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Threshold Autoregressive Model of Exchange Rate Pass through Effect: The Case of Croatia

SVEUČILIŠTE U
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Abstract

In this paper exchange rate pass-through effect in Croatia is estimated with nonlinear (asymmetric) threshold autoregressive model (TAR). In total 12285 regressions is estimated and a strong case of nonlinearity with single threshold is proven. According to our estimation there is a threshold at 2.69% of monthly change of nominal exchange rate of German mark (Euro) and the way in which nominal exchange rate affects inflation is asymmetric around it. Below the threshold, effect of change in nominal exchange rate on inflation is statistically insignificant and above the threshold the effect is strong and significant.

Keywords
threshold autoregressive model, pass-through effect, exchange rate, inflation, nonlinear econometrics

JEL classification
E31, E58, F31

1. Introduction

The discovery of nonlinear dynamical behavior in economic and financial time series is the most exciting development in applied econometrics over the past decade. This papers aims to introduce nonlinear econometrics to the discussion on the one of the most popular issues of macroeconomic policy design in Croatian economy.

Threshold autoregression model is used in estimation of pass-through effect, as one of the most confronted theories in the last decade of Croatian economy. In the first part of paper the exchange rate pass-through theory is briefly explained and several contemporary research of the theory is surveyed. In the second part of the paper data series used in this paper are analyzed. In the third part of paper, methodology of estimation of threshold autoregressive model is presented. In the last part, empirical findings together with limitations, implications and recommendations are presented.

2. Exchange rate Pass-through (ERPT) effect

The strength of the impact of the exchange rate changes on the domestic prices has several important implications to thinking of the role of the exchange rate in macroeconomic policy design. According to the theory, if the degree of pass-through is high, the exchange rate does not have much impact on the trade balance. On the other hand, if the degree of pass-through is low, the exchange rate changes will change the relative prices of tradables and non-tradables, so that the adjustment in trade balances will be relatively prompt. For example, imported goods become more expensive, if pass-through is low, so that expenditure switching from imports to domestic goods will occur and external balances will be corrected in several months (Ito and Sato 2006, pp. 3).

Besides relative prices, important aspect is the interaction between the exchange rate and domestic prices including both tradables and non-tradables. Suppose that a country is experiencing trade deficits and the exchange rate depreciates, then export competitiveness is strengthened, resulting in improvement in external balances. However, if domestic prices in general respond to the nominal exchange rate depreciation one-to-one—that is, pass-through not only to import prices but to CPI in general—then any export competitiveness from nominal depreciation would be cancelled out with zero effect on trade balance. A combination of nominal depreciation and high inflation leaves the export competitiveness unchanged, while corporations and financial institutions that had net foreign-currency liabilities become burdened by larger real debts and nonperforming loans (Ito and Sato 2006, pp. 4.).

Empirical studies have shown that movements in the exchange rate and prices do not go one to one in the short to medium run. In his seminal paper, Dornbusch (1987) justifies incomplete pass-through as arising from imperfect competition firms that operate in a market and adjust their mark-up in response to an exchange rate shock. Burstein et al. (2003) emphasize the role of non-traded domestic inputs in the chain of distribution of tradable goods. Another line of reasoning stresses more the role that monetary and fiscal authorities play, by partly offsetting the impact of changes in the exchange rate on prices (Gagnon and Ihrig, 2004; Ito and Sato 2006). Devereux and Engel (2001) and Bacchetta and van Wincoop (2003) explore instead the role of local currency pricing in reducing the degree of ERPT.

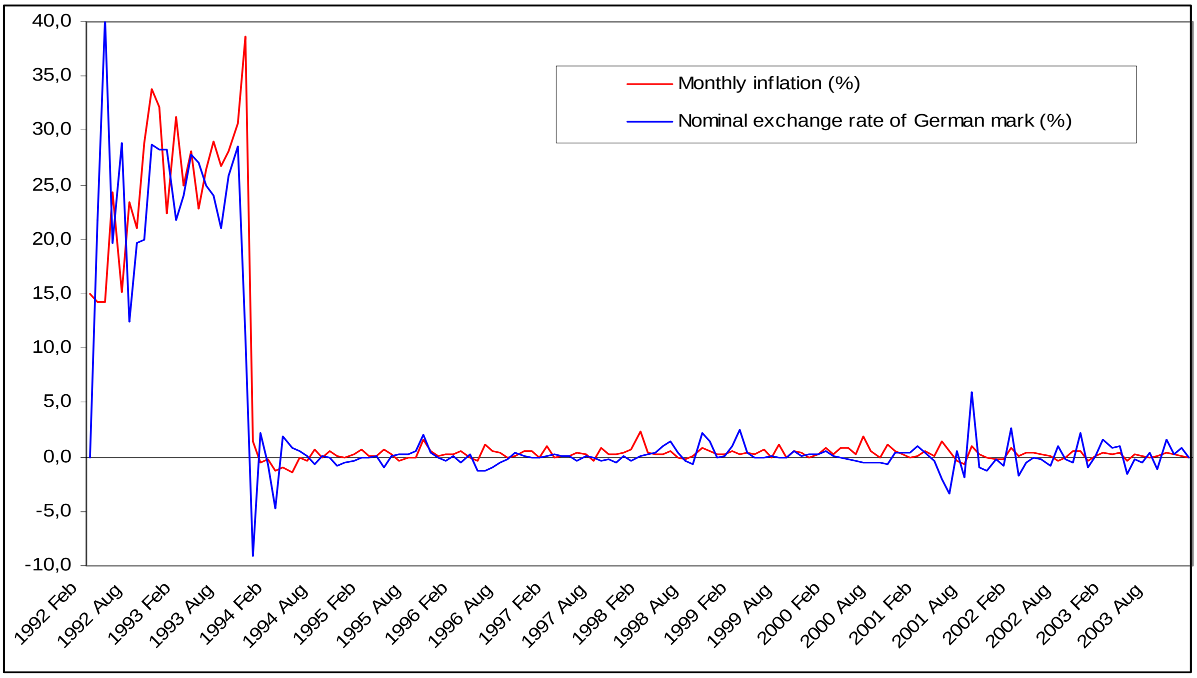
The body of evidence on ERPT effect is constantly growing. Zorzi, Hahn and Sanchez (2007, pp. 6.) even divide empirical research on the ERPT effect on the studies conducted for the case of developed countries (Anderton 2003; Campa and Goldberg 2004; Campa et al. 2005; Gagnon and Ihrig 2004; Hahn 2003; Ihrig et al. 2006 and McCarthy 2000) and studies conducted for the case of developing countries (Ito and Sato 2006; Choudhri and Hakura 2006; Frankel et al. 2005; Coricelli, Jazbec and Masten 2004; and Mihaljek and Klau 2001).

In Croatia, the ERPT effect has been a central question of almost all debates on the possible shifts in the macroeconomic policy design since the stabilization process. Almost all critiques of post-stabilization macroeconomic policy emphasized growth oriented exchange rate policies and simply assumed or even ignored strength of ERPT effect in Croatia (Zdunic 2003; 2004a; 2004b; Nikic 2004; Zdunic and Grgic 1995; Grgic and Zdunic 1999). On the other side, majority of advocates of present economic policy simply assumed that stability of nominal exchange rate is crucial factor of price stability even in the short run (Babić 2006; Sonje 2000; Nestic 2000; Sonje and Vujcic 2000; Sonje and Skreb 1997; Anusic et. al. 1995). Up until now, with few exceptions (Botric and Cota 2006) and some indirect "back of the envelope" estimates of the effect (Druzic, Tica, Mamic 2006) no one thoroughly researched ERPT effect in Croatia.

3. Data description

In this paper data series for monthly retail price index and monthly (end of the period) exchange rate of German mark is used in order to estimate ERPT effect in Croatia (HNB 2007). Due to several reasons data span between February 1992 and December 2003 is chosen. In January 1992, Croatia became an independent country so it seamed reasonable to start at that point. Furthermore, since 323% devaluation in January 1992 is quite a big outlier in the data set, first observation is simply ignored in further analysis. The explanation for such an early end of the time series is the fact that in January 1998 Statistical Office of Croatia replaced retail price index by consumer price index and in December 2003 retail price index ceased to exist.

Figure: 1 Monthly inflation and end of period monthly change in nominal exchange rate of German mark



4. Methodology

It is a well known fact that during pre stabilization period, domestic prices in general have responded to the nominal exchange rate depreciation one-to-one (Anušić et. al. 1995; Sonje and Skreb 1997; Druzic, Tica, Mamic 2006) and that after the successful stabilization process nominal exchange rate moved between -9 and 6% monthly without any obvious effect on price levels. The fact that strength of the ERPT might be affected by the level of depreciation/inflation calls for application of nonlinear econometrical approach to estimating ERPT effect in Croatia.

Behavior of inflation and nominal exchange rate implies that there might be a level of devaluation that acts as a threshold between to regimes of ERPT effect in Croatia. According to the model, bellow hypothetical threshold nominal exchange rate do not affect prices and above threshold prices respond one-to-one to the nominal exchange rate depreciation. Such a regime switching model might be estimated with threshold autoregressive model:

$$\pi_t = I_{t-d}\left[\alpha_{10} + \sum_{i=0}^{k}\alpha_{1i}e_{t-i}\right] + (1 - I_{t-d})\left[\alpha_{20} + \sum_{i=0}^{k}\alpha_{2i}e_{t-i}\right]$$
$$I_{t-d} = 1\_if\_e_{t-d} \geq \tau$$
$$I_{t-d} = 0\_if\_e_{t-d} < \tau \qquad (1)$$

According to the equation 1, inflation π is a function of change in nominal exchange rate e. Time lags of independent variable are represented by *i*, and time lags of threshold variable are represented by *d*. Variable I_{t-d} is dummy variable, where I_{t-d}=1 if change in nominal exchange rate e_{t-d} is equal or larger than a threshold τ and I_{t-d}=0 if change in nominal exchange rate e_{t-d} is smaller than a threshold τ.

Obviously in order to estimate the model it is necessary to choose a threshold. Enders (2004, p. 413.) and Chan (1993) offer quite intuitive three step methodology for threshold selection process:
1. First step is to sort the threshold variable from lowest to the highest value. In our sample threshold variable is a change in nominal exchange rate of German mark.
2. Second step is to estimate a TAR model in the form of equation 1 using successive values of nominal exchange rate changes as thresholds. After estimation sum of squared residuals are saved for every observation (threshold) of nominal exchange rate change. Only middle 70% of sorted thresholds (observations) should be used.
3. Third step is to create a graph of successive values of sum of squared residuals. If there is a single threshold, there should be a single trough in the graph. With respect to model selection criteria, according to Enders (2004, p. 413.) the model with lowest sum of square residuals and according to Shen and Hakes (1995, p. 363.) the model with highest t-ratio is the model that represents nonlinear data generating process most accurately.

It should be noted here that the sole assumption of threshold makes residual unit root test or cointegration tests between two variables questionable. If there is a threshold, variables are not cointegrated and also their stationarity can be proven below or/and above the threshold, but not with linear unit root test. For example in our case, if there is threshold that divides Croatian economy into two regimes, inflation and changes of nominal exchange rate are going to be cointegrated above the threshold (large changes of nominal exchange rate) and residuals of regression will have stochastic trend below the threshold. Combined in a single regression, residuals power to reject null hypothesis of unit root will depend on the number of observations above and bellow of threshold (Enders 2004, p. 429-433.).

5. Empirical results

Equation 1 was estimated for all successive values of thresholds with both a dependent variable lag length *i* and a threshold lag length *d* going from 0 to 12. In total, 91 TAR models combining various *i*-s and *d*-s have been estimated for each of successive values of threshold going from 143 observations for *i*=0, 142 observations for *i*=1, 141 observations for *i*=1, … , and 131 observations for *i*=12.[1] In total, according to our methodology, 12285 regressions have been estimated.

Table 1 and Table 2 show the results. For each combination of dependent variable lag *i* and threshold lag *d*, only the threshold observation with smallest sum of squared residual is represented in the table. Due to the

[1] The threshold data series in our sample spans through 143 months starting in February 1992 and ending in December 2003. Each additional lag decreases the size of the sample and the number of possible thresholds.

amount of estimated data (12285 thresholds and SSRs), for each *i* and *d* combination, all thresholds with the exception of the threshold with minimum sum of squared residual have been omitted.

Table 1: Thresholds for the regression model with smallest sum of squared residuals for each combination of i and d lags.

i\d	0	1	2	3	4	5	6	7	8	9	10	11	12
0	11.13	0	0	0	0	0	0	0	0	0	0	0	0
1	11.13	19.632	0	0	0	0	0	0	0	0	0	0	0
2	11.13	19.632	12.414	0	0	0	0	0	0	0	0	0	0
3	12.414	19.681	25.768	12.414	0	0	0	0	0	0	0	0	0
4	11.13	12.414	25.768	12.414	24.061	0	0	0	0	0	0	0	0
5	11.13	26.987	25.768	12.414	24.061	24.959	0	0	0	0	0	0	0
6	11.13	19.681	25.768	12.414	24.061	24.959	26.987	0	0	0	0	0	0
7	11.13	12.414	24.061	19.632	24.061	24.959	24.061	24.959	0	0	0	0	0
8	11.13	19.681	21.818	21.818	24.046	24.061	24.061	24.959	24.046	0	0	0	0
9	5.9102	19.681	19.681	21.818	21.818	24.046	24.046	24.061	24.061	24.046	0	0	0
10	5.9102	5.9102	19.681	21.041	21.041	21.041	21.818	21.041	24.046	21.818	24.046	0	0
11	2.4409	2.6927	5.9102	11.13	19.681	19.681	19.681	21.041	21.041	21.818	24.046	21.82	0
12	2.2291	2.2652	2.4409	**2.6927**	5.9102	11.13	12.414	19.632	19.681	19.681	21.041	21.82	21.82

Source: calculation by authors

Table 2 represents sum of squared residual for the presented thresholds in the table 1. As in the previous case, for each value of *i* and *d* only the models with smallest sum of squared residuals are reported, while other values are omitted.

Table 2: The minimum sum of squared residuals for each combination of *i* and *d*.

i\d	0	1	2	3	4	5	6	7	8	9	10	11	12
0	932.3	0	0	0	0	0	0	0	0	0	0	0	0
1	588.9	572.93	0	0	0	0	0	0	0	0	0	0	0
2	536.3	532.06	556.39	0	0	0	0	0	0	0	0	0	0
3	372.84	370.85	475.33	452.49	0	0	0	0	0	0	0	0	0
4	225.28	225.28	302.03	385.64	312.63	0	0	0	0	0	0	0	0
5	195.73	154.18	231.01	354.77	263.9	279.01	0	0	0	0	0	0	0
6	152.95	142.77	217.79	300.67	215.32	265.91	119.77	0	0	0	0	0	0
7	84.899	84.899	198.81	279.71	190.53	205.86	95.71	206.77	0	0	0	0	0
8	33.782	33.782	88.216	212.3	96.39	115.52	70.929	139.45	245.66	0	0	0	0
9	25.62	26.095	39.71	161.47	86.566	88.097	63.698	71.138	163.22	159.21	0	0	0
10	24.064	23.312	23.375	39.324	51.547	49.459	55.869	42.107	65.423	84.666	91.998	0	0
11	23.978	23.045	22.993	23	23	45.821	46.46	41.869	43.822	52.285	74.419	48.92	0
12	22.938	22.918	22.943	**22.396**	22.669	22.947	22.947	33.332	36.064	31.56	33.28	39.14	35.54

Source: calculation by authors

In the third step, due to a large number of estimated equations, only a 3D figure of successive values of sum of square residuals of dependant variables and thresholds as moving averages $\frac{\sum_{i=1}^{k} e_{t+i}}{k}$, for k=1,…,12 is presented (Figure 2, 3 and 4). In that way, instead of heaving 12 different figures for each threshold lag *d*, a moving average for all thresholds is shown on a single figure. Figures 1, 2 and 3 depict in 3D all estimated combinations of i, d and τ viewed from various angles. All figures quite clearly show that there is only **one trough** in the data, strongly indicating **presence of nonlinearity with a single threshold**. Due to a limited space and a large amount of estimated regression, figures for *d* going from 1 to 12 are omitted.

Figure: 2 Sum of squared residuals, thresholds and moving averages (right view)

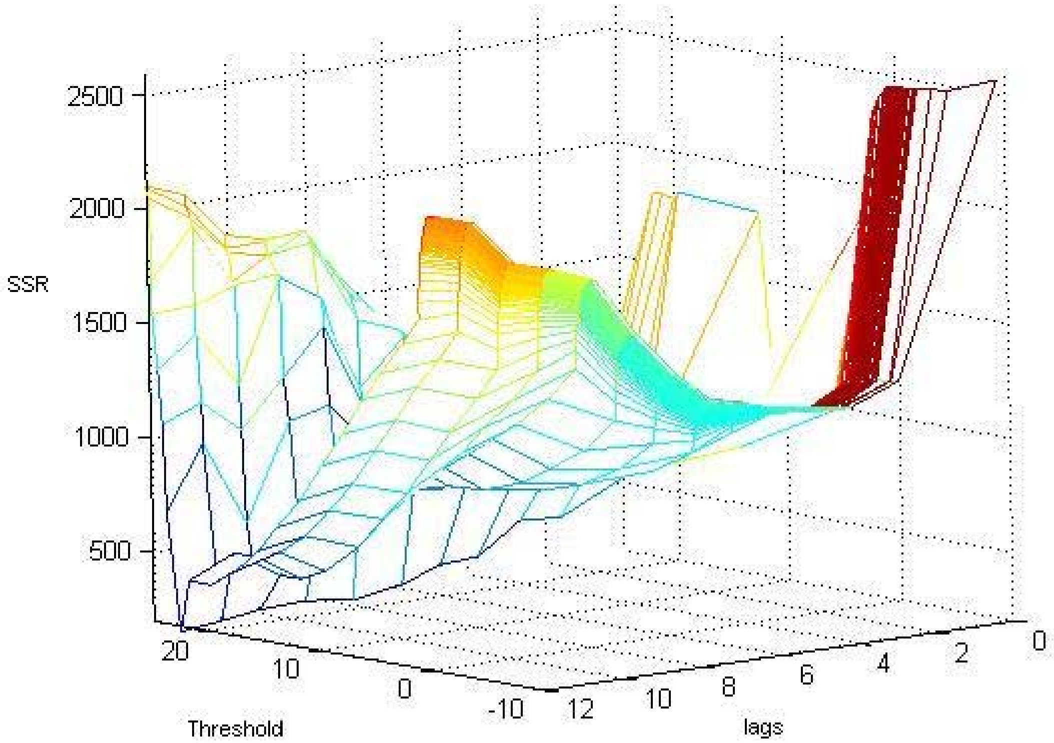


Figure: 3 Sum of squared residuals, thresholds and moving averages (right center)

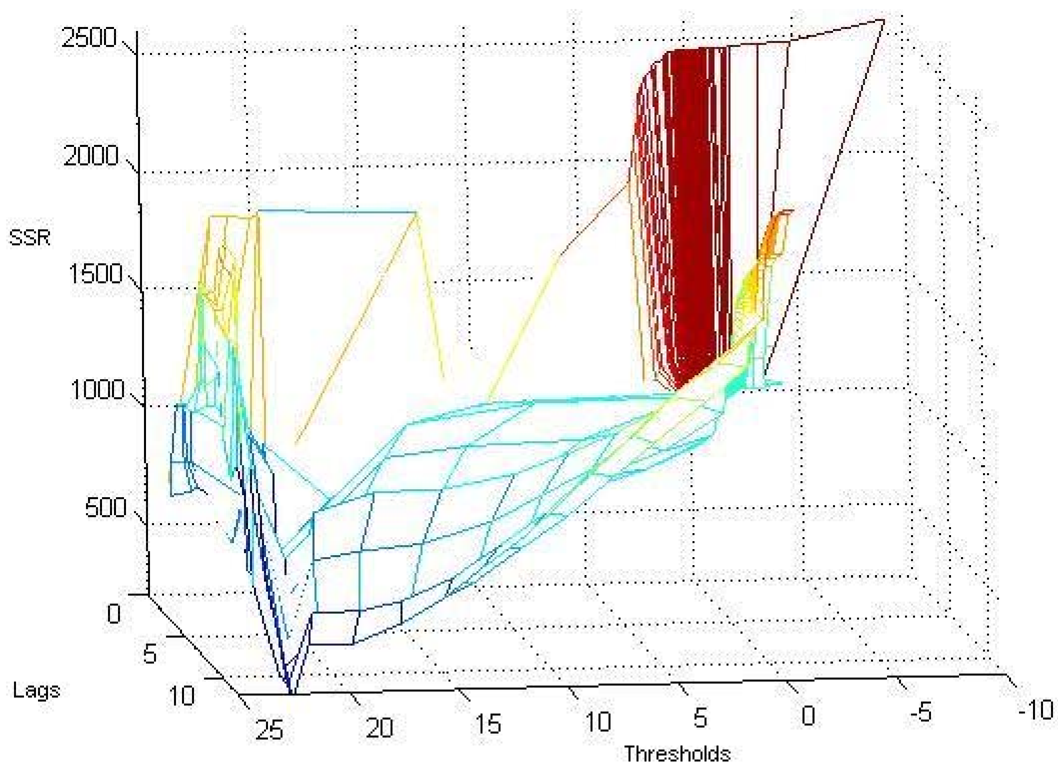
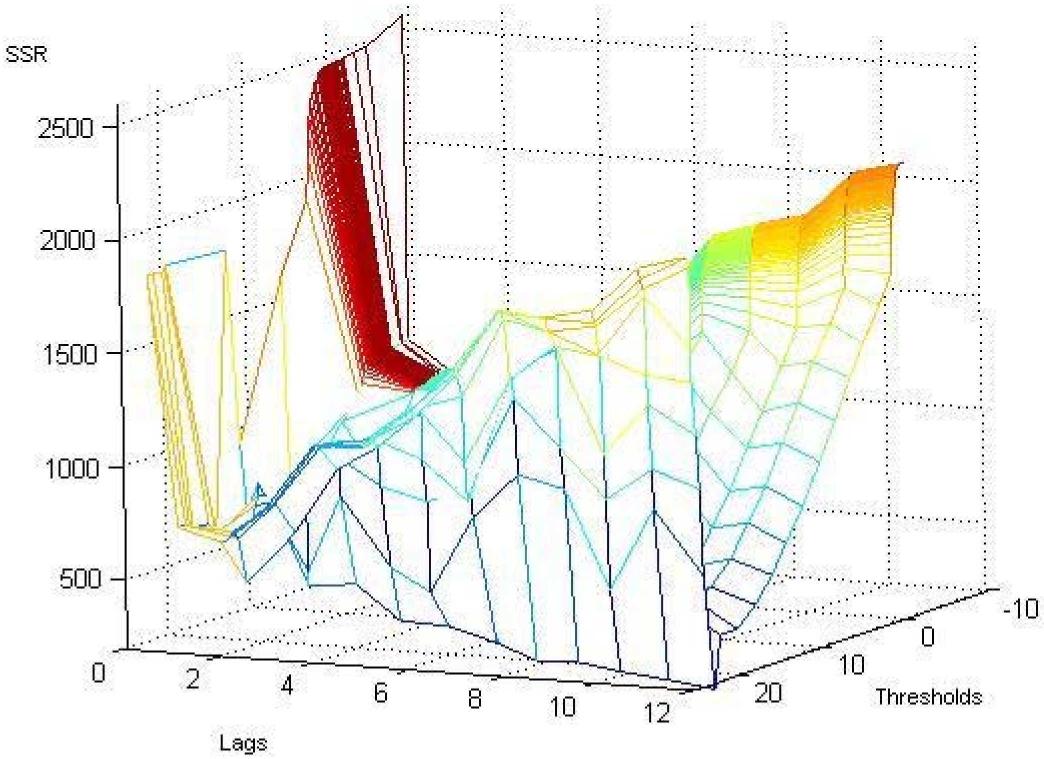


Figure: 4 Sum of squared residuals, thresholds and moving averages (left view)



After the existence of nonlinearity with single threshold has been proven, a model with smallest sum of squared residuals has been re-estimated in E-views. As Table 1 and 2 clearly indicates the regression model with dependent variable lag length i=12, threshold lag d=3 and threshold τ =2.6927 resulted with the smallest sum of squared residual compared to estimated 12284 regression models.

Table 3: E-views output for the model with smallest sum of square residual

Dependent Variable: P				
Method: Least Squares				
Date: 05/29/07 Time: 00:32				
Sample (adjusted): 1993M02 2003M12				
Included observations: 131 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
I(t-3)	-10.78030	2.201027	-4.897851	0.0000
Et-0* I(t-3)	2.519358	0.091264	27.60513	0.0000
Et-1* I(t-3)	-0.386550	0.077905	-4.961796	0.0000
Et-2* I(t-3)	0.291470	0.133915	2.176524	0.0318
E t-3* I(t-3)	-1.002622	0.212600	-4.716003	0.0000
E t-4* I(t-3)	-2.771138	0.249764	-11.09504	0.0000
E t-5* I(t-3)	-0.955162	0.190998	-5.000914	0.0000
E t-6* I(t-3)	-5.505414	0.303770	-18.12360	0.0000
E t-7* I(t-3)	4.022975	0.188241	21.37135	0.0000
E t-8* I(t-3)	2.415460	0.201131	12.00940	0.0000
E t-9* I(t-3)	-1.440252	0.154146	-9.343409	0.0000
E t-10* I(t-3)	1.794289	0.100106	17.92380	0.0000
E t-11* I(t-3)	2.129534	0.113475	18.76661	0.0000
E t-12* I(t-3)	1.251093	0.063435	19.72257	0.0000
1-I(t-3)	0.323850	0.045134	7.175386	0.0000
Et-0* 1-I(t-3)	0.059954	0.042588	1.407747	0.1622
Et-1* 1-I(t-3)	-0.036815	0.041926	-0.878107	0.3819
Et-2* 1-I(t-3)	0.009748	0.041870	0.232816	0.8164
E t-3* 1-I(t-3)	0.022078	0.046493	0.474868	0.6359
E t-4* 1-I(t-3)	-0.004373	0.031104	-0.140581	0.8885
E t-5* 1-I(t-3)	0.026117	0.023178	1.126801	0.2624
E t-6* 1-I(t-3)	-0.044109	0.022008	-2.004216	0.0477
E t-7* 1-I(t-3)	0.000153	0.021720	0.007053	0.9944
E t-8* 1-I(t-3)	-0.028002	0.022768	-1.229870	0.2215
E t-9* 1-I(t-3)	0.008256	0.021912	0.376781	0.7071
E t-10* 1-I(t-3)	-0.000465	0.020704	-0.022459	0.9821
E t-11* 1-I(t-3)	-0.015464	0.020433	-0.756808	0.4509
E t-12* 1-I(t-3)	0.004897	0.014559	0.336354	0.7373
R-squared	0.996717	Mean dependent var		2.202290
Adjusted R-squared	0.995856	S.D. dependent var		7.243442
S.E. of regression	0.466300	Akaike info criterion		1.499037
Sum squared resid	**22.39585**	Schwarz criterion		2.113583
Log likelihood	-70.18689	Durbin-Watson stat		1.932283

Source: calculation by authors

Table 3 presents regression estimate for the 'i=12, d=3, τ =2.6927' model. It is more than obvious that all coefficients multiplied with I_{t-3} are statistically significant, while all the coefficients multiplied with 1- I_{t-3} are statistically insignificant at 5% (with exception of E_{t-6}*(1-I_{t-3})). In other words, lagged values of nominal exchange rate significantly affect inflation rate in period t if, and only if nominal depreciation in the period $t-3$ is equal or larger than 2.69% per month. If change of nominal exchange rate is lower, the effect of nominal exchange rate on inflation is not significant. Furthermore, it should be highlighted that d=3, or in other words if monthly devaluation exceeds threshold value, prices will be affected with three months delay.

6. Implications

Translated to the level of macroeconomic policy design findings of this research can be summed in a single sentence. In order to keep prices stable, depreciation/devaluation should never or at least never persistently exceed 2.69% monthly.

7. Limitations

There are several limitations to this research. At this point in time only 12285 regression forms have been estimated. The true generating process for the relationship between inflation and prices is obviously nonlinear, but it is still questionable does the equation presented in this paper represent the genuine data generating process for the pass-through effect in Croatia. More autoregressive terms, a moving average threshold or an intercept uninfluenced by threshold might improve the performance of the model. Another significant limitation is the difficult task of identifying the right form of the nonlinearity. In this research, we have simply assumed that pass-through process is TAR process, although it is possible that BL, LSTAR, ESTAR or M-TAR might perform much better.

8. Recommendations

Translated to the recommendation for future work, there are at least two ways in which future applied nonlinear econometric research on pass-through effect should proceed. This paper explores only limited number of regressions and only one form of nonlinear process. Estimation of other regression forms and alternative nonlinear models will definitively improve our understanding of pass-through effect in Croatia.

References

1. Anderton, R., 2003. "Extra-Euro Area Manufacturing Import Prices and Exchange Rate Pass-Through", *ECB Working Paper No. 219.*
2. Anušić, Z., 1995. et. al.: *A Road to Low Inflation, The Government of the Republic of Croatia*; Zagreb.
3. Babić, M., 2006. *Od dezinflacije u zaduženosti hrvatska privreda 1994-2004;* Binoza Press.
4. Bacchetta, P. and van Wincoop, E., 2003. "Why do Consumer Prices React Less than Import Prices to Exchange Rates?", *Journal of European Economic Association*, 1, 662-670.
5. Burstein, A., Neves, J. and Rebelo, S., 2003. "Distribution Costs and Real Exchange Rate Dynamics During Exchange-Rate-Based-Stabilizations", *Journal of Monetary Economics*, 50, 1189-1214.
6. Campa, J. and Goldberg, L., 2004. "Exchange Rate Pass-Through into Import Prices", *CEPR Discussion Paper No. 4391.*
7. Campa, J., Goldberg, L. and González-Mínguez, J., 2005. "Exchange Rate Pass-Through to Import Prices in the Euro Area", *Federal Reserve Bank of New York Staff Paper No. 219.*
8. Chan, K. S., 1993. "Consistency and Limiting Distribution of the Least Squares Estimator of a Threshold Autoregressive Model", *The Annals of Statistics*, 21, 520-33.
9. Choudhri, E. and Hakura, D., 2006. "Exchange Rate Pass-Through to Domestic Prices: Does the Inflationary Environment Matter?", *Journal of International Money and Finance*, 25, 614-639.
10. Coricelli, F., Jazbec, B., Masten, I., 2004. "Exchange Rate Policy and Inflation in Acceding Countries: The Role of Pass-through", *William Davidson Institute Working Papers Series 2004-674.*
11. Cota, B., Botrić, 2006. "Sources of Inflation in Transition Economy: The Case of Croatia", *Ekonomski pregled*, 12, 835.
12. Devereux, M, and Engel, C., 2001. "Endogenous Currency of Price Setting in a Dynamic Open Economy Model", *NBER Working Paper No. 8559.*
13. Dornbusch, R., 1987. "Exchange Rates and Prices", *American Economic Review*, 77, 93-106.
14. Frankel, J., Parsley, D. and Wei, S., 2005. "Slow Pass-Through Around the World: A New Import for Developing Countries", *NBER Working Paper No. 11199.*
15. Gagnon, J. and Ihrig, J., 2004. "Monetary Policy and Exchange Rate Pass-Through", *International Journal of Finance and Economics*, 9, 315-338.
16. Grgic, M. and Zdunic, S., 1999. "Exchange Rate and Protection Policy in Croatian Development Strategy", *Zagreb International Review of Economics and Business*, Zagreb, vol. 2, issue 1, p. 83-98.
17. Hahn, E., 2003. "Pass-Through of External Shocks to Euro Area Inflation", *European Central Bank Working Paper No. 243.*
18. McCarthy, J., 2000. "Pass-Through of Exchange Rates and Import Prices to Domestic Inflation in Some Industrialised Economies", *Federal Reserve Bank of New York Staff Report No. 111.*
19. Mihaljek, D. and Klau, M., 2001. "A Note on the Pass-Through from Exchange Rate and Foreign Price Changes to Inflation in Selected Emerging Market Economies", *BIS Papers*, 8, 69-81.

20. Nestić, D., 2000. "Visoka razina cijena u Hrvatskoj - Neki uzroci i posljedice", *HNB Povremene publikacije – istraživanja*, I, 2 ožujak.
21. Nikić, G., 2004. "Gospodarski aspekti pristupa Hrvatske Europskoj uniji - proteklih deset godina i deset godina ispred nas", *Ekonomski pregled*, 3-4, 197.
22. Šonje, V. i Vujčić, B., 2000. "Hrvatska u drugoj fazi tranzicije, 1994. – 1999", *HNB Povremene publikacije – istraživanja*, I, 4 lipanj.
23. Šonje, V., 2000. "Tečaj i proizvodnja nakon velike ekonomske krize i tijekom tranzicijskog razdoblja u Srednjoj Europi", *HNB Povremene publikacije – istraživanja*, I, 6 rujan.
24. Šonje, V., Škreb, M., 1997. "Exchange Rate and Prices in a Stabilization Program: The Case of Croatia", in M. Blejer i M. Škreb, eds., *Macroeconomic Stabilization in Transition Economies*, Zagreb, p. 212-233.
25. Zdunić, S., 2003. "Relativne cijene, tečaj i konkurentnost hrvatskoga gospodarstva - uz desetu godišnjicu Stabilizacijskog programa", *Ekonomski pregled*, 11-12, 859.
26. Zdunić, S., 2004. "Politika stabilizacije i razvoja u hrvatskoj 90-ih", *Ekonomski pregled*, 3-4, 256.
27. Zdunić, S., 2004. "Relativne cijene i izvori rasta - komparativna analiza", *Ekonomski pregled*, 11-12, 853.
28. Zdunić, S., Grgić, M., 1995. *Politika intervalutarnog tečaja i zaštite u strategiji razvitka hrvatskog gospodarstva*, Ekonomski institut Zagreb, Hrvatska gospodarska komora Zagreb, Zagreb.