) for The Bahamas presented a significant challenge, since this indicator is only compiled on an annual basis. However, for the purpose of the model, a quarterly real GDP series needed to be obtained to employ the econometric techniques required, since annual data would have significantly diminished the validity of any statistical tests conducted, due to the low level of the degrees of freedom[14] and limited the ability to create VAR models. In order to disaggregate the annual *real_GPD* series, the variables which were important in affecting *real_GPD* over time and for which quarterly data was available, needed to be determined initially. In the context of The Bahamas, where tourism and foreign direct investment are two of the main drivers of economic activity, the variables air arrivals (*air_arrivals*) and foreign direct investment (*FDI_BAH*) were used in the model. Credit to the private sector (*P_credit_BAH*) was also included in the model given its close correlation with consumption.[15] The final variable selected was real GDP in the United States (*real_GPD_US*), given the fact that the country is historically The Bahamas' major trading partner, accounting for the majority of visitor arrivals, imports and foreign investment. The regression was conducted using the ordinary least squares (OLS) technique

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13 See website: <www.bea.gov>.

14 That is, in a model with n observations and k variables, there exists $n-k$ degrees of freedom.

15 Based on the expenditure approach, private consumption accounted for an estimated 61% of output in 2011.

and the results for the best model, based on the reported statistics, are shown in equation 1.

1
$$real\_GDP = \underset{(8.930073)}{0.681014}\, real\_GDP\_US + \underset{(2.694389)}{0.001131}\, air\_arrivals - \underset{(-3.262680)}{0.771236}\, FDI\_BAH$$

$$R^2 = 0.943641 \quad \bar{R}^2 = 0.928271 \quad DW = 1.703817$$

Note: *t*-statistic values are in parenthesis. All are significant at 5% level.

All of the variables had the a priori signs, with the exception of *FDI _ BAH*. Further analysis of the negative value for the *FDI _ BAH* coefficient, led to the theory that due to the high correlation between *FDI* and imports (almost 90%) an increase in *FDI* would initially retard growth due to its positive effect on imports and hence negative impact on GPD.[16] As the R^2 and $\bar{R}^2$ values show, the model is a very good fit for *real_GPD* over the period 1997 to 2011,[17] accounting for 94.3% and 92.8%, respectively, of the movement in the *real_GPD* series.

The next step involved disaggregating the annual *real_GPD* series into quarterly data, utilizing the Chow and Lin (1971) procedure. This technique was chosen based on the work conducted by Abeysinghe and Lee (1998), who noted that disaggregated GDP series based on the Chow-Lin (C-L) procedure produced superior estimates when compared to series, which were generated solely from univariate techniques.

According to Abeysinghe and Rajaguru (2004), the methodology used stems from the procedure developed by Chow and Lin (1971). The basic idea is to find GDP-related quarterly series and determine a predictive equation by running a regression of annual GDP on annual values of the related series.

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[16] These results were also found to be insensitive to lagged values for *FDI*.

[17] The real GDP series for 1997 to 2011 was obtained from the Department of Statistics and is based on the latest estimates, which were rebased in 2010.

The quarterly figures of the related series were then utilized to predict the quarterly GDP figures.[18]

The econometric software package RATS® was employed to generate the results based on the C-L procedure.[19] For the purpose of this exercise, we used specific settings, based inter alia on the assumption that a linear relation exists between the variables and that the quarterly real GDP series sum to the annual values. Following the work of Frain (2004), we used a value of p that was sufficiently large to ensure that the estimate converges, in this case 0.95%. Since the procedure disaggregated the data to ensure that real GDP summed to the annual GDP series, and seasonal factors such as changes in tourism sector output also impacted the estimates, quarterly changes in real GDP were estimated based on the formula shown in Equation 2:

2 $$\Delta real\_GDP_{qt} = \frac{real\_GDP_{qt} - real\_GDP_{qt-4}}{real\_GDP_{qt-4}} \times 100$$

According to the quarterly estimates,[20] the Bahamian economy has experienced three recessions[21] since 1997, with the latest beginning in 2008Q3 and ending in 2009Q3 –this was also the longest and most severe recession based on the estimates.

4.3 Results: Nonperforming Loans

4.3.1 Long-run Results

To explore the effect of the explanatory variables on nonperforming loans, the VAR methodology was employed. In the initial step, we tested the variables for the order of integration,

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[18] See Appendix B for a derivation of the Chow Lin methodology.

[19] RATS uses two procedures to disaggregate series into a higher frequency, the Chow-Lin and Dissagregate procedures; however, given the parameters specified in the model, both techniques produced very similar results.

[20] See Appendix A, Table A.3.

[21] Defined as two consecutive quarters of economic contraction.

i.e., whether or not they were stationary, using the Philips-Perron (PP) test. As expected all of the interest rate variables were integrated of order zero $I(0)$, as well as *INF_BAH*, *air_arrivals_BAH* and *FDI_BAH*, while the other variables were $I(1)$. Due to the limited number of observations and large number of regressors, an OLS model was first estimated and the significant explanatory variables in the model were determined by the general to specific methodology. Variables which were not significant in the regression were dropped as noted by their *p*-values at the 5% level of significance. Equation 3 shows the results for the optimal model estimated.

3

$$P\_NPL = \underset{(4.217336)^*}{2{,}060} + \underset{(9.46589)^*}{0.162349}\, P\_credit\_BAH - $$
$$-\underset{(-5.239256)^*}{1.358177}\, real\_GDP$$
$$R^2 = 0.748462 \quad \bar{R}^2 = 0.733666 \quad DW = 0.520262.$$

The variables which proved to be significant in the model were *P_credit_BAH*, and *real_GPD*.[22] The variables were then placed in a VAR framework and tests for cointegration conducted.[23] Given that all of the variables in Equation 3 were $I(1)$, the maximum number of cointegrating vectors can be $k-1$ where k is the number of variables in the model. Then, we conducted a Johansen cointegration test to determine the number of cointegrating vectors, optimal lag length and type of cointegrating equation, as determined by the Schwartz criteria. Table A.4 presents the results of the cointegration test (Appendix A). Sequential tests using different lag pairs were conducted and the test which produced the smallest value of the Schwartz information criterion (SIC)[24] was used to select

[22] The results of the Durbin-Watson statistic show that there is first order serial correlation in the model; however this was eliminated when two lags of the dependent variable are included in the model.

[23] See Verbeek (2000) for a detailed description of the VEC methodology.

[24] Due to data constraints, only six lag pairs were tested.

the model specification, and number of cointegrating equations. Based on the results of the test, a vector error correction (VEC) model with one cointegrating equation, lag pairs 1 to 2, and model specification intercept and no trend was estimated. Equation 4 shows the results for the long-run model. As expected both the *real_GPD* and *P_credit_BAH* variables had the correct sign. The coefficient of the *real_GPD* suggests a greater effect on *P_NPL* from an increase than for *P_credit_BAH* and both coefficients were significant at the 5% level.

4

$$P\_NPL_{(-1)} = \underset{(5.64314)}{7{,}240.770} - \underset{(-5.239256)}{4.798655}\, real\_GDP_{(-1)} + \\ + \underset{(10.1763)}{0.477958}\, P\_credit\_BAH_{(-1)}$$

4.3.2 Short-run Results

Table A.5 (Appendix A) shows that the short-run model which normalized on the *P_NPL* variable had a valid error correction term (i.e., negative and significant), which showed that the cointegrating relation between the variables was valid. Then, we conducted a Granger causality/block exogeneity test to determine if the selected endogenous variables should be treated as exogenous and the results indicated that all of the variables should be treated as endogenous.[25]

In order to explore the short-run dynamics of the system, for each of the variables in the system[26] we generate some generalized impulse-response functions. These functions measure the time profile of the effects of shocks at a given point in time on the (expected) future values of variables in a dynamic system and are insensitive to the ordering of the variables in the system.

Based on the results for the accumulated responses over a three year (12 quarters) period (Figure A.2, Appendix C), an innovation or positive shock to *real_GPD* equal to one standard deviation, ceteris paribus, resulted in a persistent reduction

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[25] See Table 6 (Appendix A).

[26] See Pesaran and Shin (1998).

in the *P_NPL* variable. Meanwhile, a shock of similar relative magnitude to *P_NPL* has an almost identical effect on *real_GPD*. This result is not surprising for The Bahamas, given that over the period estimated, the growth in GDP was accompanied by increased levels of employment and most likely generally higher salaries, since a significant portion of the population receive salary increases when new union agreements are reached. This therefore provided greater scope for individuals to obtain and repay new loans, based on several criteria including their level of compensation. In addition, it is worth noting that a positive one standard deviation innovation to *P_credit_BAH* resulted in an increase in *P_NPL* over time; however, a positive shock to *P_NPL* results in a decrease in *P_credit_BAH* over time.

The analysis appears to suggest that there is a feedback relation between the *real_GPD* and *P_NPL*, or that output growth tends to reduce NPLS over time, and that increases in NPLS also appear to have a retarding effect on real GDP –the effects are rather small initially but increase rapidly over time. A positive shock of one standard deviation to quarterly output reduces NPLS by a mere $16 million in the first quarter; however, the accumulated impact is approximately $76.5 million by the end of the first year and goes to over $400 million by the end of third year, or approximately 40% of NPLS at end-December 2011. Similarly, a one standard deviation innovation to NPLS reduces real GDP by only an estimated $24.9 million in the first quarter, and this rapidly increases to $93.2 million by the end of the first year and by the end of the third year, the value of the accumulated responses is $343.5 million, equivalent to 5% of 2011's total GDP. In addition, one standard deviation positive innovation to private sector credit appears to have weaker positive effect on NPLS, resulting in an increase in NPLS of $5.2 million by the end of the first quarter and this rises to $33.7 million by the end of the first year and the accumulated responses reach $249.2 million by the end of the 12th quarter. In contrast, a one standard deviation increase in NPLS appears to have a negative effect on private sector credit, with the exception of the first period, when credit rises by $11.1 million, but then declines by a total of $94.0 million after year one and by an accumulated response of $866.3 million by year three.

The results appear to be relatively robust, as the replacement of *P_NPL* with ratio of NPLS to total private sector loans (*P_NPL_RATIO*), as the dependent variable, produced similar accumulated impulse response profile.[27] In addition, with the exception of the positive relation between shocks to private sector credit and NPLS, the results for the *P_NPL* model are generally consistent with those observed by other authors such as Nkasu (2011), and Espinoza and Prasad (2010). Note, for the former that an adverse shock to GDP growth for a panel of 26 advanced countries causes an increase in the ratio of NPLS to total loans, while an increase in NPLS tends to slow GDP growth. Moreover, Nkasu found a negative relation between NPLS and private sector credit, as defined by the ratio of private sector credit to GDP. Similarly, as reported in Section 2, Espinoza and Prasad noted that the high non-oil GDP growth reduced the ratio of NPLS to total loans for a model of six countries GCC countries, while an increase in the NPL ratio tended to reduce GDP growth. Further, the authors found that higher NPLS tended to reduce credit growth and vice versa.

5. CONCLUSION AND POLICY IMPLICATIONS

The paper analyzed the trends noted in commercial banks arrears and nonperforming loans over a ten year period based on quarterly data. It then provided an analysis of the impact of key economic indicators on non-accrual loans in the banking system, to determine whether there was a feedback effect on economic growth from an increase in NPLS.

The tests show that based on the results of the regression, which conform to similar findings noted by other authors, growth in economic activity tends to lead to a reduction in NPLS in both the short- and long-run; however, there was also a feedback effect from NPLS to real GDP.

[27] See Chart 5 (Appendix C).

From a policy perspective, the results imply that policy makers should implement countercyclical policy measures, aimed at reducing the potential for a significant build up in NPLS during periods of economic downturn as this could slow the pace of a subsequent economic recovery over time. Further, the analysis suggests that the authorities could seek ways of restraining credit growth over the long-term, although the direct effects on NPL from an expansion in this variable are weaker than those obtained from shocks to output in both the long- and short-run. Finally, the study indicates that economic growth in the economy could reduce NPLS over time and this most likely reflects the effect of growth on employment and business conditions and hence borrowers' ability to repay loans.

However, it is worth noting that the results are preliminary and the quarterly GDP series calculated serves only as a proxy to GDP obtained using more robust data collection methods. Finally, the span of the data series is still quite short at 10 years and only includes three recession periods, based on the results of the C-L disaggregation. A longer time series could assist in strengthening the results or reveal other important relations.

Appendices

Appendix A

Table A.1

KEY CREDIT QUALITY INDICATORS OF THE BAHAMIAN BANKING SYSTEM, 2002-2011

	2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*
Total private sector arrears (millions of dollars)	356.9	386.7	373.3	370.2	394.2	529.9	765.8	1,090.1	1,139.1	1,208.1
As percentage of total private sector loans	9.9	10.4	9.4	8.3	7.7	9.4	12.7	17.8	18.6	19.3
Total private sector arrears (31-90 days) (millions of dollars)	168.5	189.3	176.5	168.6	178.1	278.2	398.0	513.7	393.2	392.0
As percentage of total private sector loans	4.7	5.1	4.4	3.8	3.5	5.0	6.6	8.4	6.4	6.3
Total private sector nonperforming loans (millions of dollars)	188.4	197.4	196.8	201.6	216.0	251.8	367.8	576.4	745.9	816.1
As percentage of total private sector loans	5.2	5.3	5.0	4.5	4.2	4.5	6.1	9.4	12.2	13.0
Total provisions (millions of dollars)	68.6	78.8	87.8	89.5	118.2	120.7	169.1	213.6	272.7	299.6
As percentage of total private sector loans	1.9	2.1	2.2	2.0	2.3	2.2	2.8	3.5	4.4	4.8
Debt consolidation loans (millions of dollars)	350.9	343.7	346.8	413.2	459.8	496.3	594.6	648.0	714.6	828.6
Percentage of change		−2.1	0.9	19.1	11.3	7.9	19.8	9.0	10.3	16.0
Total private sector loans (millions of dollars)	3,597.0	3,723.1	3,969.6	4,466.3	5,140.8	5,610.6	6,012.6	6,109.9	6,132.6	6,266.7

Source: Central Bank of The Bahamas.

Table A.2

VARIABLE NAMES AND EXPECTED SIGNS

Endogenous variable: private sector nonperforming loans (P_NPL)

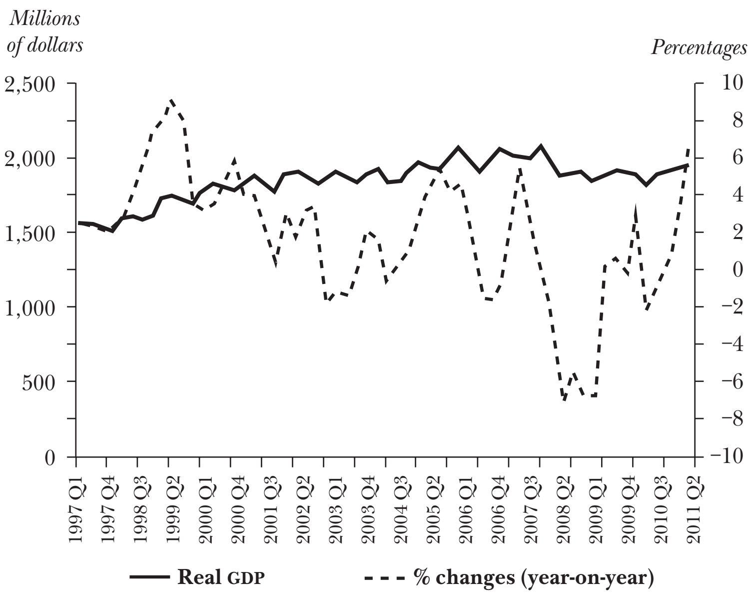
Exogenous variables	*Regressors*	*Expected signs*	*Order of integration (PP test)*[1]
Weighted average interest rate on loans and overdrafts	WAIR_BAH	+	I(0)
Average loan value/cost ratio (commercial)	COM_RATIO L_TO_C	+/−	I(0)
Average loan value/cost ratio (residential)	RES_RATIO_ LTO_C	+/−	I(0)
Credit to the private sector	P_CREDIT_BAH	+	I(1)
Inflation	INF_BAH	+	I(0)
Air arrivals	AIR_ARRIVALS	−	I(0)
Foreign direct investment	FDI_BAH	−	I(1)
Real GDP US	REAL_GPD_US	−	I(1)
Real GDP Bahamas	REAL_GPD	−	I(1)
Private sector nonperforming loans	P_NPL	N/A	I(1)

Source: The Central Bank of The Bahamas.

[1] Philips-Perron test, with significance at 5% level.

Figure A.1

DISAGGREGATED REAL GDP RESULTS FOR THE CHOW-LIN MODEL



Source: Author's calculations.

Table A.3

DESCRIPTIVE STATISTICS OF VARIABLES

Variable	*Mean*	*Median*	*Maximum*	*Minimum*	*Standard deviation*	*Skewness*	*Kurtosis*
WAIR_BAH (%)	10.92	10.84	12.17	9.79	0.62	0.16	2.50
COM_RATIO L_TO_C (%)	69.01	69.10	77.30	55.70	5.40	−0.75	3.05
RES_RATIO_LTO_C (%)	77.78	78.90	84.40	70.60	3.71	−0.30	1.00
P_CREDIT_BAH (millions of dollars)	5,407.29	5,668.70	6,599.50	3,940.00	1,063.62	−0.19	1.32
INF_BAH (%)	0.59	0.47	3.13	−0.95	0.67	1.44	7.19
AIR_ARRIVALS	349,572.80	340,832.50	449,996.00	273,943.00	49,789.55	0.19	1.92
FDI_BAH (millions of dollars)	187.42	172.41	397.40	36.07	102.74	0.68	2.65
Real_GPD_US (billions of USD)	12,648.89	12,813.50	13,337.80	11,467.10	590.34	−0.70	2.21
Real_GPD (millions of dollars)	1,922.22	1,915.57	2,067.22	1,815.65	68.95	0.49	2.45

Source: The Central Bank of The Bahamas.

Table A.4

SCHWARZ COINTEGRATION RANK TEST

Number of lags, intervals	*Number of cointegration equations*	*No intercept, no trend*	*Intercept, no trend*	*Linear, intercept, no trend*	*Linear, intercept, trend*	*Quadratic, intercept, trend*
1 to 1	0	32.67330	32.67330	32.45570	32.45570	32.17106
	1	32.26853	32.19732	32.12249	32.06932	31.78807 [a]
	2	32.69038	32.31988	32.26563	32.27329	31.93986
	3	33.29672	32.85512	32.85512	32.54098	32.54098
1 to 2	0	32.01370	32.01370	31.99809	31.99809	31.75863
	1	31.82763	31.71572 [a]	31.73903	31.84267	31.71612
	2	32.18269	31.93131	31.88795	31.95441	31.89436
	3	32.65790	32.48472	32.48472	32.32156	32.32156
1 to 3	0	31.96516	31.96516	31.98598	31.98598	31.94709 [a]
	1	32.08142	32.18724	32.11592	32.11914	32.13494
	2	32.40040	32.59854	32.45441	32.56007	32.47482
	3	32.96258	33.06745	33.06745	33.00594	33.00594

1 to 4	0	32.76148	32.76148	32.80383	32.80383	32.80887
	1	32.79105	32.73431	32.72803 [a]	32.83612	32.86541
	2	33.23501	33.11234	33.01944	33.06642	33.11310
	3	33.83446	33.66579	33.66579	33.49220	33.49220
1 to 5	0	33.52564	33.52564	33.44681	33.44681	33.48619
	1	33.59402	33.38666	33.20254	33.04321	32.97311 [a]
	2	33.82684	33.56583	33.33057	33.24954	33.08182
	3	34.44927	33.91078	33.91078	33.57197	33.57197
1 to 6	0	34.32558	34.32558	34.31555	34.31555	33.87578
	1	34.03797	33.92025	33.79722	33.51885	32.98641
	2	34.33061	33.75843	33.54010	33.37479	32.98483 [a]
	3	34.90628	34.17243	34.17243	33.56974	33.56974

Note: [a] Indicates lag intervals, number of cointegrating vectors and model specification based on minimal value of SIC.

Table A.5

VECTOR ERROR CORRECTION MODELS			
	Δ(P_NPL)	*Δ(REAL_GPD)*	*Δ(P_CREDIT_BAH)*
ECT_{t-1}	−0.130540 [a]	−0.064857	−0.101304
Δ(P_NPL(−1))	−0.938736 [a]	−0.411608	−0.637971
Δ(P_NPL(−2))	−0.428427	−1.102832 [a]	−1.017267
Δ(REAL_GPD(−1))	0.241532 [a]	0.194829	0.909926 [a]
Δ(REAL_GPD(−2))	0.225546 [a]	−0.618311	0.618514 [a]
Δ(P_CREDIT_BAH(−1))	0.094391	−0.094393	0.387471 [a]
Δ(P_CREDIT_BAH(−2))	−0.098694	0.156464	0.441436 [a]
R^2	0.558116	0.569969	0.632216
Adjusted R^2	0.459920	0.474407	0.550486

Serial correlation lm test (p-value= 0.7820)

Jarque-Bera normality test (p-value = 0.9534)

White test for heteroskedasticity (p-value = 0.4395)

Notes: All variables except for the error terms (ECT_{t-1}) are in first differences Δ.
[a] Indicates significance at 5% level.

Table A.6

VECTOR ERROR CORRECTION
GRANGER CAUSALITY/BLOCK EXOGENEITY TEST

Excluded	χ^2	*Durbin-Watson*	*P-value*
Dependent variable: Δ (P_NPL)			
Δ (REAL_GPD)	9.536548	2	0.0085 [a]
Δ (P_CREDIT_BAh)	1.936261	2	0.3798
All	17.017610	4	0.0019 [a]
Dependent variable: D(REAL_GPD)			
Δ (P_NPL)	6.983435	2	0.0304 [a]
Δ (P_CREDIT_BAH)	2.240443	2	0.3262
All	8.711221	4	0.0687 [b]
Dependent variable: D(P_CREDIT_BAH)			
Δ (P_NPL)	2.351879	2	0.3085
Δ (REAL_GPD)	23.92296	2	0.0000 [a]
All	24.48301	4	0.0001 [a]

Note: [a, b] indicates Granger causality at 5%and 10% level, respectively.

Appendix B

As outlined by Abeysinghe and Rajaguru, The fundamental equation for Chow-Lin disaggregation of n annual GDP figures to $4n$ quarterly figures is:

5

$$\hat{y} = X\hat{\beta}_a + VC'\left(CVC'\right)^{-1}\hat{u}_a$$

$$\hat{\beta}_a = \left[X'C'\left(CVC'\right)^{-1}CX\right]^{-1}X'C'\left(CVC'\right)^{-1}y_a$$

6

$$C = \begin{bmatrix} 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & \dots & . & . & . & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & \dots & . & . & . & 0 \\ . & . & . & . & . & . & . & . & \dots & . & . & . & . \\ 0 & . & . & . & . & . & . & . & \dots & 1 & 1 & 1 & 1 \end{bmatrix},$$

$\hat{y}$ is the vector of disaggregated quarterly GDP figures, y_a is the observed $n \times 1$ vector of annual GDP figures, X is a $4n \times k$ matrix of k predictor variables, V is a $4n \times 4n$ covariance matrix of quarterly error terms, u_t , $\hat{u}_a = y_a - X_a\hat{\beta}_a$ is an $n \times 1$ vector of residuals from an annual regression of GDP on predictor variables, $(X_a = CX)$ where C is an $n \times 4n$ aggregation matrix (or an averaging matrix if multiplied by 0.25), and $\hat{\beta}_a$ is a $k \times 1$ vector of generalized least squares (GLS) estimates of regression coefficients derived from an annual regression.

C-L presented two forms of the vector V. The simpler one is the case where u_t is white noise in which case V is diagonal and the GLS estimator reduces to OLS. In this case, the second term on the RHS of equation 1 amounts to allocating 1/4 of the annual residual to each quarter of the year. The second form is to assume that u_t follows an AR(1) process of the form: $u_t = \rho u_{t-1} + \varepsilon_t \, |\rho| < 1$ and $\varepsilon_t \sim i.i.d.\left(0, \sigma_\varepsilon^2\right)$, which case V has the form:

7

$$V = \sigma_\varepsilon^2 \begin{bmatrix} 1 & \rho & \rho^2 & \dots & \rho^{4n-1} \\ \rho & 1 & \rho & \dots & \rho^{4n-1} \\ . & . & . & \dots & . \\ \rho^{4n-1} & . & . & \dots & 1 \end{bmatrix}$$

By extending the monthly-quarterly case considered by c-l to the quarterly-annual case equation 8 can be used to estimate ρ from the annual estimate $\hat{\rho}_a$:

8 $$\hat{\rho}_a = \frac{\left(\rho^7 + 2\rho^6 + 3\rho^5 + 4\rho^4 + 3\rho^3 + 2\rho^2 + \rho\right)}{\left(2\rho^3 + 4\rho^2 + 6\rho + 4\right)}.$$

Appendix C

Figure A.2

Generalized Accumulated Impulse-Response Functions
(millions of dollars)

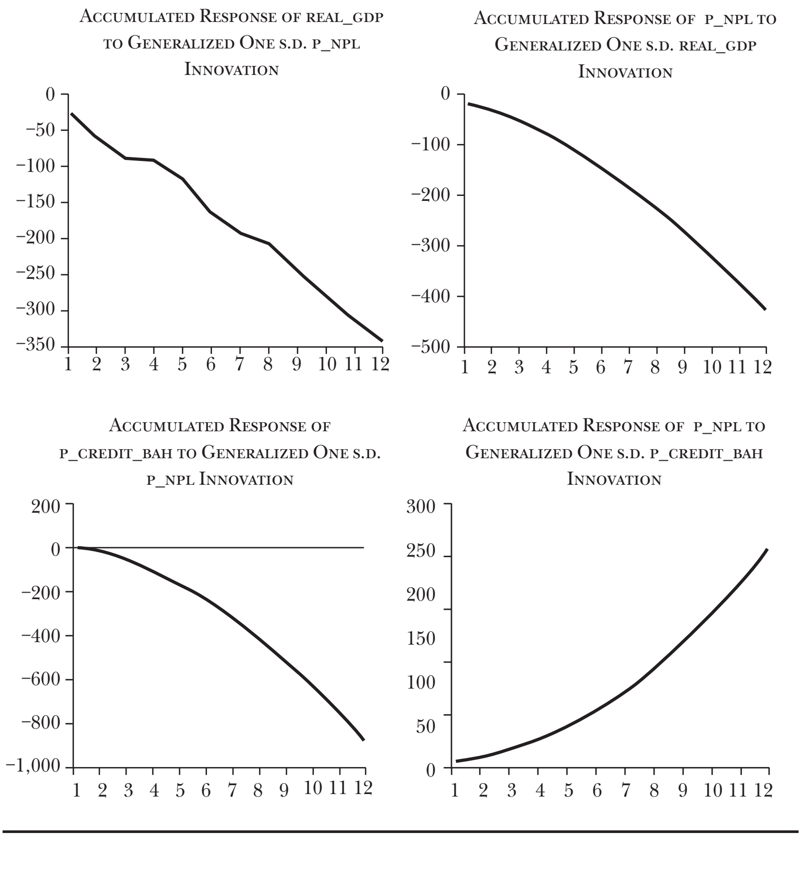
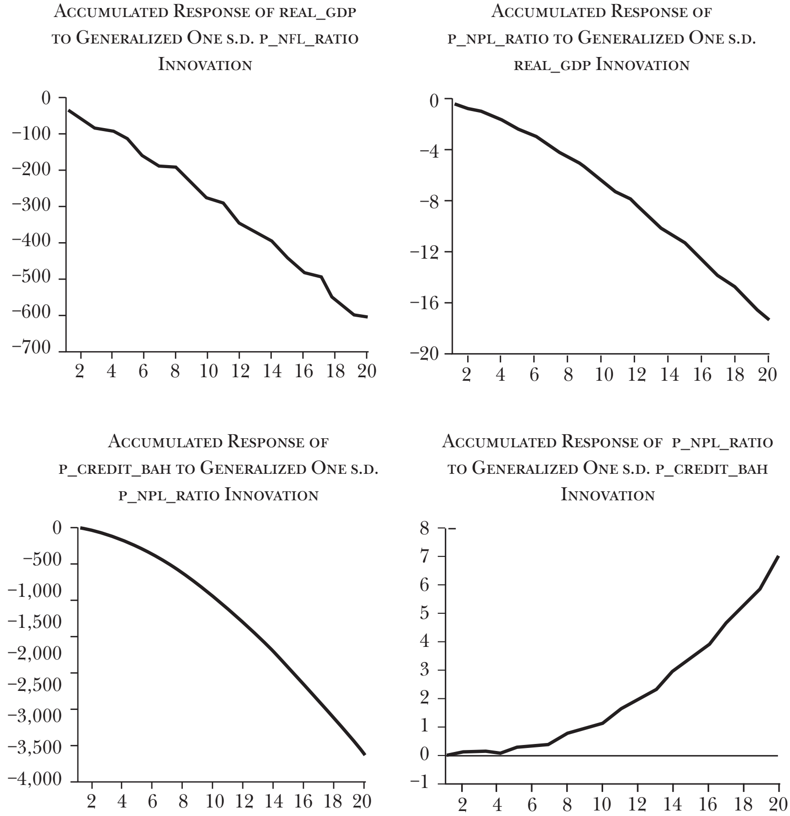


Figure A.3

GENERALIZED ACCUMULATED IMPULSE-RESPONSE FUNCTIONS USING RATIO OF NPLS TO TOTAL LOANS (P_NPL_RATIO)



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Bruno Martins
Ricardo Schechtman

Loan Pricing Following a Macroprudential Within-sector Capital Measure

CENTRAL BANK AWARD RODRIGO GÓMEZ, 2013

Abstract

This paper investigates the consequences on loan spreads of a within-sector macroprudential capital measure in Brazil. Due to concerns related to a possibly too fast and unbalanced expansion of the auto-loan sector, regulatory capital was raised for auto-loans with specific long maturities and high LTVs. Our results show that Brazilian banks, after the regulatory measure, increased spreads charged on the same borrower for similar auto-loans whose regulatory risk weights have increased. In comparison to the set of untargeted loans, the increase was at least of 13%. On the other hand, evidence on increase of spreads also for loans whose risk weights have not been altered is not robust. Finally, this paper shows that the later withdrawal of the regulatory capital measure was associated, similarly, to lower spreads charged on auto loans whose risk weights have decreased. Nevertheless, when measured relatively, this reduction in spreads was smaller than the original increase.

Keywords: *bank capital requirement; macro prudential measure; auto loans; loan spreads*

JEL Classification: *G21, G28.*

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Monetaria is published twice a year (Spring, Autumn) in Spanish and English (two volumes) by the Centro de Estudios Monetarios Latinoamericanos, Durango 54, colonia Roma Norte, delegación Cuauhtémoc, 06700 México, D.F. Printed in Master Copy, S. A. de C. V. , avenida Coyoacán núm. 1450, 03220 México, D. F. (400 copies).

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ISSN: 0185-1136