Monetary policy, relative prices and inflation rate: an evaluation based on New Keynesian Phillips Curve for the U.S. economy

Tito Belchior Silva Moreira*
Department of economy, Catholic University of Brasilia, Brazil: tito@pos.ucb.br
Mario Jorge C. Mendonça
Department of economics, Institute for Applied Economic Research, Rio de Janeiro, Brazil: Mario.mendonca@ipea.gov.br
Adolfo Sachsida
Department of economics, Institute for Applied Economic Research, Brasília, Brazil: adolfo.sachsida@ipea.gov.br
Paulo Roberto Amorim Loureiro
Department of economics, University of Brasilia, Brasília, Brazil: pauloloureiro@unb.br

Abstract

This paper investigates the direct impact of monetary policy on variation to the relative prices and, in turn, the direct effect of the change in relative prices on the inflation rate considering the New Keynesian Phillips Curve (NKPC). Thus, we analyze the indirect impact of the change of Federal Funds Rate on the inflation rate through the change in relative prices. We use GMM with instrumental variables to estimate several systems of two equations for the U.S. economy based on quarterly time-series from 1975 to 2015. The empirical results show that a change of the Funds Rate has a direct effect on change in relative prices and that, in turn, affects indirectly the inflation rate, through the change in relative prices. Hence, change in the relative prices affects directly the inflation rate via NKPC. In this context, variations of relative prices can be interpreted as a transmission channel of monetary policy. Furthermore, there are empirical evidences that the change of relative prices Granger-cause the inflation rate.

Key words: Monetary policy, relative prices, inflation rate, NKPC, U.S. economy, GMM.
JEL Classification: B22, B31, E22, E31, E32, E42, E51, E52

(*) Corresponding author: SQN 308, Bloco A, Apto.101, Asa Norte, Brasilia-DF, Brazil, 70.747-010. E-mail: tito@pos.ucb.br and titoeco@yahoo.com.br

1. Introduction

Economists discuss the relationship between relative prices and general price level for decades. This issue is relevant because the quantitative theory of money (QTM) assumes that there is no relation between change in relative prices and change in general price level. It is a useful paradigm of economic theory because only real forces explain the relative prices and, hence, the variations in relative prices are not related with the quantity of money.

More precisely, the quantity theory of money states that changes in real variables such as real GDP, employment and technological shocks explain only changes in relative prices, while changes in the money supply explain only absolute price movements. This postulate is known as dichotomy between relative prices and general price level. This dichotomy means that, other things equal, such as, supply of money, velocity of money and level of output, changes induced by a real shock on the relative prices generate compensatory variations in other relative prices, in order that the absolute level of prices remain unchanged (Humphrey, 1997).

One the one hand, it is difficult to defend the postulate of the dichotomy between absolute prices and relative prices, because the net effect of changes in relative prices across the economy on the index of general prices, stemming from a real shock, should be null. This assumption of quantitative theory can be valid in the long run, however there is stickiness of prices in the short run and, therefore, it is expected that the effects of real shocks on relative prices and, consequently, the variability of relative prices resulting from real shocks affects the absolute level of prices. On the other hand, it becomes even more difficult to accept that monetary shocks do not affect the relative prices and, furthermore, if they affect, there is not effect of relative prices on the general price level considering an economy with stickiness of prices.

Rigidities may occur due to pressure from trade unions, employment contracts, etc., but also due to the nature of the goods. The prices of tradable goods are more volatile than the non-tradable goods. The price of services, for instance, tends to be more stable. In addition, a change in monetary policy does not affect all the prices of goods and services at the same time nor in the same intensity. In another perspective, a change in monetary policy does not affect all the prices of goods and services at the same time nor in the same intensity across the different sectors of the economy.

In this sense, it is reasonable assume that the monetary policy executed via change in the money supply or via change in basic interest rate affects one of the most important relative prices, i.e., the real wage. For example, if we assume that nominal wage is rigid in the short run and the prices of the goods and services rises due to an expansionist monetary policy, it means that the monetary policy affects the relative prices, because the workers' purchasing power decrease.

Ohanian, Stockman and Kilian (1995) show that monetary shocks affect the relative prices, based on hybrid model of an economy with many industries that produce different goods, in which have flexible prices, as well as sticky prices. The authors show that unexpected changes in the money supply change the relative price of the sticky-price good in terms of the flexible-price good, so the real effects of monetary disturbances differ across sectors. Moreover, they show that in the sticky-price model with demand-determined output, relative prices fluctuate in response to monetary and real shocks. The authors also stand out that any variability on the relative prices in this model is entirely due to the existence of price stickiness.

In this paper, we are interested in analyze at first, the effect of a demand shock on the relative prices, rather than the supply shock on relative prices. More specifically, we are interested in evaluate the effects of change in the basic nominal interest rate practiced by Federal Reserve on variation of relative prices. However, what kind of mechanism links the change in basic interest rate and relative prices in the same chain?

This link can be explained because a change in interest rate promoted by the Central Bank affects unequally the capital structure and the price of the different kind of markets. In this context, a variation in quantity of money in the economy generates the conditions to provoke changes in relative prices. Following this pattern, a change in the quantity of money can distort relative prices and, therefore, modify the signals emitted by prices. Here the return rates of the various combinations of capital are altered. This new arrangement of relative prices will be distinct from those generated by the fundamentals. In this sense, the new relative prices generate an increase in the profits of some companies at the expense of others firms (Hayek, 1933 and 1935).

Many studies have shown that the change in relative prices can improve our understanding of the inflation rate. One of approaches regarding this thematic, evaluates whether relative prices changes can help to clarify the Phillips Curve relationship between inflation and output or not (Vining and Elwertowski, 1976; Fischer, 1981; Domberger, 1987; Ball and Mankiw, 1994 and 1995; Roberts, 1995; Aoki, 2001; Çatik, Martin and Onder, 2011). Generally, changes in relative prices are used as proxy of supply shocks in Phillips curve equations, in order to model the short run output-inflation trade-off. Based on empirical literature, changes in the relative prices, such as food and energy, are commonly used as a measure related to shocks of supply, which shift the Phillips curve in the short-run. In the presence of price stickiness, these shocks can modify aggregate real product, as well as the general price level. Nevertheless, relative prices can be affected by several factors other rather than supply shocks, for example, elasticities of substitution between goods and demand shocks (Aoki, 2001).

Parks and Cutler (1983) standout that in 1970's and the beginning of 1980's the economists have discussed more closely the connection between the inflationary process and the movements in relative prices. The authors point out that there was accumulated considerable evidence to show that the distribution of relative prices and of aggregate price level are interrelated. However, the nature of the connection was not fully understood, because the original question of causation is the following: whether relative prices changes cause inflation or inflation causes relative prices to change (Parks and Cutler, 1983).

As already explained the quantitative theory does not admit an interconnection between relative prices and general price level. However, what are the implications of a connection between aggregate and relative movements in prices? Why is this question so important? Because, whether relative prices changes cause inflation or vice-versa, then either one of causal effect alone is sufficient to question the view that inflation is not neutral. Cukierman (1983) argues that exists some misunderstanding about this issue, because the economy is fundamentally neutral to monetarily induced changes in the price level. Nevertheless, according to the same author, because of temporary confusions between general and relative movements in prices, money growth is non-neutral in the short term.

However, what kind of economic interactions show links among change on Federal Funds Rate, changes on relative prices and inflation rate. We model a relationship between changes in relative prices and changes in the basic interest rate based on the quantity theory of money. Furthermore, we highlight critically the postulate of quantitative theory of money (QTM) in which states the existence of a dichotomy between absolute prices and relative prices. After that, we discuss the effect of monetary policy on the relative prices taking into account the stick prices and the direct link between the relative prices and general price level. We connect the relationship between relative prices and general price level with the Phillips curve literature. Finally, we also discuss the interdependence between change in relative prices and inflation rate and show Granger-causality tests for both variables.

In this paper, we are interested to analyze at first, the effect of a demand shock (nominal interest rate shock) on the relative prices, rather than supply shock, or more specifically, the effect of change in the basic nominal interest rate practiced by Federal Reserve on variation of relative prices. In turn, based on a modified Phillips curve in which is introduced relative prices as explanatory variable, we evaluate the impact of change in the relative prices on aggregated inflation rate. This paper combines three distinct literatures: the quantitative theory of money, the Phillips curve and the literature on the effects of changes in relative prices on the inflation rate.

Using quarterly data from 1975:01 to 2015:02 for the U.S. economy, we perform an econometric analysis based on systems estimative of two regressions to evaluate the following issues: i) the direct effect of the variation in the Federal Funds Rate on the changes in relative prices; ii) the direct effect of the change in relative prices on the inflation rate considering Phillips curve; iii) the indirect impact of the change of Federal Funds Rate on the inflation rate through the variation in relative prices; iv) the causal relationship between variations in relative prices and changes in absolute price level.

Our database allows evaluating distinct relative prices. We opt for combining pairs of several indexes price to represent the relative price variable, such as consumer price index, producer price index, house price index and implicit price deflator index.

From the point of view of monetary policy, there is an important difference between the supply and demand shock effects on the relative prices and therefore on the inflation rate. On the one hand, in the case of supply shocks, they are exogenous shocks to the monetary policy formulator. For example, a shock in the price of oil can provoke disturbance in the relative prices of several markets, which in turn can affect the inflation rate.

On the other hand, a demand shock due to changes in the basic interest rate can significantly affect the relative prices, which in turn can affect the inflation rate. As the FED uses the basic interest rate to keep the inflation rate close to an inflation target, one should take into account that changes in monetary policy can also significantly affect the relative prices, which in turn can affect the inflation rate. In this context, changes in relative prices can be considered as transmission mechanisms of monetary policy.

Besides this introduction, we present in the section 2 the theoretical and empirical aspects in which show firstly an economic relationship between changes in the relative prices and variations in the nominal interest rate, taking into account the quantitative theory of money (QTM). Secondly, we discuss one of the QTM's postulates known as dichotomy between relative prices and absolute prices, in which it refers to the effects of real and nominal shocks on relative prices and on the absolute level of prices respectively, considering price stickiness. We introduce a New Keynesian Phillips Curve (NKPC) adjusted with the introduction of a change in relative prices. Finally, we show the database and the econometric approach. In the section 3, we display the empirical results and in the section 4, we discuss the final remarks.

2. Theoretical and empirical aspects

The quantitative theory of money proposes a positive relationship between variations in the money supply and variations in price of goods and services in the long-term context. The QTM asserts that increasing the quantity of money in the economy will eventually generate to a proportional percentage rise in the prices of goods and services. The equation of quantitative theory is

$$M^{s}V = PY \tag{1}$$

where M^s represents the money supply, V represents the velocity of money, P represents the average price level and Y represents the real output. Since our interest is to discuss the effect of monetary policy on relative prices, it is required a new price index P' such as P' ≠ P. Hence, we can modify the equation (1) in the follow way:

$$\frac{M^{s}}{P'}V = \frac{P}{P'}Y \tag{2}$$

In addition, after some algebraic transformation we have

$$\frac{M^{s}}{P'} = k\frac{P}{P'}Y \tag{3}$$

where k = 1/V. Now we show the demand function for money represented as

$$\frac{M^d}{P'} = \frac{\alpha Y}{\delta R} \tag{4}$$

where $\alpha > 0$ and $\delta < 0$ represent the parameters associated to real income (Y) and nominal interest rate (R) respectively. In this context, we can make $\frac{M^s}{P'} = \frac{M^d}{P'}$ to obtain a relation between relative price and nominal interest rate

$$\frac{P'}{P} = \varphi R \tag{5}$$

where $\varphi = (k\delta)/\alpha$. If we take the logarithm of both sides in the equation (5) and, after that, we also apply a total differentiation, we found the equivalence between change in relative price and change in nominal interest rate such as

$$\Delta(\frac{P'}{P}) = \Delta(R) \tag{6}$$

we can test empirically the equation (6) as follow

$$\Delta(P'/P)_t = \phi_0 + \phi_1 \Delta(P'/P)_{t-1} + \phi_2 \Delta(R)_t + v_t \tag{7}$$

Since that the equation (7) shows an stochastic relation between change in nominal interest rate and change in relative prices, i.e., shows the impact of monetary policy on change in relative prices, it becomes necessary has a link between change in relative prices and change in absolute price level, in which can be found in a modified Phillips curve.

Despite have originally been proposed for more than half a century, the negative correlation between inflation and unemployment shown in the Phillips curve; remains at the center of the current macroeconomic debate. The importance of this relationship can be proven by the fact that studies of the Phillips curve are common in most central banks around the world, especially those that adopt the regime of inflation targeting (Hargreaves et alii, 2006). In addition, Annable (2007) states that the Phillips curve is among the most important relationships studied by macroeconomics.

An extensive literature on the inflation dynamics is based on the New Keynesian Phillips curve, i.e., a fixing pricing model with nominal rigidities that implies that inflation can be explained by the expected evolution of the real marginal cost (Cogley and Sbordone, 2006). Empirically there is a large econometric debate on the relevance of the New keynesian Phillips curve. The studies of Galí and Gertler (1999) and Galí and Lopez-Salido (2001) present statistical results favorable to the NKPC, we also have studies suggesting that the empirical relevance of the Phillips curve should be considered weak (Rudd and Whelan, 2005; Lindé, 2005; and Bardsen et al,2004).

We estimate an open economy New Keynesian Phillips Curve (NKPC) to characterize the inflation dynamic of the U.S. economy based initially on “hybrid” model of the Phillips Curve, proposed by Gali and Gertler (1999), so that

$$\pi_t = (1-\theta)\pi_{t-1} + \theta\delta E_t \pi_{t+1} + \gamma mc_t \tag{8}$$

where θ captures the relative weight on the forward-looking price setting, δ is the discount rate and *mc* is the proportional deviation of marginal cost from its steady-state value. We introduce change in the relative prices and the pass-through effect in the equation (8) such as

$$\pi_t = c + (1-\theta)\pi_{t-1} + \theta\delta E_t \pi_{t+1} + \gamma(output\_gap)_t + \lambda\Delta(Exch\_rate)_t + \rho\Delta(P'/P) \tag{9}$$

where we assume that output gap can be used as a proxy to marginal cost (Çatik, Martin and Onder, 2011). Moreover, $\Delta(Exch\_rate)$ represents change in the real exchange rate and $\Delta(P^{'}/P)$ denotes change in the relative prices, where $P^{'}, P$ are distinct prices index such as $P_i \neq P_j$.

According to Sims (1999, 2001) a forward-looking specification has an equivalent backward looking model. In this line, we assume that expected inflation rate is given by $E_t\pi_{t+1} = \alpha\pi_t$. The value of the parameter α represents the effect of current inflation rate, π_t, on expected inflation rate, $E_t\pi_{t+1}$. As higher is the value of α, the bigger is the impact of π_t on the revision of the economic agent's expectation regarding to $E_t\pi_{t+1}$. In this context, we can introduce a stochastic version of the equation (9) as follow

$$\pi_t = \beta_0 + \beta_1\pi_{t-1} + \beta_2\Delta(Exch\_rate)_t + \beta_3 outputgap_t + \beta_4\Delta(P^{'}/P) + u_t \tag{10}$$

where

$$\beta_0 = \frac{c}{(1-\theta\delta\alpha)},\ \beta_1 = \frac{1-\theta}{(1-\theta\delta\alpha)},\ \beta_2 = \frac{\gamma}{(1-\theta\delta\alpha)},\ \beta_3 = \frac{\lambda}{(1-\theta\delta\alpha)} \text{ and } \beta_4 = \frac{\rho}{(1-\theta\delta\alpha)}$$

In this context, we can analyze three cases. When $\beta_1 = 0$, one obtains the original Phillips curve, whether we do not consider the exchange rate and the relative prices. There is only a simple relation between inflation rate and output gap – proxy for unemployment rate. When β_1 is positive, the inflation rate depends not only on the output gap, but also on lagged inflation rate, of real exchange rate changes and of relative prices. Finally, if $\beta_1 = 1$, the output gap, the real exchange rate changes and the variation of relative prices affect not the inflation rate, but the variation of inflation rate.

In sum, in this section, we introduce a model to evaluate if change in the nominal interest rate really produces effects on change in relative prices and, thereafter, if these changes in relative prices influence on the inflation rate. For that, we estimate a system of two simultaneous regressions via GMM. The first regression shows the effect on variation of relative prices due to variation in the nominal interest rate (Funds_rate), and the second one displays the effect on inflation rate due to change in relative prices. The first equation is estimated as

$$\Delta(P'/P)_t = \phi_0 + \phi_1\Delta(P'/P)_{t-1} + \phi_2\Delta(R)_t + v_t \tag{11}$$

where Δ (P_i/P_j) identifies the change in relative prices and Δ (*Funds_rate*) is the change in the nominal interest rate, specifically change in the effective Federal Funds Rate. The federal funds rate (*R*) can be understood as the interest rate in which the depository institutions trade overnight, or from a day to other one, federal funds with each other. The federal funds rate is the basic interest rate in the American financial market. The parameter ϕ_1 in the autoregressive components captures the inertia in the dynamics of the dependent variable and v_t is the error term.

The second equation of the system is a NKPC adjusted with the introduction of a change in relative prices specified as

$$\pi_t = \beta_0 + \beta_1\pi_{t-1} + \beta_2\Delta(Exch\_rate)_t + \beta_3 outputgap_t + \beta_4\Delta(P_i/P_j) + u_t \tag{12}$$

Equation 12 estimates the impact of our variable of interest on the inflation rate, i.e., the effect of changes in the relative prices on the rate of inflation, where π_t is defined as the change in consumer price index. This equation take into account as well, the inertia effect of the variable π_{t-1}. The inflation rate also responds to change in the real exchange rate, as well as it responds to the output gap. Thus, we have systems of simultaneous equations to estimate and evaluate.

We investigate the indirect effect of the change in the nominal interest rate on the inflation rate through the relative price by the term $\phi_2\beta_4$, in which it is the result of the product of their respective estimated coefficients. We also assume that $c(v_t, u_t) \neq 0$.

The system composed by equations (11) and (12) is subject to some sources of endogeneity. The Federal Reserve (FED) has adopted the Taylor rule since 1980s[1] and we use time series since 1975. Then, it is possible that exist some sources of endogeneity, because in the 1970s possibly the variable of the FED control was the money supply (exogenous variable) and consequently the federal funds rate was an endogenous variable.

Equations (11) and (12) define a simultaneous equations model. Because can exist endogeneity problem, we use GMM (Generalized method of moments) with IV (instrumental variables). In this context, the instruments must be "good instruments" to be relevant and valid for the appropriate use of the IV method. It means that the instruments must be not only correlate with endogenous regressors, but also has to be orthogonal to the disturbance. In this sense, we use some statistical tests for our econometric specification: the test of underidentification (Cragg and Donald, 1993), the test of overidentifying Sargan-Hansen, in which it is also known as J-statistic, and the Stock-Yogo test (Stock and Yogo, 2005) to analyze the hypothesis of instruments weakness.

We stand out that specific problems arise in conventional inference regarding to OLS regressions when the variables are not stationary. In this sense, Johnston and DiNardo (1997) highlight the relevance of knowing whether similar issues happen in the two-stage approach, least squares regressions. Hsiao (1997a, 1997b) analyzes this problem and concludes that the inference with two-stage least squares estimators using IV stays effectual, even in the case in that time series are considered non-stationary or non-co-integrated. In that context, the conclusions of Hsiao are valid when GMM is applied.

We use the procedure of Newey and West (1987a, 1987b) for all estimated models to solve the two problems of the serial correlation arising of the residuals and unknown heteroscedasticity. They have suggested a more general covariance estimator, which is consistent in the presence of both heteroscedasticity and autocorrelation of an unknown form.

In order to analyze the causal relation between changes in relative prices and change in absolute price, it is used the methodology of Granger (Hamilton, 1994). To carry out the Granger causality test, it is necessary, at first, to verify the stationarity tests of the time series of the respective variables to define the corresponding integration order. Thus, one can choose the optimal number of lags to be used in the analysis. The null hypothesis (Ho) to be tested is that the coefficients of the variables evaluated are

[1] Taylor (1993) shows that this rule closely approximates Federal Reserve policy during the 1980s until the beginning of 1990s.

significantly equal to zero. The decision is based on the F statistic for the joint significance of the coefficients. In this case, if Ho is not accepted, we conclude that the estimated coefficients are statistically different from zero and a given variable causes, in the Granger sense, another one.

We have consulted the economic database of Federal Reserve Bank of St. Louis (FRED), available at http://research.stlouisfed.org/fred2/, to obtain all quarterly data from 1975:01 to 2015:02. Table 1 shows the description of variables.

Table 1: Description of Aggregate Variables (Frequency: Quarterly)

Series ID	Acronym	Title	Units
CPIAUCSL	CPI	Consumer Price Index for All Urban Consumers: All Items	Index 1982-1984 =100
PPIACO	PPI	Producer Price Index for All Commodities	Index 1982=100
USSTHPI	HPI	All-Transactions House Price Index for the United States	Index 1980: Q1 =100
GDPDEF	GDPDEF	Gross Domestic Product: Implicit Price Deflator	Index 2009=100
FEDFUNDS	Funds_rate	Effective Federal Funds Rate	Percent
RNUSBIS	Exch_rate	Real Narrow Effective Exchange Rate for United States	Index 2010=100
WTB3MS	Tbill_rate	3-Month Treasury Bill: Secondary Market Rate	Percent
GDPC96	RGDP	Real Gross Domestic Product	Billions of Chained 2009 Dollars
AHETPI	Wage	Average Hourly Earnings of Production and Nonsupervisory Employees: Total Private, Seasonally Adjusted	Dollars per Hour

Source: Federal Reserve Bank of St. Louis: Federal Reserve Economic Data - FRED

We use proxies to relative prices (P_i/P_j) based on combination of several index prices such as Consumer Price Index (CPI), Producer Price Index (PPI), House Price Index (HPI), Implicit Price Deflator (GDPDEF), in which results in the following relative prices: CPI/GDPDEF, PPI/GDPDEF, HPI/GDPDEF, CPI/PPI, HPI/CPI, HPI/PPI. Moreover, we use the Effective Federal Funds Rate (Funds_rate) to represent the variable of monetary policy.

The specification of Phillip curve (equation 12) uses the change of CPI as dependent variable (cpi_rate) and the lag of inflation rate [cpi_rate(-1)], change in real exchange rate (d_exch_rate), output gap and change in relative prices (d_P_i/P_j) as independents variables. The variables RGDP and (P_i/P_j) are transformed in logarithmic. Hence, d_$P_i/P_j = \text{Log}[P_i/P_{j)t} / (P_i/P_{j)t-1}]$ and output gap = Log(RGDP)_t – HPtrend, where HPtrend is obtained via HP filter (Hodrick-Prescott Filter). The others variables is defined as: cpi_rate = $\log(cpi_t/cpi_{t-1})$ and d_exch_rate = ($exch\_rate_t$ - $exch\_rate_{t-1}$).

The next section shows the econometric results of the estimated models defined by equations (11) and (12) based on generalized method of moments (GMM). We analyze four systems of equations for each pair of tables. Each system is composed by two equations. In this sense, we have 3 pairs of tables: tables 2 and 3, tables 4 and 5 and tables 6 and 7. For example, the first system is composed by the models 1A (table 2 – Equation 11) and 1B (tables 3 – Equation 12). The forth system is composed by the models 4A (table 2 – Equation 11) and 4B (tables 3 – Equation 12). Hence, one can evaluate the indirect effect of the change in the federal funds rate on the rate of inflation through the relative price.

3. Econometric results

This section shows empirical evidences on the connection among monetary policy, relative prices and inflation rate at subsection 3.1 and presents Granger-causality tests between change in relative prices and change in absolute price level at subsection 3.2.

3.1 Monetary policy, relative prices and inflation rate

Table 2 displays the regressions according to equation 11, i.e., the models 1A, 2A, 3A and 4A. The empirical results presented show that for any of these models, all variables are statistically significant at the 1% level, except the constant terms of models 3A and 4A. The J-statistics present p-values higher than 0.12 and, thus, these results do not provide evidence to reject the hypothesis of overidentification. Therefore, the model specification is not rejected.

At the end of Table 2, the F statistic shows empirical evidences for the rejection of the null hypothesis of weak instruments. The value of Cragg-Donald F-statistic is 40.24375 and the Stock-Yogo critical values at the 5% level of significance are 20.23 for the models 1A and 2A. The models 3A and 4A also present values of F-statistic (29.53132) higher than critical values at the 5% level (20.84).

The effects of the percentage change in the federal funds rate on the percentage change in the relative prices are positive for all models in Table 2. In this context, there is an empirical evidence that changes in relative prices are explained by changes in nominal interest rate. In other words, monetary policy affects changes in relative prices, specifically the change in Consumer Price Index/ Implicit Price Deflator and Producer Price Index/Implicit Price Deflator.

Table 2: Estimation Method: GMM (Equation 11 – 1975:01 to 2015:02 – quarterly data)

Dependent variables	d_cpi_gdpdef		d_ppi_gdpdef	
	Model 1A	Model 2A	Model 3A	Model 4A
Variables	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)
Constant	0.000954* (3.39E-05)	0.000969* (4.08E-05)	-0.000461 (0.000683)	-0.000196 (0.000612)
d_cpi_gdpdef(-1)	0.345311* (0.010914)	0.341252* (0.014218)	xxx	xxx
d_ppi_gdpdef(-1)	xxx	xxx	0.303146* (0.021229)	0.310892* (0.01848)
d_funds_rate	0.001067* (3.11E-05)	0.001068* (3.60E-05)	0.006319* (0.000598)	0.006685* (0.000531)
R2	0.117711	0.118140	0.144538	0.144423
J Statistics	0.129916	0.152443	0.301912	0.170196
[p-values]	0.95	0.99	0.99	0.80
OBS	157	157	155	155
Weak Instrument Diagnostics - Stock-Yogo test				
Cragg-Donald F-Statistic	40.24375	40.24375	29.53132	29.53132
Critical values (relative	20.23	20.23	20.84	20.84

bias) 5%				

Source: Prepared by authors. Note 1: (S.E.) = Standard error; Note 2: (*) = p-value ≤ 0.01, (**) = 0.01 < p-value ≤ 0.05, (***) = 0.05 < p-value ≤ 0.10; Note 3: Instruments Models 1A and 2A: Exch_rate (-1to-4), L_ppi_gdpdef (-1to-4), d_Tbill_rate (-1to-4), cpi_rate (-1to-4), c; Note 4: Instruments Models 3A and 4A: Exch_rate(-1to-4), L_cpi_gdpdef(-1to-4), d_Tbill_rate(-1to-6), cpi_rate(-1to-4), d_tbill_rate, d_ppi_gdpdef(-2to-6), ppi_hpi, ppi_hpi(-1to-4), c.

Table 3 displays the estimates results of the Models 1B, 2B, 3B and 4B according to equation (12). The results presented by Models 1B to 4B revel that all estimated coefficients are significant at 5% level, except the coefficient of output gap relative to model 2B. As expected, the estimated coefficients of output gap and change in real exchange rate present positive signs.

The first system is exhibited by Model 1A in Table 2 and by model 1B in Table 3. Model 1B demonstrates the direct effect of the percentage change in the relative prices on the inflation rate, on which the estimated coefficient value is 0.865427. However, the indirect effect demonstrates that variations in the federal funds rate affect relative prices (Model 1A), which thereafter affect the rate of inflation (Model 1B). This means that a quarterly increase of 1% in d_funds_rate will affect positively Δ(Pi/Pj) (%) by 0.001067%. Given that a 1% increase in Pi/Pj (%) increases inflation rate (π) by 0.865427%, the final effect of a 1% increase in d_funds_rate (%) will cause a quarterly increases in π in 0.000923%, i.e., 0.001067*0.865427. Notice that if the relative prices were defined as (Pj / Pi), opposite to (Pi / Pj), the estimated coefficients of the change in relative prices will display opposite signs to those found in Tables 2 and 3.

The second system is composed by Model 2A in Table 2 and by model 2B in Table 3. Model 2B shows the direct effect of the percentage change in the relative prices on the inflation rate, in which the value of the estimated coefficient is 1.014896. Hence, the indirect effect shows that variations in the federal funds rate affect relative prices (Model 2A), which in turn affect the rate of inflation (Model 2B). This means that a quarterly increase of 1% in d_funds_rate will positively affect Δ(Pi/Pj) (%) by 0.001068%. Given that a 1% increase in Pi/Pj (d_cpi_gdpdef) increases inflation rate by 1.014896%, the final effect of a 1% increase in d_funds_rate (%) will cause a quarterly increase in π in 0.001084%.

In the same vein, the third system is represented by Model 3A in Table 2 and by model 3B in Table 3. The empirical results show that a quarterly increase of 1% in d_funds_rate will positively affect Δ(Pi/Pj) (%) by 0.006319% based on Model 3A. Given that a 1% increase in Pi/Pj (%) increases inflation rate (d_ppi_gdpdef) by 0.100262%, the final effect of a 1% increase in d_funds_rate (%) will cause a quarterly increase in π in 0.000633%. In the same line, the fourth system is composed by Model 4A in Table 2 and by model 4B in Table 3. A quarterly increase of 1% in d_funds_rate will positively affect Δ(Pi/Pj) (%) by 0.006685%, according to Model 4A. Given that a 1% increase in Pi/Pj (d_ppi_gdpdef) increases inflation rate by 0.104621%, the final effect of a 1% increase in d_funds_rate (%) will cause a quarterly increases in π in 0.000699%.

Table 3: Estimation Method: GMM (Equation 12 – 1975:01 to 2015:02 – quarterly data)

Dependent variables	cpi_rate		cpi_rate	
	Model 1B	Model 2B	Model 3B	Model 4B
Variables	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)

Constant	0.002817* (0.000107)	0.002821* (0.000195)	0.003291* (0.000256)	0.003276* (0.000249)
cpi_rate(-1)	0.549732* (0.06167)	0.517009* (0.014607)	0.626771* (0.022786)	0.634414* (0.022214)
d_exch_rate	xxx	0.000571* (6.06E-5)	xxx	0.000170** (6.64E-05)
Output gap	0.030761* (0.006200)	0.017020 (0.011005)	0.030346** (0.014490)	0.037749* (0.013286)
d_cpi_gdpdef	0.865427* (0.024984)	1.014896* (0.036750)	xxx	xxx
d_ppi_gdpdef	xxx	xxx	0.100262* (0.002865)	0.104621* (0.003397)
R2	0.804067	0.781027	0.680809	0.684263

Source: Prepared by authors. Note 1: (S.E.) = Standard error; Note 2: (*) = p-value $\leq$ 0.01, (**) = 0.01 < p-value $\leq$ 0.05, (***) = 0.05 < p-value $\leq$ 0.10; Note 3: Instruments Models 1B and 2B: Exch_rate (-1to-4), L_ppi_gdpdef (-1to-4), d_Tbill_rate (-1to-4), cpi_rate (-1to-4), c; Note 4: Instruments Models 3B and 4B: Exch_rate(-1to-4), L_cpi_gdpdef(-1to-4), d_Tbill_rate(-1to-6), cpi_rate(-1to-4), d_tbill_rate, d_ppi_gdpdef(-2to-6), ppi_hpi, ppi_hpi(-1to-4), c.

Table 4 displays the regressions according to equation 1, i.e., the models 1C, 2C, 3C and 4C. The empirical evidences show that all variables are statistically significant at the 5% level for any of these models. The J-statistics do not provide evidence to reject the hypothesis of overidentification, take into account a p-values higher than 0.14. In this way, the model specification is not rejected.

There is empirical evidence for the rejection of the null hypothesis of weak instruments, based on F statistic, as displayed in Table 4. The value of Cragg-Donald F-statistic is 77.65620 and the Stock-Yogo critical values at the 5% level of significance is 20.23 for models 1C and 2C. The models 3C and 4C also present values of F-statistic (29.53132) higher than critical values at the 5% level (20.84).

The effects of the percentage change in the federal funds rate on the percentage change in the relative prices are negative for all models in Table 4. In this context, there is empirical evidence that monetary policy affects changes in relative prices, specifically the changes in Consumer Price Index/Producer Price Index and House Price Index /Implicit Price Deflator.

Table 4: Estimation Method: GMM (Equation 11 – 1975:01 to 2015:02 – quarterly data)

Dependent variables	d_cpi_ppi		d_hpi_gdpdef	
	Model 1C	Model 2C	Model 3C	Model 4C
Variables	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)
Constant	0.001249* (0.000187)	0.001305* (0.000213)	0.001253* (0.000313)	0.001093* (0.000103)
d_cpi_ppi(-1)	0.328470* (0.016036)	0.328757* (0.019017)	xxx	xxx
d_hpi_gdpdef(-1)	xxx	xxx	0.664797* (0.033111)	0.670696* (0.015779)
d_funds_rate	-0.002633* (0.000169)	-0.002696* (0.000196)	-0.000893** (0.000357)	-0.000637* (0.000174)
R2	0.144741	0.144363	0.399369	0.400412
J Statistics	0.150125	0.147514	0.331222	0.360105
[p-values]	0.99	0.99	0.99	0.99

OBS	157	157	155	155
Weak Instrument Diagnostics - Stock-Yogo test				
Cragg-Donald F-Statistic	77.65620	77.65620	29.53132	29.53132
Critical values (relative bias) 5%	20.23	20.23	20.84	20.84

Source: Prepared by authors. Note 1: (S.E.) = Standard error; Note 2: (*) = p-value $\leq$ 0.01, (**) = 0.01 < p-value $\leq$ 0.05, (***) = 0.05 < p-value $\leq$ 0.10; Note 3: Instruments Models 1C and 2C: Exch_rate (-1to-4), L_ppi_gdpdef (-1to-4), d_Tbill_rate (-1to-4), cpi_rate (-1to-4), d_tbill_rate, c; Note 4: Instruments Models 3C and 4C: Exch_rate(-1to-4), L_cpi_gdpdef(-1to-4), d_Tbill_rate(-1to-6), cpi_rate(-1to-4), d_tbill_rate, d_ppi_gdpdef(-2to-6), ppi_hpi, ppi_hpi(-1to-4), c.

Table 5 shows the estimates of the Models 1D, 2D, 3D and 4D according to equation (2). The results shown by Models 1D to 4D indicate that all estimated coefficients are significant at 5% level.

The first system is represented by Model 1D in Table 5 and by model 1E in Table 6. The indirect effect shows that variations in the federal funds rate affect relative prices (Model 1D), which in turn affect the rate of inflation (Model 1E). This means that a quarterly increase of 1% in d_funds_rate will negatively affect d_cpi_ppi (%) by -0.002633%. Given that a 1% increase in d_cpi_ppi (%) reduces inflation rate (cpi_rate) by -0.033912%, the final effect of a 1% increase in d_funds_rate (%) will cause a quarterly increases in π in 0.000089%.

The indirect effect of the variations in the federal funds rate on relative prices, which in turn affect the rate of inflation for the second (Models 2C, 2D) , third (Models 3C, 3D) and fourth (Models 4C, 4D) systems are -0.002696*-0.056674=0.00015, -0.000893*-0.203429=0.00018 , -0.000637*-0.197020=0.00013 respectively.

Table 5: Estimation Method: GMM (Equation 12 – 1975:01 to 2015:02 – quarterly data)

Dependent variables	cpi_rate		cpi_rate	
	Model 1D	Model 2D	Model 3D	Model 4D
Variables	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)
Constant	0.003032* (0.000150)	0.003087* (0.000169)	0.004209* (0.000311)	0.004191* (0.000103)
cpi_rate(-1)	0.665523* (0194426)	0.660713* (0.024548)	0.577396* (0.030580)	0.589523* (0.015050)
d_exc_rate	xxx	0.000193* (6.43E-05)	xxx	0.000104* (2.91E-05)
Output gap	0.077752* (0.010921)	0.067712* (0.013608)	0.169068* (0.017823)	0.166038* (0.007851)
d_cpi_ppi	-0.033912** (0.013874)	-0.056674* (0.014217)	xxx	xxx
d_hpi_gdpdef	xxx	xxx	-0.203429* (0.017859)	-0.197020* (0.008157)
R2	0.561084	0.566266	0.488265	0.493988

Source: Prepared by authors. Note 1: (S.E.) = Standard error; Note 2: (*) = p-value $\leq$ 0.01, (**) = 0.01 < p-value $\leq$ 0.05, (***) = 0.05 < p-value $\leq$ 0.10; Note 3: Instruments Models 1D and 2D: Exch_rate (-1to-4), L_ppi_gdpdef (-1to-4), d_Tbill_rate (-1to-4), cpi_rate (-1to-4), d_tbill_rate, c; Note 4: Instruments Models 3D and 4D: Exch_rate(-1to-4), L_cpi_gdpdef(-1to-4), d_Tbill_rate(-1to-6), cpi_rate(-1to-4), d_tbill_rate, d_ppi_gdpdef(-2to-6), ppi_hpi, ppi_hpi(-1to-4), c.

Table 6 displays the regressions according to equation 11, i.e., the models 1E, 2E, 3E and 4E. The results show that for any of these models all variables are statistically significant at the 1% level, except the constant term of model 1E which the estimated coefficient is not statistically significant at 10% level. The J-statistics, based on p-values higher than 0.30, do not provide evidence to reject the hypothesis of overidenfication. Hence, the model specification is not rejected.

The F statistic indicates evidence for the rejection of the null hypothesis of weak instruments, as shown in Table 6. The value of Cragg-Donald F-statistic is 22.32817 and the Stock-Yogo critical values at the 5% level of significance is 20.86 for models 1E and 2E. The models 3E and 4E also present values of F-statistic (50.92116) higher than critical values at the 5% level (20.86).

The effects of the percentage change in the federal funds rate on the percentage change in the relative prices are negative for all models in Table 6. In this context, there is empirical evidence that monetary policy affects changes in relative prices, specifically the changes in House Price Index/Consumer Price Index and House Price Index/ Producer Price Index.

Table 6: Estimation Method: GMM (Equation 11 – 1975:01 to 2015:02 – quarterly data)

Dependent variables	d_hpi_cpi		d_hpi_ppi	
	Model 1E	Model 2E	Model 3E	Model 4E
Variables	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)
Constant	0.000567 (0.000379)	0.000559* (0.000103)	0.002203* (0.000407)	0.002106* (0.000414)
d_hpi_cpi(-1)	0.676638* (0.032336)	0.676890* (0.008046)	xxx	xxx
d_hpi_ppi(-1)	xxx	xxx	0.426480* (0.020667)	0.421869* (0.020727)
d_funds_rate	-0.001959* (0.00030)	-0.001779* (7.28E-05)	-0.003336* (0.000367)	-0.003262* (0.000363)
R2	0.313230	0.313215	0.198469	0.198624
J Statistics	0.366070	0.351142	0.319425	0.317814
[p-values]	0.99	0.99	0.99	0.99
OBS	155	155	155	155
Weak Instrument Diagnostics - Stock-Yogo test				
Cragg-Donald F-Statistic	22.32817	22.32817	50.92116	50.92116
Critical values (relative bias) 5%	20.86	20.86	20.86	20.86

Source: Prepared by authors. Note 1: (S.E.) = Standard error; Note 2: (*) = p-value $\leq$ 0.01, (**) = 0.01 < p-value $\leq$ 0.05, (***) = 0.05 < p-value $\leq$ 0.10; Note 3: Instruments Models 1E and 2E: Exch_rate (-1to-3), L_cpi_gdpdef (-1to-4), d_Tbill_rate (-1to-6), cpi_rate (-1to-4), d_tbill_rate, d_tbill_rate d_ppi_gdpdef(-2to-6) pp_hpi ppi_hpi(-1to-4) l_cpi_hpi l_cpi_hpi(-1), c; Note 4: Instruments Models 3E and 4E: exch_rate(-1to-3) l_cpi_gdpdef(-1to-4) d_tbill_rate(-1to-6) cpi_rate(-1to-4) d_tbill_rate, d_ppi_gdpdef(-2to-6), ppi_hpi ppi_hpi(-1to-4) l_cpi_hpi l_cpi_hpi(-1), c.

Table 7 shows the estimates of the Models 1F, 2F, 3F and 4F according to equation (12). The results shown by Models 1F to 4F indicate that all estimated coefficients are significant at 1% level.

The indirect effect of the variations in the federal funds rate on relative prices, which in turn affect the rate of inflation for the first (Models 1E, 1F), second (Models 2E, 2F) , third (Models 3E, 3F) and fourth (Models 4E, 4F) systems are -0.001959*-0.159536=0.000312, -0.001779*-0.152735=0.000272, -0.003336*-0.122345=0.000408, -0.003262*-0.127411=0.000416 respectively.

Table 7: Estimation Method: GMM (Equation 12 – 1975:01 to 2015:02 – quarterly data)

Dependent variables	cpi_rate		cpi_rate	
	Model 1F	Model 2F	Model 3F	Model 4F
Variables	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)
Constant	0.003626* (0.000253)	0.003733* (7.85E-05)	0.004064* (0.000188)	0.004070* (0.000195)
cpi_rate(-1)	0.608010* (0.025450)	0.594276* (0.006431)	0.591199* (0.018259)	0.587436* (0.017509)
d_exc_rate(-1)	xxx	0.000100* (1.36E-05)	xxx	0.000196* (4.71E-05)
Output gap	0.122721* (0.016813)	0.111104* (0.004997)	0.093167* (0.011080)	0.099696* (0.012142)
d_hpi_cpi	-0.159536* (0.008100)	-0.152735* (0.002694)	xxx	xxx
d_hpi_ppi	xxx	xxx	-0.122345* (0.003712)	-0.127411* (0.004671)
R2	0.587538	0.589190	0.645278	0.651379

Source: Prepared by authors. Note 1: (S.E.) = Standard error; Note 2: (*) = p-value $\leq$ 0.01, (**) = 0.01 < p-value $\leq$ 0.05, (***) = 0.05 < p-value $\leq$ 0.10; Note 3: Instruments Models 1F and 2F: Exch_rate (-1to-3), L_cpi_gdpdef (-1to-4), d_Tbill_rate (-1to-6), cpi_rate (-1to-4), d_tbill_rate, d_tbill_rate d_ppi_gdpdef(-2to-6) ppi_hpi ppi_hpi(-1to-4) l_cpi_hpi l_cpi_hpi(-1), c; Note 4: Instruments Models 3F and 4F: exch_rate(-1to-3) l_cpi_gdpdef(-1to-4) d_tbill_rate(-1to-6) cpi_rate(-1to-4) d_tbill_rate, d_ppi_gdpdef(-2to-6), ppi_hpi ppi_hpi(-1to-4) l_cpi_hpi l_cpi_hpi(-1), c.

In sum, the empirical results show that the monetary policy affect changes in relative prices. Moreover, changes in relative prices, resulting from changes in federal funds rate, are transmission mechanisms of monetary policy because they indirectly affect the inflation rate.

Besides, all the estimated coefficients regarding to Phillips curve estimations, according equation (12), present the coefficient $\beta_1 < 1$, i.e., the coefficient of the lagged inflation rate é lower one unit. It means that, in the considerate period, there is a trade-off between output gap and inflation rate, rather than between output gap and variation of inflation rate. The lagged values of the inflation rate represent an inertial effect of past inflation on current inflation. Nevertheless, such lagged values also reflect some price rigidity in the economy. The idea of inflationary inertia is well aligned with the idea of nominal rigidity in the new Keynesian approach.

A relevant result, which is not highlighted in the literature, refers to the lagged variables associated with changes in relative prices. Tables 2, 4 and 6 show that the estimated coefficients of these variables are statistically significant and show some degree of "relative prices rigidity".

It is interesting to note that the relative prices associated with the house price index, such as d_hpi_gdpdef (table 4) and d_hpi_cpi (table 6), show the highest estimated coefficients among all relative price changes lagged, around 0,67. When comparing this value of 0.67 with the estimated coefficient highest of the lagged inflation rate, we find a similar value around 0.66 in table 5. This means that the rigidity of the inflation rate, which is the variation of the absolute price level, is as high as the rigidity of the change in relative prices. These results are intriguing. Which explains rigidities in relative price changes? Why are they so high? What are the economic implications of such rigidities? Why the house index price stands out among the others ones.

The real estate price index evaluates prices of goods that can be considered durable consumer, as well as capital goods. Perhaps, this peculiar nature of this good may partly explain the inertial effect of their relative prices. In this context, the viscosity of the relative prices of the real estate market in relation to the average prices of other goods can become larger. The aforementioned aspects may somehow to explain the effects of the housing bubble of the American economy, known as subprime crisis. This is not the purpose of this article, but perhaps these considerations may inspire future research.

3.2 The interdependence between relative prices and the general price level

The tables show Granger's causality tests among the changes relative prices and the inflation rate (CPI). Considering that all the variables are stationary, as shown in the appendix, the optimal number of lags can be obtained based on the SC, HQ, LR, FPE and AIC criteria via VAR models.

The table 8 shows the pairwise Granger causality tests between the variables D_CPI_GDPDEF and CPI_RATE. The empirical results show a causality for both variables, i.e., D_CPI_GDPDEF Granger-cause CPI_RATE and CPI_RATE also Granger-cause D_CPI_GDPDEF. The results are valid for the different lags combined with their respective criteria. Of course, it is expected a mutual Granger-causality (bi-causality) between the change of CPI index and the change of the ratio CPI index / GDP deflator, because CPI is part of both indicators.

However, the empirical results of Granger causality tests between CPI_RATE and changes of the other relative prices are different. Tables 9 to 13 show that change of relative prices Granger-cause the change of absolute price for all kind of criteria associated with their respective lags.

Table 8: Pairwise Granger Causality Tests (D_CPI_GDPDEF & CPI_RATE)

Lags	Criterion	Null Hypothesis	Obs.	F-Statistic	P-value
2	SC	D_CPI_GDPDEF does not Granger Cause CPI_RATE	159	15.8196	6.E-07
		CPI_RATE does not Granger Cause D_CPI_GDPDEF		3.13069	0.0465
4	HQ	D_CPI_GDPDEF does not Granger Cause CPI_RATE	157	5.94015	0.0002
		CPI_RATE does not Granger Cause D_CPI_GDPDEF		4.48528	0.0019
7	LR	D_CPI_GDPDEF does not Granger Cause CPI_RATE	154	5.92749	5.E-06
		CPI_RATE does not Granger Cause D_CPI_GDPDEF		4.51561	0.0001
8	FPE, AIC	D_CPI_GDPDEF does not Granger Cause CPI_RATE	153	5.28964	9.E-06
		CPI_RATE does not Granger Cause D_CPI_GDPDEF		3.83579	0.0004

Source: Prepared by authors. Note: Indicates lag order selected by the criterion: LR: sequential modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion.

The empirical results of table 9 show that taking into account 3 lags and SC and HQ criterions, the null hypothesis in which D_PPI_GDPDEF does not Granger Cause CPI_RATE is not accepted with the value statistic F of 7.59821 and a p-value < 0.0001. Besides, the null hypothesis in which CPI_RATE does not Granger Cause D_PPI_GDPDEF is not rejected with the value statistic F of 0.59905 and a p-value of 0.6166. These results are confirmed by LR, FPE and AIC criterions, considering 5 lags.

Table 9: Pairwise Granger Causality Tests (D_PPI_GDPDEF & CPI_RATE)

Lags	Criterion	Null Hypothesis	Obs.	F-Statistic	P-value
3	SC, HQ	D_PPI_GDPDEF does not Granger Cause CPI_RATE	158	7.59821	9.E-05
		CPI_RATE does not Granger Cause D_PPI_GDPDEF		0.59905	0.6166
5	LR, FPE, AIC	D_PPI_GDPDEF does not Granger Cause CPI_RATE	156	5.06313	0.0003
		CPI_RATE does not Granger Cause D_PPI_GDPDEF		1.79227	0.1180

Source: Prepared by authors. Note: Indicates lag order selected by the criterion: LR: sequential modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion.

The empirical evidences of table 10 show that with 3 lags and SC and HQ criterions, the null hypothesis in which D_CPI_PPI does not Granger Cause CPI_RATE is not accepted with the value statistic F of 6.12679 and a p-value of 0.0006. The null hypothesis in which CPI_RATE does not Granger Cause D_CPI_PPI is not rejected with the value statistic F of 0.51388 and p-value of 0.6733. These results are the same considering LR, FPE and AIC criterions with 5 lags.

Table 10: Pairwise Granger Causality Tests (D_CPI_PPI & CPI_RATE)

Lags	Criterion	Null Hypothesis	Obs.	F-Statistic	P-value
3	SC, HQ	D_CPI_PPI does not Granger Cause CPI_RATE	158	6.12679	0.0006
		CPI_RATE does not Granger Cause D_CPI_PPI		0.51388	0.6733
5	LR, FPE, AIC	D_CPI_PPI does not Granger Cause CPI_RATE	156	3.93116	0.0023
		CPI_RATE does not Granger Cause D_CPI_PPI		1.33063	0.2545

Source: Prepared by authors. Note: Indicates lag order selected by the criterion: LR: sequential modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion.

The empirical results of table 11 show that with 3 lags and SC and HQ criterions, the null hypothesis in which D_HPI_GDPDEF does not Granger Cause CPI_RATE is not accepted, meanwhile the null hypothesis in which CPI_RATE does not Granger Cause D_HPI_GDPDEF is not rejected. These results are validated for FPE and AIC criterions with 5 lag as well as for LR criterion with 9 lags.

Table 11: Pairwise Granger Causality Tests (D_HPI_ GDPDEF & CPI_RATE)

Lags	Criterion	Null Hypothesis	Obs.	F-Statistic	P-value
3	SC, HQ	D_HPI_GDPDEF does not Granger Cause CPI_RATE	158	3.31864	0.0216
		CPI_RATE does not Granger Cause D_HPI_GDPDEF		1.99493	0.1172
5	FPE, AIC	D_HPI_GDPDEF does not Granger Cause CPI_RATE	156	3.10553	0.0108
		CPI_RATE does not Granger Cause D_HPI_GDPDEF		1.20366	0.3104
9	LR	D_HPI_GDPDEF does not Granger Cause CPI_RATE	152	2.61214	0.0082
		CPI_RATE does not Granger Cause D_HPI_GDPDEF		1.22413	0.2855

Source: Prepared by authors. Note: Indicates lag order selected by the criterion: LR: sequential modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion.

The empirical results of table 12 show that with 3 lags and SC and HQ criterions, the null hypothesis in which D_HPI_CPI does not Granger Cause CPI_RATE is not accepted and the null hypothesis in which CPI_RATE does not Granger Cause D_HPI_CPI is not rejected. These results are validated for FPE and AIC criterions with 5 lag as well as for LR criterion with 9 lags.

Table 12: Pairwise Granger Causality Tests (D_HPI_ CPI & CPI_RATE)

Lags	Criterion	Null Hypothesis	Obs.	F-Statistic	P-value
3	SC, HQ	D_HPI_CPI does not Granger Cause CPI_RATE	158	4.63329	0.0040
		CPI_RATE does not Granger Cause D_HPI_CPI		1.22056	0.3043
5	FPE, AIC	D_HPI_CPI does not Granger Cause CPI_RATE	156	3.72163	0.0034
		CPI_RATE does not Granger Cause D_HPI_CPI		1.15758	0.3330
9	LR	D_HPI_CPI does not Granger Cause CPI_RATE	152	2.59627	0.0086
		CPI_RATE does not Granger Cause D_HPI_CPI		0.76079	0.6527

Source: Prepared by authors. Note: Indicates lag order selected by the criterion: LR: sequential modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion.

Finally, the empirical results of table 13 show that with 3 lags and LR, SC and HQ criterions, the null hypothesis in which D_HPI_PPI does not Granger Cause CPI_RATE is not accepted, meanwhile the null hypothesis in which CPI_RATE does not Granger Cause D_HPI_PPI is not rejected. These results are validated taking into account FPE, AIC criterions with 5 lags.

Table 13: Pairwise Granger Causality Tests (D_HPI_PPI & CPI_RATE)

Lags	Criterion	Null Hypothesis	Obs.	F-Statistic	P-value
3	LR, SC, HQ	D_HPI_PPI does not Granger Cause CPI_RATE	158	7.82286	7.E-05
		CPI_RATE does not Granger Cause D_HPI_PPI		0.17434	0.9136
5	FPE, AIC	D_HPI_PPI does not Granger Cause CPI_RATE	156	5.39676	0.0001
		CPI_RATE does not Granger Cause D_HPI_PPI		0.52519	0.7569

Source: Prepared by authors. Note: Indicates lag order selected by the criterion: LR: sequential modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion.

Taking into account the empirical results, it is possible analyze the implications of these results. In terms of economic policy, the results suggest that if the policymaker imposes variability of the basic interest rate used by the FED to conduct the monetary policy, it is expected some variability in relative prices and, consequently, variability of inflation rate as well. It means that the policymaker should not make abrupt changes in monetary policy to avoid undesirable and unpredictable fluctuations on the inflation rate.

4. Final remarks

Based on quarterly database of the U.S. economy for the period 1975:01 to 2015:02, the empirical results show that variations in the federal funds rate have effect on change of relative prices, which in turn indirectly affect the inflation rate via change of the same relative prices. In sum, the monetary policy directly affects the change of relative prices and, in turn, the changes of relative prices directly affect the inflation rate via NKPC. Hence, the monetary policy indirectly affects the inflation rate via change of relative prices. Besides, we found empirical evidences in which change in relative prices Granger-cause change in inflation rate measured by CPI rate.

In this context, exist a relevant implication that must be considered regarding to monetary policy transmission mechanisms, which occurs through the changes in relative prices. There may be more difficulty for policymakers predict the outcome of the monetary policy on relative prices and, hence, on variables of interest, such as inflation rate. Therefore, we find empirical evidences in which the change of relative prices can be considered a transmission channel of monetary policy.

Besides, all the estimations Phillips curve show the coefficient of the lagged inflation rate lower than one unit does. It means that, in the considerate period, there is a trade-off between output gap and inflation rate rather than between output gap and variation of inflation rate.

A relevant result, which is not highlighted in the literature, refers to the lagged variables associated with changes in relative prices, i.e., refer to inertial effects. These results show some degree of "relative prices rigidity". Based on the empirical results, one can inquire which explains rigidities in relative price changes. What are the economic implications of these rigidities? These issues can be investigated in further researches.

References

Annable, J. Adjusting wages for price inflation: The rational-arrangements Phillips curve, (2007), text available in SSRN: http://ssrn.com/abstract=1045321.

Aoki, Kosuke. “Optimal monetary policy responses to relative-price changes”. *Journal of Monetary Economics* 48, (2001): 55-80.

Ball, L. and Mankiw, N.G. “Asymmetric price adjustment and economic fluctuations”, *Economic Journal* 104, no. 423 (1994): 247-61.

Ball, L. and Mankiw, N.G. “Relative-price changes as aggregate supply shocks”, *Quarterly Journal of Economics*. 11, no. 1 (1995): 161-93.

Bardsen, G.; Jansen, E. S. and Nymoen, R. “Econometric evaluation of the new Keynesian Philips curve”, *Oxford Bulletin of Economics and Statistics* 66 (2004): 671–686, text available in URL: http://dx.doi.org/10.1111/j.1468-0084.2004.00097.

Çatik, A. Nazif; Martin, Christopher and Onder, A. Ozlem. “Relative price variability and the Phillips Curve: evidence from Turkey”, *Journal of Economic Studies*, 38, no. 5 (2011): 546 – 562.

Cogley, T. and Sbordone, A. M. “Trend inflation and inflation persistence in the New Keynesian Phillips curve”, *Staff Report 270, Federal Reserve Bank of New York Staff Reports*, (2006).

Cragg JG and Donald SG. “Testing Identifiability and Specification in Instrumental Variables Models”, *Econometric Theory* 9, (1993): 222–240.

Cukierman, A. “Relative price variability and inflation: a survey and further results”, *Carnegie-Rochester Conference Series on Public Policy* 19, (1983): 103-38.

Domberger, S. “Relative price variability and inflation: a disaggregated analysis”, *Journal of Political Economy* 95, no. 3, (1987): 547-66.

Fischer, S. “Relative shocks, relative-price variability, and inflation”, *Brookings Papers on Economic Activity*, no. 2, (1981): 381-441.

Galí, J. and Gertler, M. “Inflation dynamics: a structural econometric analysis”, Journal of Monetary Economics 44, no. 2, (1999): 195-222

Galí, J., Gertler, M. and Lopez-Salido, J. D. “European inflation dynamics”, *European Economic Review* 45, no. 7, (2001): 1237–1270.

Hamilton, James D. Times Series Analysis. Princeton University Press’s, NJ, (1994).

Hargreaves, David; Kite, Hannah and Hodgetts, Bernard. “Modelling New Zealand inflation in a Phillips curve”, *Reserve Bank of New Zealand: Bulletin*. 69, no. 3, (2006): 23 – 37.

Hayek, Friedrich. *Monetary Theory and the Trade Cycle*. Augustus M. Kelley, 1933.
Hayek, Friedrich. *Prices and Production*, 2nd ed. New York: Augustus M. Kelley, 1935.
Hsiao C. "Statistical properties of the two-stage last squares estimator under cointegration", *The Review of Economic Studies* 64, (1997a): 385–398.
Hsiao C. "Cointegration and dynamic simultaneous equations models", *Econometrica* 65, (1997b): 647–670.
Humphrey T. "Fisher, Wicksell on the Quantity Theory", *Federal Reserve Bank of Richmond Quarterly*, 83, no.4, (1997).
Johnston J and DiNardo J. *Econometric Methods*, NewYork, McGraw-Hill, 1997.
Lindé, J. "Estimating new-keynesian phillips curves: A full information maximum likelihood approach", *Journal of Monetary Economics* 52, no.6, (2005): 1135–1149.
Newey W and West K. "Hypothesis testing with efficient method of moments estimation", *International Economics Review*, 28, (1987a): 777–787.
Newey W and West K. "A simple positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix", *Econometrica* 55, (1987b): 703–708.
Ohanian, L.; Stockman, A. and Kilian, L. "The effects of real and monetary shocks in a business cycle model with some sticky prices", *Journal of Money, Credit, and Banking* 27, no. 4, (1995): 34–1209.
Parks, Richard W. and Cutler, Harvey. "Relative price variability and inflation: A survey and further results: A Comment", *Carnegie-Rochester Conference Series on Public Policy*, 19, (1983): 158-166.
Roberts, J., "New Keynesian economics and the Phillips curve", *Journal of Money, Credit, and Banking* 27, no 4, (1995): 84–975.
Rudd, J. and Whelan, K. "New tests of the new Keynesian Phillips curve", *Journal of Monetary Economics* 52, no. 6, (2005): 1167–1181.
SIMS, C. "Drifts and Breaks in Monetary Policy", *Discussion Paper*, Princeton University, (1999).

________. "Stability and Instability in US Monetary Policy Behavior", *Discussion Paper*, Princeton University, (2001).

Stock JH; Wright JH and Yogo M. "A Survey of Weak Instruments and Weak Identification in Generalized Method of Moments", *Journal of Business and Economic Statistics* 20, (2002): 518–29.
Stock JH and Yogo M. *Testing for Weak Instruments in Linear IV Regression. In Identification and Inference for Econometric Models, Essays in Honor of Thomas Rothenberg*, ed. Andrews DW, Stock JH, Cambridge University Press, (2005): 80–108.
Taylor, John B. "Discretion versus Policy rules in practice", *Carnegie-Rochester Conference Series on Public Policy* 39, (1993): 195-214, North-Holand.
Vining, D.R. and Elwertowski, T.C., "The relationship between relative prices and general price level", *American Economic Review* 66, no. 4, (1976): 699-708.

Appendices

Table A.1 –Unit root test: database of the U.S. economy (1975:01 to 2015:02)

Variables	ADF test	ADF (SIC)	ADF (SIC)	PP test	PP test	PP test
	Critical value 5%	Student t-statistic	p-value	Critical value 5%	Adj. t-statistic	p-value

D_cpi_gdpdef*	-1.942910	-2.256594	0.0236	-1.942830	-8.954387	< 0.00001
D_ppi_gdpdef*	-1.942843	-9.983076	< 0.00001	-1.942830	-8.391860	< 0.00001
D_funds_rate*	-1.942830	-10.71861	< 0.00001	-1.942830	-10.71861	< 0.00001
Cpi_rate**	-2.879727	-2.757577	0.0668	-2.879494	-4.884547	0.0001
D_exch_rate*	-1.942830	-9.444261	< 0.00001	-1.942830	-9.382484	< 0.00001
Output gap*	-1.942843	-4.568985	< 0.00001	-1.942818	-3.937011	0.0001
D_hpi_gdpdef	-1.942856	-2.727828	0.0066	-1.942830	-6.908936	< 0.00001
D_hpi_cpi*	-1.942856	-3.459306	0.0006	-1.942830	-7.825093	< 0.00001
D_hpi_ppi*	-1.942856	-5.295690	< 0.00001	-1.942830	-7.826328	< 0.00001
D_cpi_ppi*	-1.942843	-9.335710	< 0.00001	-1.942830	-8.320466	< 0.00001
D_wager	-1.942830	-8.532205	< 0.00001	-1.942830	-8.733798	< 0.00001
(D_hpi_gdedef)* (D_ppi_gdpdef)	-1.942856	-5.939272	< 0.00001	-1.942830	-1.942830	< 0.00001

Source: Prepared by the authors. Note 1: ADF = Augmented Dickey-Fuller and PP = Phillips-Perron; Note 2: Ho display unit root; Note 3: SIC = Schwartz information criterion; Note 4: * represents test without constant and ** represents test with constant. Only the Cpi_rate variable presented the constant term statistically significant in the unit root tests. Note 5: Elliott-Rothenberg-Stock DF-GLS test statistic. Ho display CPI_RATE has a unit root. Critical value 5%: -1.942856. T-statistic value -2.559571.