Some Evidence of Smooth Transition Nonlinearity in Colombian Inflation

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Abstract

Evidence of smooth transition autoregressive (STAR) representations is found in two, out of three, time series of different measures of annual inflation in Colombia during this decade for monthly data. The STAR-type nonlinearities are asymmetric for inflation computed as the variation of CPI while for (a measure of) core inflation are symmetric. Thus, LSTAR and ESTAR models were, respectively, estimated. No evidence of nonlinearity is found for traded goods inflation. Given the local dynamic properties of the estimated LSTAR model, only positive shocks to prices could shift negative accelerating inflation rate from the upper to the lower regime. By the same token, only stochastic shocks can move the core accelerating inflation rate from the outer regime to the middle one but the explosive nature of this regime will impulse the accelerating inflation rate to the outer one.

Version for comments

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1. Introduction

Despite that testing for linearity is now a standard procedure in the characterisation of the time series properties of any process, nonlinearity has been an issue of the province of business cycles (output and unemployment fluctuations), stock returns, and exchange rates markets, where asymmetries have clear interpretations. For business cycles phenomenon, it has been well documented the fact that the distance from peak to trough is different from the distance from trough to peak which suggests that the motion of economic activity is different for booming and slow down phases (Teräsvirta and Anderson, 1992; Zarnowitz, 1992; Granger, Teräsvirta, and Anderson, 1993; Peel and Speight, 1998)[1]. In the case of stock returns, the nonlinear fashion in which volatility series evolves over time has been related to clusters of outliers (Cao and Tsay, 1992), whereas in the case of the real exchange rates, nonlinearity could show the effects of transaction costs on the transient process towards the long run equilibrium (Michael et al., 1997). However, with respect to prices, or more precisely to inflation, as measured as the variation of annual CPI, nonlinearity has not been as well documented. Furthermore, such a lack of evidence is sharper for core or underlying inflation and inflation of traded and non-traded goods of any economy. It is surprisingly so, regardless that full-price flexibility is both currently assumed and currently argued in economics.

As in other countries, the (recently) independent central bank in Colombia, has a price-targeting monetary policy. In this environment, the central bank has been using some indicators of underlying or core inflation which, apparently, have the virtue of being a better guide for monetary policy than inflation measured as the variation of total CPI, given that the latter is affected by different kind of shocks. In contrast, core inflation indicators can isolate the demand (monetary supply) factors, to yield a measure of inflation not affected by idiosyncratic supply shocks (for this debate see Eckstein, 1981; Parkin, 1984; Bryan and Cecchetti, 1994; Quah and Vahey, 1995; and, Melo and Hamann, 1998). To understand the concept of underlying inflation as a guide for setting the money supply, let us take as an hypothetical example an economy where the guide is the variation of total CPI. In this case, bad weather events would increase prices of some goods of the consumer

[1] *Keynes (1936) and Mitchell (1927) are references on asymmetries in this context.*

basket due to scarcity, so that for reaching the target a tighter monetary policy will result. In other country, where information is taken from underlying inflation indicators, the stance of policy will be unaffected for that kind of supply shocks.

One measure of underlying inflation can be obtained in a number of ways (see also Melo et al., 1997). For example, by eliminating, from the total CPI, those components of higher volatility, such as *primary food prices*, sensitive to weather and transport phenomena and other components such as *public services* and *transport* whose prices are directly affected by (fiscal) government policies. Therefore, our core inflation indicator is supposed to show the effects of monetary policy on prices. Inflation of traded goods, clearly affected by exchange rate policy and international competition, is also tested for linearity. This price indicator is also supposed to be hedged against the aforementioned idiosyncratic supply shocks. Establishing a difference in terms of the data generating process of either indicator of inflation is important for having a description of their underlying dynamics better than that obtained from the ARMA representations. These models are able of generating only symmetric fluctuations as a result of random events.

Colombian inflation is quite a striking case since it is a current reference of what a moderately high inflation is, while during the eighties it was an example of a good inflationary performance in the Latin American context, where hyper-inflation was a commonplace to some of these economies. Inflation in Colombia has achieved between 18% and 32% during nineties. Reduction-inflation gradual programs undertaken by the authorities have been ineffective since no inflation target has been reached but one in 1997. This inflationary process has the characteristic of getting to moderately high levels rather quickly while lower levels are slower (and more difficult) to obtain. So, it seems that asymmetries are intrinsic to the Colombian inflationary process. The assumption we maintain in this work is that the only alternative of having a non-linear data generating process is that of a STAR model (see Teräsvirta, 1994; Granger and Teräsvirta, 1993). In other words, we assume that an asymmetric error process is not the source of any potential non-linearity. A STAR model allows that the acceleration of inflation rate alternates smoothly between two regimes. That is, smooth rather than abrupt changes are expected for Colombian inflationary process. This paper is aimed to obtain a description of the nonlinear dynamics of some inflation rates measures.

Apart from the present introduction, the remainder of this paper evolves as follows. The second section, is devoted to the explanation of the method of testing for linearities and the selection of the STAR model. In essence, this section shows the procedures of Teräsvirta (1994) and Granger and Teräsvirta (1993). The third section, presents data and an abridged discussion about the time series properties of the measures of inflation we test here. The fourth section, shows the results and discusses some dynamics of the extreme regimes of the models. The fifth section, presents some conclusions.

2. Testing linearities and model selection

The only alternative of having a non-linear representation of the data generating process of accelerating inflation rate that we consider is the smooth transition autoregressive model of order p [STAR(p)], which can be written as:

$$y_t = b_0 + \sum_{j=1}^{p} b_j y_{t-j} + (b_0^* + \sum_{j=1}^{p} b_j^* y_{t-j}) F(y_{t-d}) + e_t \qquad (1)$$

where y_t is stationary, F is a transition function bounded by zero and one (where F becomes heaviside), and e_t is an *i.i.d.* process with zero mean and finite variance. The main property of this model is the "smooth transition" between regimes instead of an sudden jump from one regimen to the other. Hence, we discard the threshold autoregressive (TAR) model[2], although, as we shall see below, the delay parameter d is selected as in the TAR modelling of Tsay (1989). Following Teräsvirta (1994)[3], the testing strategy is carried out on two transition functions: the *logistic* function:

$$F(y_{t-d}) = (1 + \exp\{-g\,(y_{t-d} - c)\})^{-1}, \qquad g > 0 \qquad (2)$$

which replaced into (1) yields the logistic STAR(p) model [LSTAR(p)], and the U-shaped *exponential* transition function:

$$F(y_{t-d}) = 1 - \exp(-g\,(y_{t-d} - c)^2), \qquad g > 0 \qquad (3)$$

[2] *See Tong (1990) and Priestley (1988).*
[3] *For a description of the method see also Teräsvirta and Anderson (1992), Granger and Teräsvirta (1993), Granger et al. (1993), Michael et al. (1997) and Arango (1998).*

which replaced in (1) yields the exponential STAR(p) model[4] [ESTAR(p)]. g represents the speed of the transition process.

The "heaviside" properties of the transition function F can be seen as follows. In (2) we can note that when $g \rightarrow \infty$ and $y_{t-d} > c$ then $F = 1$, but when $c \geq y_{t-d}$, $F = 0$, so that (1) becomes a TAR(p) model. When $g \rightarrow 0$, (1) becomes an AR(p) model. In (3) we can note that the ESTAR model becomes linear [AR(p)] both when $g \rightarrow 0$ and when $g \rightarrow \infty$. In either transition function, the variable y_{t-d} can generate monotonic changes in the parameters of (1) rather than discrete movements between regimes. The LSTAR model can describe asymmetric realisations. That is, in our particular case, this model can generate one type of dynamics for increasing accelerating inflation rate of an economy and another for reductions of such a variable. With the transition function (2) either in the upper ($F = 1$) or the lower regime ($F = 0$), expression (1) becomes a different linear AR(p) model. The ESTAR model implies that increases and reductions of accelerating inflation rate have similar dynamics. For this model, the outer regime ($F = 1$) corresponds to $y_{t-d} = \pm\infty$ and (3) is replaced in (1) to obtain a linear AR(p) model; the middle regime ($F = 0$) results when $y_{t-d} = c$, and (3) replaced into (1) yields a linear AR(p) model.

The strategy for building a STAR model involves the three steps. First, carry out the complete specification of a linear AR(p) model. The maximum value of the lag p has to be determined from the data if the economic theory is not explicit about it[5]. Second, test linearity for different values of the delay parameter d. If linearity is rejected for more than one value of d, choose the one for which the P-value of the test is the lowest. Testing the null H_o:$g = 0$ in (1) -with either (2) or (3)-, assuming that y_t is stationary and ergodic under H_o, is a non-standard testing problem since (1) is only identified under the alternative H_1:$g \neq 0$. To solve the problem, Terasvista (1994) followed firstly, the

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[4] *Data are generally used for distinguishing between LSTAR and ESTAR models since economic theory does not use to help for that. An exception can be found in Michael, et al., (1997).*

[5] *Michael, et al. (1997) use the partial autocorrelation function, but other techniques such as the information criteria, complemented with a portmanteau test for residual autocorrelation such as the Ljung-Box test, can be employed. If the true model is nonlinear, it is possible that the value selected for p is greater than the maximum in the nonlinear model. This could reduce the power of the test compared to the case where the maximum lag is known. Conversely, if the selected value for p is too low, the estimated AR(p) model could have autocorrelated residuals. In this case, the test is biased against rejecting the nonlinear model when the true model is linear.*

procedure suggested by Davies (1977) where an auxiliary regression, with the unidentified values kept fixed, is used to derive a Lagrange multiplier-type test that has an asymptotic c^2 distribution and, secondly, the approach of Luukkonen, Saikkonen and Teräsvirta (1988) in which (2) is replaced by its third-order Taylor approximation. Therefore, the problem is solved by estimating the artificial regression:

$$y_t = p_{00} + \sum_{j=1}^{p}(p_{0j}y_{t-j} + p_{1j}y_{t-j}y_{t-d} + p_{2j}y_{t-j}y_{t-d}^2 + p_{3j}y_{t-j}y_{t-d}^3) + e_t \qquad (4)$$

and then testing the null H_0: $p_{1j} = p_{2j} = p_{3j} = 0$, (*j =1,...,p*), against the alternative that H_0 is not valid. In practice, the Lagrange multiplier-type test of linearity is replaced by an *F*-test in order to improve the size and power of the test.

Third, consider the value of *d* as given and use a sequence of tests nested in (4) to choose between ESTAR and LSTAR models. Such a sequence is:

$$H_{03} : p_{3j} = 0, \qquad j=1,..., p. \qquad (5)$$

$$H_{02} : p_{2j} = 0 | \; p_{3j} = 0, \qquad j=1,..., p. \qquad (6)$$

$$H_{01} : p_{1j} = 0 | \; p_{2j} = p_{3j} = 0, \; j=1,..., p. \qquad (7)$$

and is based on the relationship between the parameters in (4) and (1) with either (2) or (3). For the ESTAR model $p_{3j} = 0, j = 1,...., p$, but $p_{2j} = 0$ for at least one *j* if $b_j^* \neq 0$. For the LSTAR model $p_{1j} \neq 0$ for at least one *j* if $b_j^* \neq 0$. If H_{03} is rejected, a LSTAR model is selected. If H_{03} is accepted and H_{02} is rejected then an ESTAR model is selected. If H_{03} and H_{02} are accepted but H_{01} is rejected a LSTAR model is selected. No clear-cut conclusion is obtained when H_{02} and H_{01} are rejected. In this case we test:

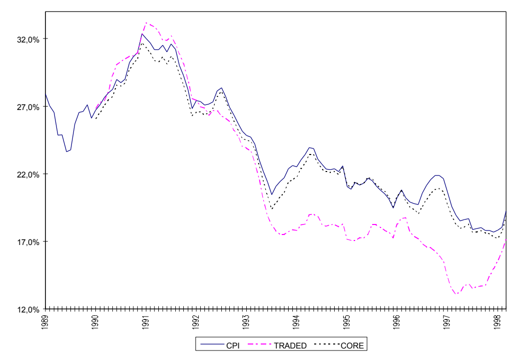
$$H'_{02} : p_{2j} = 0 \; | \; p_{1j} = p_{3j} = 0, \qquad j=1,..., p \qquad (8)$$

however, if H_{02} is rejected, then H'_{02} should be rejected even more strongly. In any case, the decision is based on whether H_{03}, H_{02} or H_{01} is rejected more strongly. Teräsvirta (1994) found that the selection procedure works very well when the true model is LSTAR or ESTAR; in the latter case the observations do not have to be symmetrically distributed around *c*. The procedure finds it difficult to distinguish between the two types of models when only a small number of observations are located at one of the tails of the transition function.

3. Data and time series properties inflation measures

Measures of inflation are usually obtained as a percentage change either by taking the difference of a logged price index (total CPI, CPI less some components, CPI of traded goods, etc.) at two different moments of time or as the ratio of the difference of a price index at two different moments to the same price index at the initial time. Under some conditions these two procedures can be approximated each other, although for this work, given the level of Colombian CPI, we use the second way. Either transformation implies a first linearization of the series which is required for increasing efficiency of parameter estimation and to facilitate the model interpretation.

Figure 1. Behaviour of Some Inflation Measures



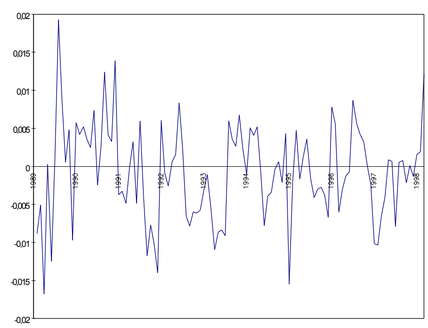
As we pointed out in the introduction, *price targeting* makes the central bank to implement some measures of inflation independent of supply shocks in order to improve the intuition about the underlying dynamics of inflationary process. This information is necessary for monetary policy making based on the "true" evolution of prices. Figure 1, shows the evolution of the inflation measures used in this work: inflation as annual variation of total CPI (CPI), inflation as annual variation of CPI without primary food, public services and transport (CORE) and inflation as annual variation of CPI of traded goods (TRADED)[6]. It is evident that CPI and CORE have had a closer behaviour each

[6] *Source: DANE for raw data. Calculations from Banco de la República (SGEE). For traded goods inflation, SGEE uses the arrangement of Departamento Nacional de Planeación (SITOD).*

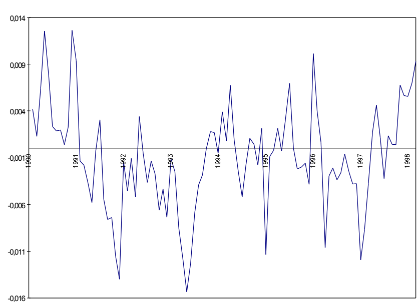
other for the span while after 1993 TRADED has been below them, as a result of real exchange rate appreciation undergone by this economy from that period on.

Since the approach outlined in the last section requires stationary variables, we test for unit roots on the three measures of inflation: CPI, CORE and TRADED. All of them were found to be I(1) processes both under ADF and KPSS (Kwiatkowski, et al., 1992) procedures. However, in this search for (non) linear realisations, we also use the Rank ADF as a third test (see Granger and Hallman, 1991), finding results consistent with those of ADF and KPSS methods. Accordingly, since stationarity is needed, we use the first difference of the three measures of inflation (Figure 2, panels a-c). Thus, we shall refer to accelerating inflation rate rather than to inflation rate.

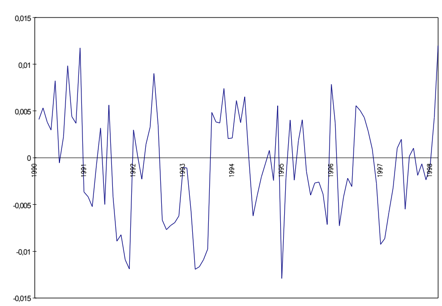
Figure 2.



a. First Difference of CPI Inflation



b. First Difference of Traded Goods Inflation



c. First Difference of Core Inflation

4. Results and analysis of dynamics

Following the procedure outlined in section three, we test for linearity in total, core and traded goods annual accelerating inflation rates for monthly data between 1989:2 (1990:2) and 1998:3.

Table 1. Minimum p-value of delay parameter and (non)linear model for CPI, core, and traded goods accelerating inflation rates.

Variable	*Maximum Lag**	*Minimum p-value over 1£ d £ 5*	*Selected delay*	*Type of model*
CPIAIR (1989:2 – 1998:3)	4	0.016	4	LSTAR
CAIR (1990:2 – 1998:3)	4	0.031	1	ESTAR
TGAIR (1990:2 – 1998:3)				LINEAR

** Selected on a white noise residual basis by using the Ljung-Box criterion.*

According to the results in table 1, the null of linearity could be rejected for CPI (total) accelerating inflation rate (hereafter CPIAIR) and core accelerating inflation rate (CAIR), whereas it was not rejected for traded goods accelerating inflation rate (TGAIR). Thus, we will not longer worry about this variable. Both the LSTAR and the ESTAR models are of order four while the delay parameter of each is 4 and 1, respectively. The LSTAR model we have estimated for CPIAIR, by using nonlinear least squares is:

$$y_t = \underset{(0.07)}{-1.211}y_{t-2} \underset{(0.05)}{-0.180}y_{t-4} + (\underset{(0.00)}{0.347}\,y_{t-1} + \underset{(0.03)}{1.446}y_{t-2})*(1+\exp\{\underset{(0.45)}{-4.745}(y_{t-4} + \underset{(0.00)}{0.012})/\hat{\sigma}_y\})^{-1} + \hat{u}_t$$

$$s = 0.0056,\ DW = 1.94,\ sk = -0.12,\ ek = 0.25,\ JB = 0.57\,(0.749),\ s/s_{AR} = 0.981$$

where $\hat{u}_t$ are the errors, $\hat{\sigma}_y$ is the standard deviation of CPIAIR ($\hat{\sigma}_y$=0.0063089), the numbers in parenthesis correspond to the *p*-values of the estimates, *s* is the standard deviation of the estimate, *DW* is the Durbin-Watson statistic, *sk* is skewness, *ek* is excess kurtosis, *JB* statistic is the Jarque-Bera statistic of normality accompanied with the *p*-value in parenthesis and, s_{AR} is the standard error estimate of the AR(4) model. The ratio between the residuals standard deviation of the AR and the LSTAR models (s / s_{AR}) is slightly less than unity (=0.98) which means that the latter marginally outperforms the former. In addition, *JB* fails to reject the null of normality of the residuals. There is evidence of negative skewness and positive excess kurtosis.

The estimated value for *c*, $\hat{c}$= -1.2%, shows the intermediate point between increasing and decreasing inflation. This interpretation is direct from the fact that when

y_{t-4}=-1.2%, then $\hat{F} = 1/2$. The estimated value of g, $\hat{g} = (4.7448/\hat{s}_y)$, suggests a quick transition from one regime to the other to the extent that it could mimic a TAR model. The high standard error of $\hat{g}$ could show that accurate estimation is difficult when y_{t-4} is very close to *c* and *F* increases rapidly[7]. An accurate estimation of g, requires that many observations (of *y*) are in the neighbourhood of *c*, which does not seem to be the case according to Figure 2a; however, $\hat{c}$ is within the range of $\{y_t\}$, which is a symptom of goodness of the model. The estimated delay parameter, $\hat{d}$=4, indicates that some months are needed for having a faster negative accelerating inflation rate after a peak has been reached.

The difficulty to interpret the other estimates can be overcome by analysing the limit values that describe the local dynamics of high ($F = 1$) and low ($F = 0$) accelerating inflation rate. For doing so, we use the roots of the LSTAR model which can be obtained as usual from:

$$z^p - \sum_{j=1}^{p} (\hat{b}_j + \hat{b}_j^* F) z^{p-j} = 0 \qquad (9)$$

for $F = 0, 1$ (Table 2). Figure 3, shows the estimated transition function of the LSTAR model of CPIAIR.

In the upper regime it can be seen that the process is convergent with modulus 0.71 and a period of 12.2 months while in the lower regime there is an explosive complex pair with (an almost hyperbolic) modulus 1.02 and a period of 4 months. The dynamic properties depicted by the LSTAR(4) model means that if the dynamics starts close to the lower regime, the negative accelerating inflation rate converts to a positive one too easily while the situation is not the same when the initial point is at the upper regime. However, if this was the case, inflation will reduce through any shock of negative sign (a good weather phenomenon, for instance) since this is the only way in which the variable can go back from the upper to the lower regime otherwise it will

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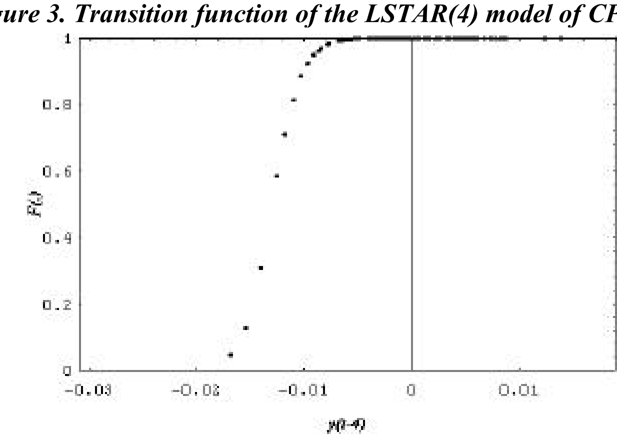
[7] *See Teräsvirta and Anderson (1992) about this interpretation. This is the result of joint estimation of the two parameters in F. See also Haggan and Ozaki(1981).*

remain there[8]. Notice that the asymmetry of this model is mirrored by movements of the accelerating rate mainly within the positive side.

Table 2. Characterisation of extreme regimes polynomials and dominant roots

Variable	*Regime*	*Roots*	*Modulus*	*Period*
CPIAIR	Upper (F=1)	$0.62 \pm 0.35i$	0.71	12.2
	Lower (F=0)	$0.00 \pm 1.01i$	1.02	4.0
CAIR	Outer (F=1)	0.69±0.51i	0.86	9.95
	Middle (F=0)	1.10	1.10	

Figure 3. Transition function of the LSTAR(4) model of CPIAIR

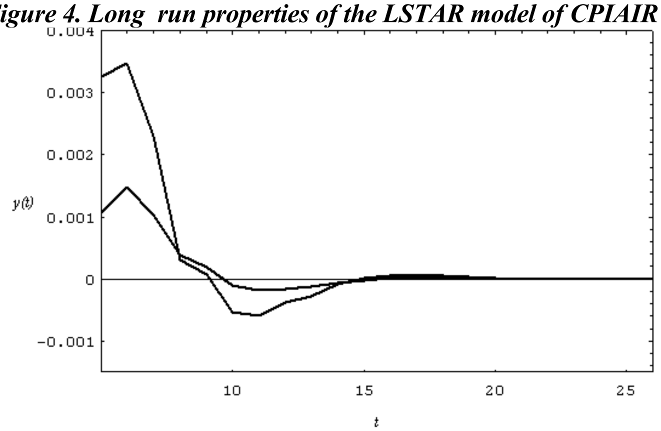


Finally, the long run properties of the model can be analysed by taken a set of initial values to observe what happen to the artificial process behaviour when there is a change of initial conditions. It can be seen in Figure 4 that the process converges to a stable stationary point as time evolves. This lack of sensitive dependence to initial conditions is an evidence against a strange attractor for CPIAIR process: the *butterfly effect* that we could capture by changing the initial values is a property of chaotic realisations.

The estimated ESTAR model outperforms the estimated AR model since the residuals standard deviation of the former are less than those of the latter (s / s_{AR} =0.96). Based on the *JB* statistic, the null of normality of the residuals is not rejected at a suitable level. There is evidence of negative skewness and positive excess kurtosis.

[8] *In other words, accelerating inflation moves rather quick from faster negative rates to slower ones, but there is no way within the intrinsic dynamics to explain how accelerating inflation can return from this regime to faster negative rates. Only exogenous positive shocks could produce such a shift.*

Figure 4. Long run properties of the LSTAR model of CPIAIR



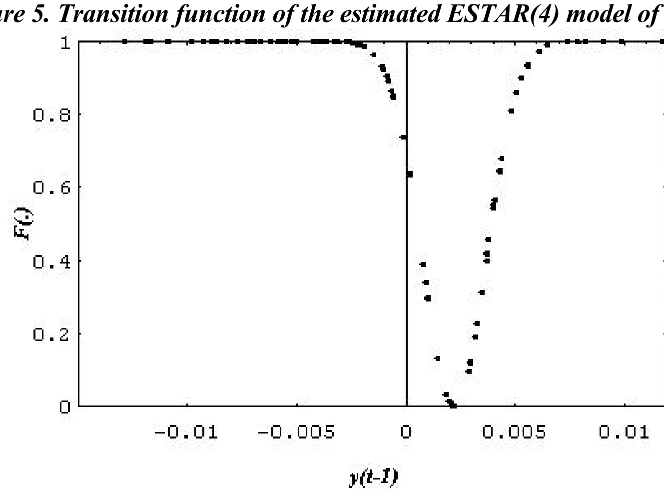
The ESTAR model estimated for CAIR, by using non-linear least squares is:

$$y_t = 0.554y_{t-1} + 0.679y_{t-3} + (-0.714y_{t-3} - 0.308y_{t-4}) * (1 - \exp\{-1{,}352.83(y_{t-1} - 0.002)^2 / \hat{s}_y\}) + \hat{u}_t$$

(0.000) (0.017) (0.02) (0.009) (0.187) (0.000)

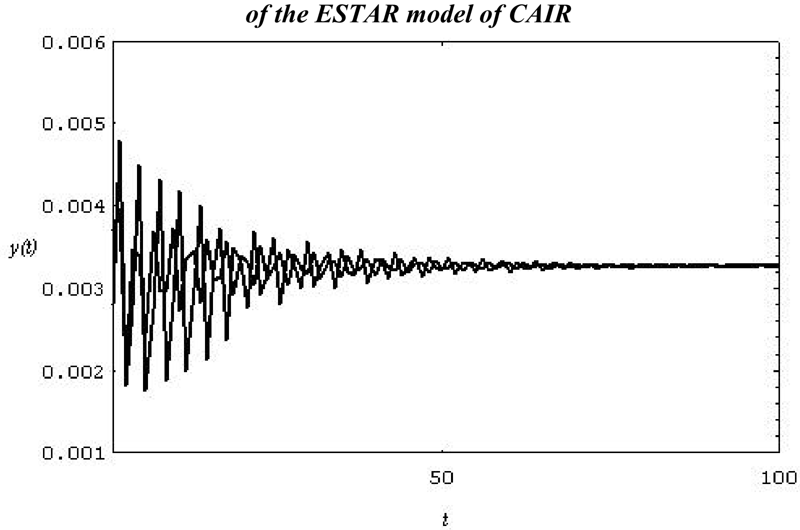
$s = 0.0047$ $DW = 1.84$, $sk = -0.196$, $ek = 0.856$, $JB = 3.479\,(0.176)$, $s/s_{AR} = 0.943$, $\hat{s}_y = 0.005$

Figure 5. Transition function of the estimated ESTAR(4) model of CAIR



The estimated model is attractive in a number of respects. First, it is noticeable that by eliminating primary food, public services and transport prices, from the CPI, the asymmetry is ruled out from the nonlinear behaviour of accelerating inflation rate. That is, by trimming off the CPI, we shift from the LSTAR representation of CPIAIR to a ESTAR model for CAIR. In other words, the so-called effects of monetary policy on the nonlinear behaviour of this accelerating inflation rate are symmetric. Second, the estimated speed for the movement from one extreme regime to the other $\hat{g} = 1{,}352.83 / \hat{s}_y$. is very much quicker than in the LSTAR case. However, the estimate of the threshold value (the limit regime) is closer to zero[9] ($\hat{c}$=0.002) and the estimated delay parameter is one ($\hat{d} = 1$) (Figure 5). This can be associated to cycles of period less than those predicted by the LSTAR model of CPIAIR (see table 2), which is the case. Third, in the outer regime the process described by the ESTAR model is convergent with a modulus lying in the unit circle (0.86) with a period of 10.3 months. In the middle regime, the process has a pair complex roots with modulus 1.03 and a period of 3.5. Hence, the accelerating inflation can depart from nearly zero rates rather easily, though, for going back to this regime a stochastic shock is needed. The symmetric property of the ESTAR model is observed in the fact that both positive and negative rates can be reached in the outer regime of the core accelerating inflation given the instability of the middle regime of this process. Thus, in the case that shock prices throw CAIR to the negative side of the outer regime and subsequent shocks can be isolated from the trimmed CPI evolution, core inflation will show, as a result, a steady reduction given that the variable that is supposed to drive this indicator (money supply) supports this behaviour.

Figure 6. Sensitive dependence to initial conditions of the ESTAR model of CAIR



Finally, the model does not present any sensitive dependence to initial conditions as we can see in Figure 6, although a clear cyclical pattern arises.

5. Conclusions

[9] *It can be seen in figure 2c, that there are many observations of CAIR in both tails of the exponential function, which is typical for ESTAR models*

Smooth transition autoregressive (STAR) nonlinearity has been chosen as the only alternative to linear behaviour of three different accelerating inflation rates. However, only two of them were found to be nonlinear processes: the accelerating inflation rate computed on CPI basis (CPIAIR) and the core accelerating inflation rate computed by suppressing foods, public services and transport prices from CPI (CAIR), which is one of the measures used by central bank as an indicator of the performance of the monetary policy with respect to prices. The type of nonlinearity is different since an asymmetric model (LSTAR) was estimated to the former and a symmetric model (ESTAR) to the latter. No evidence of nonlinear STAR-type behaviour were found for the accelerating inflation rate process of traded goods. The results suggest that for shifting CPIAIR from the upper to the lower extreme regime, shocks of negative sign in either food, public services or transport prices are needed. Otherwise, it is pretty easy to go from the lower to the upper regime given the explosive local properties of that regime. In the case of CAIR, both positive and negative values can be obtained given the instability of the middle regime. In the case that shock prices impulse CAIR to the negative side of the outer regime and subsequent shocks can be neutralized from the trimmed CPI evolution, core inflation could show a reduction given that money supply supports this behaviour.

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