

**STATE UNIVERSITY – HIGHER SCHOOL OF ECONOMICS**  
Centre for Advanced Studies & New Economics School

*Victoria Dobrynskaya*

**THE OPTIMAL MONETARY POLICY  
UNDER INCOMPLETE PASS-THROUGH  
AND ASYMMETRIC PRICE RIGIDITY**

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**Dobrynskaya V.V.** The Optimal Monetary Policy under Incomplete Pass-through and Asymmetric Price Rigidity. Working paper WP13/2007/04. Moscow: State University — Higher School of Economics, 2007. — 24 p.

This paper analyses the optimal monetary policy under incomplete pass-through and asymmetric price rigidity. In a general equilibrium sticky price model of a small open economy we find that the optimal interest rate rule is to respond to all types of shocks in an economy: real exchange rate shocks, supply shocks and demand shocks. The extent of the optimal response of the interest rate to exchange rate and supply shocks depends positively on the degree of pass-through and negatively on price rigidity. Therefore, the interest rate should be adjusted more in case of an inflationary shock (e.g. depreciation of the domestic currency) than in case of a deflationary one of the same size due to higher downward price rigidity and lower downward pass-through.

*JEL classification:* E12, E31, E52, F41

*Keywords:* monetary policy, interest rate rule, exchange rate, pass-through effect, asymmetric price rigidity

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International College of Economics and Finance and Department of Economics State University – Higher School of Economics 20 Myasnitskaya st., Moscow, Russia  
vdobrynskaya@hse.ru  
Tel: +7 916 6864264, fax: +7 495 6257933

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## 1. Introduction\*

The welfare analysis of the monetary policy has been in the centre of macroeconomics since the Great Depression. Empirical observations of the Phillips curve suggest that prices are sticky in the short run and, therefore, the monetary policy may be used to smooth the business cycle and increase social welfare.

In an open economy where foreign shocks may be passed into the domestic economy the task of the monetary policy becomes even more complicated. In order to reduce exchange rate fluctuations, the monetary policy stops to be fully independent and should adjust to exchange rate shocks. Such a policy of smoothing exchange rate fluctuations is common in western economies (e.g. Parsley and Popper, 1998).

A number of theoretical papers propose that the optimal degree of intervention depends on the pass-through effect in an economy (e.g. Devereux and Engel, 2000). If pass-through is high, in the absence of intervention an exchange rate shock will be reflected in the domestic prices. Therefore, some degree of intervention is desirable in order to reduce the pass-through effect and the domestic price volatility. But the pass-through effect, in turn, appears to be endogenous to the local monetary policy (Devereux and Yetman, 2003). It is observed to be higher in countries with higher average inflation and lower degree of intervention.

Most theoretical models developed in this field are welfare-based optimizing general equilibrium models which try to capture real life peculiarities and, hence, are too complicated and cannot be solved analytically. The authors obtain their results from calibrations, but in this case comparative statics is not analysed. In order to fill this gap, we propose a simple general equilibrium sticky price model of a small open economy with incomplete pass-through. Our model is similar to the New Keynesian model of a closed economy, described in Clarida, Gali and Gertler (1999). By minimizing a social loss function, we obtain an optimal monetary policy rule and analyse the parameters, responsible for the optimal degree of monetary intervention. In particular, we find that the higher is pass-through and the more flexible are prices in an economy, the more significant should be monetary intervention in case of an exchange rate or a supply shock.

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Recent empirical literature finds that prices are more sticky downwards than upwards. This effect is called “asymmetric price rigidity” and may result from money illusion of workers, collusive behaviour of firms or search behaviour of consumers. Therefore, in our model we also assume downward price rigidity and determine the optimal monetary policy in cases of exchange rate or supply shocks of different signs. We find that the optimal rule is to adjust the interest rate more significantly in case of an inflationary shock than in case of a deflationary one. For example, while depreciation of the domestic currency should be accompanied by a rise in the interest rate, its appreciation of the same size should be accompanied by a much smaller cut in the interest rate due to lower downward pass-through and higher downward price rigidity.

The rest of the paper is organised as follows. In section 2 we review the most relevant literature on the pass-through effect, the optimal monetary policy and the asymmetric price rigidity. In section 3 we lay out the theoretical model and determine the optimal interest rate rules under symmetric and asymmetric price rigidity. Section 4 is devoted to conclusions, recommendations and further research.

## 2. Literature Review

### 2.1. Pass-Through Effect and Monetary Policy

In the earliest open economy macroeconomics it was common to think that purchasing power parity (PPP) is the reason why domestic prices react to exchange rate movements. According to PPP, an exchange rate shock should be passed onto the domestic price level in full extent, implying complete pass-through and no arbitrage opportunities of trade between countries.

But extensive literature on the pass-through effect (PTE) in different countries finds empirically that it is far from complete, although significant, and varies greatly across countries, industries and other parameters under consideration.

A number of theories were proposed to explain why PTE is incomplete in real life. Some authors argue that the ultimate explanation comes from microeconomics. The Obstfeld and Rogoff (2000) model assumes transportation costs, which increase prices of imported goods and preclude their perfect substitutability for the competing domestic goods. Also presence of non-traded goods in consumption may explain low degree of pass-through (Betts and Kehoe, 2001). Another argument is that the costs of imported inputs constitute only a small part of the total cost of a final good, but the majority of the costs being attributable to local inputs and non-traded services, such as marketing and distribution (Corsetti and Dedola, 2001; Burstein, Neves and Rebelo, 2003).

Several authors (Bergin and Feenstra, 2001; Bergin, 2001, Corsetti and Dedola, 2001; Bachetta and Wincoop, 2002) argue that PTE may be below 100% due to imperfect competition, which may create incentives for the optimal price discrimination or strategic pricing. A theoretical basis for most of these studies was the work of Dornbusch (1987), which appeals to the arguments from industrial organization. Specifically, it explains the differences in PTE by the market concentration, the degree of import penetration and the substitutability of imported and local goods. For instance, if profit-maximizing firms have significant market power in a given industry, PTE is expected to be high in spite of other factors (Phillips, 1988). On the contrary, if firms aim to maximise their market share instead of profits, PTE will be lower (Hooper and Mann, 1989; Ohno, 1990). Moreover, if opportunities to discriminate between markets exist, then the situation of pricing to market may occur, which will lead to different PTE in different segmented markets (Krugman, 1987; Gagnon and Knetter, 1992).

Finally, if an imported good is an intermediate good, which has locally produced substitutes priced in the domestic currency, the local producer may replace the imported input by the domestic one in response to exchange rate changes (Obsfeld, 2001). Such “expenditure-switching effect” may also exist in the market for final goods, reducing pass-through (Burstein, Eichenbaum and Rebelo, 2002).

Other authors claim that incomplete pass-through is more a macroeconomic phenomenon, which results from price stickiness. For example, Chaudry and Hakura (2001) present a cross-country evidence that pass-through varies systematically with the average inflation rate. They claim that high inflation countries exhibit higher degree of pass-through. Table 1 presents pass-through elasticities for three groups of countries, different by their inflation rates.

**Table 1.** Average pass-through elasticity of consumer prices

	1 quarter	4 quarters
Countries with inflation lower than 10% pa	0.04	0.14
Countries with inflation 10-30% pa	0.09	0.33
Countries with inflation higher than 30% pa	0.22	0.5

*Source:* Chaudry and Hakura (2001)

But if pass-through is systematically related to the level of inflation, which, in turn, is determined by the local monetary policy, this would have important implications for appropriate monetary policy in an open economy. Thus, the endogeneity of pass-through is studied both theoretically and empirically in Devereux and Yetman (2003). They develop an open economy sticky price model where the degree of pass-through is determined by the frequency of price adjustments by importing firms. Since higher inflation implies higher frequency

of price changes for a given size of menu cost, they claim that pass-through will be endogenous to the monetary policy regime. Their empirical test for 118 countries confirms that countries with higher inflation tend to have higher pass-through, but this relationship is non-linear.

The degree of the foreign exchange intervention seems to be also responsible for the extent of pass-through. For example, Coricelli, Jazbec and Maston (2004) find in a cross-country study that pass-through is larger when there is less exchange rate management.

So, what should be the optimal monetary policy in an open economy with sticky prices and incomplete pass-through? While in a closed economy the main problem of the monetary policy is to overcome the trade-off between inflation and unemployment, what have been extensively studied in the New Keynesian Theory (e.g. Clarida, Gali and Gertler, 1999), in an open economy there is an additional trade-off between inflation and exchange rate targeting. An economy may either leave exchange rates freely floating and use its monetary policy to target the domestic inflation, but then the economy will be more dependent on external shocks, or make the economy less dependent on external shocks by targeting the exchange rate by means of interventions in the foreign exchange market, but then the monetary policy will be endogenous to exchange rate changes and the inflation targeting will be impossible. For example, such problem of the optimal degree of intervention has been extremely relevant for Russia in recent years since the economy faces a clear trade-off between appreciating domestic currency and high inflation.

A highly relevant study of the optimal exchange rate intervention is performed in Devereux and Engel (2000). This is one of the earliest papers, which attempts to analyze exchange rate regimes within an expected-utility-maximizing framework in the presence of nominal rigidities and incomplete pass-through. Specifically, they distinguish between two types of pricing strategies in an economy: producer currency pricing (full pass-through) and local currency pricing. In a welfare-based general equilibrium two-country model they analyze to what extent monetary policy should be employed in maintaining the exchange rate. They find that under local currency pricing, the fixed exchange rate regime would be optimal in the presence of real country specific shocks, while the freely floating exchange rate is desirable when real shocks are insignificant and the country's monetary sector is stable. On the other hand, under producer currency pricing, a country would never choose a clean float, even if it had a completely stable monetary sector, because the exchange rate volatility would have a direct influence on the expected consumption and lead to welfare losses.

Another theoretical paper on the optimal monetary policy under incomplete pass-through is Devereux and Lane (2003). They build a general equilibrium sticky price model for an emerging market economy, which is assumed to be

small and subject to external shocks to the real interest rate and terms of trade. The key features of their model are a) the presence of nominal rigidities; b) lending constraints on investment financing; and c) incomplete exchange rate pass-through onto import prices. They evaluate three types of monetary rules: a fixed exchange rate rule, a CPI inflation targeting rule and a non-traded goods inflation targeting rule – using second order approximation of a utility function as a social welfare criterion. In calibration of their model they find that the degree of pass-through in import prices is central in determining the appropriate monetary policy rule. Under high pass-through it is advisable to stabilize prices of non-traded goods, since both fixed exchange rate and CPI targeting rules stabilize inflation at the expense of real output stability. With delayed pass-through, the trade-off between real stability and nominal stability disappears and the best rule is to stabilize CPI inflation. Thus, they claim, a low degree of exchange rate pass-through may be an important prerequisite for the success of inflation targeting in emerging markets.

But since lower pass-through is associated with lower inflation both theoretically and empirically, it becomes even more important to stabilize the domestic inflation. So, this mutual endogeneity of PTE and inflation should be taken into account in designing the appropriate monetary policy.

Another welfare analysis of different monetary policy rules is presented in Gali and Monacelli (2005). They lay out a New Keynesian small open economy general equilibrium model with an endogenous monetary policy. In contrast to the above study, they assume that the law of one price holds for the individual goods all the time. The authors analyze three types of rules: CPI inflation targeting, domestic inflation targeting and the effective nominal exchange rate peg. As in the study described above, they use a second order approximation of the utility function of the representative consumer as a social welfare criterion. Again, they calibrate the model in order to rank the rules according to the welfare losses they generate. They find that the domestic inflation-based Taylor rule dominates the CPI-based Taylor rule, which, in turn, dominates the exchange rate peg.

## 2.2. *Asymmetric Nominal Rigidity*

The studies described above assume symmetrically rigid prices and usually study effects of a currency depreciation on the inflation. But what would happen if the domestic currency appreciates? According to the above studies, there should be a similar burst of deflation due to the pass-through effect. Then, following the optimal rules, monetary policy should adjust to the same extent, but in the opposite direction.

But in reality we rarely observe deflation resulting from a domestic currency appreciation (Dobrynskaya and Levando, 2005). Similarly, we hardly observe

deflation resulting from a negative money supply shock, while we do observe a more significant drop in output, than in case of a positive money supply shock (Cover, 1992). Recent literature proposes asymmetric nominal rigidities as the explanation for this phenomenon. For example, asymmetric price rigidity means that prices are more sticky downwards than upwards.

Several theories are proposed to explain this phenomenon. The most traditional view is that the labour market is the primary source of the asymmetry. Many papers show that a wage cut is a much rarer phenomenon than a wage increase (e.g. Holden and Wulfsberg, 2004; Altonji and Devereux, 1999; Holzer and Montgomery, 1993). In labour economics this is termed “ratchet effect” and the first intuitive explanation for it was found in possible money illusion of workers, as proposed by Keynes. Neo-Keynesian models (e.g. Ball, Mankiw and Romer, 1988) see wage rigidity arising endogenously in bargaining process because of implicit contracts, imperfect information, efficiency wages and/or insider-outsider considerations. Most recent explanations of the downward wage rigidity such as fairness considerations, reference points and loss aversion of workers come from behavioural economics (e.g. Diamond and Tversky, 1997).

An asymmetry is also widely observed in the prices of final goods. For example, Peltzman (2000) studies over 240 markets for consumer as well as producer goods and finds that asymmetries are pervasive, substantial and durable, and exist in periods of low inflation as well as in periods of high inflation. These asymmetries also apply to price indices (Verbrugge, 1998). Among theoretical explanations for the asymmetric price rigidity are consumer search with learning from prices (Benabou and Getner, 1993), consumer search with reference prices (Lewis, 2003), tacit collusion among firms with the past price serving as a focal price (Borenstein et al., 2003), implicit coordination among firms in an industry to rise prices after a positive cost shock while not to reduce prices after a negative one (Bhaskar 2002) and a positive trend inflation in an economy (Ball and Mankiw, 1994).

As claimed by DeLong and Summers (1988) and Ball, Mankiw and Romer (1988), asymmetries in wages and prices may have important implications for the conduct of the appropriate stabilization policy. Nevertheless, such asymmetries are rarely incorporated into theoretical models of the optimal monetary policy.

For example, Holden (2002) builds a theoretical model of wage setting in which the institutional framework crucially affects the existence and importance of the downward nominal wage rigidity. His model predicts that the downward nominal wage rigidity is likely to be stronger the higher is the coverage of collective agreements and the stricter is the employment protection legislation. Under such conditions, aiming at very low inflation may involve considerable costs

in the form of higher unemployment and lower output. Hence, the downward nominal rigidity may give a rationale for positive target inflation.

A similar conclusion is drawn in Itskhoki (2004). He adds exogenously asymmetric menu costs to Ball and Mankiw (1994) model of a closed economy in order to observe asymmetric price rigidity even in case of zero trend inflation. Under this setting, he finds that positive long run inflation minimizes social losses.

So, the literature on the optimal monetary policy under asymmetric price rigidity is not rich in its recommendations. The main prescription is drawn for a closed economy, which speaks in favour of positive long-run trend inflation, since it alleviates price stickiness and smooths the business cycle.

### 3. The Model of the Optimal Monetary Policy

#### 3.1. Set-up of the Model

In this section we lay out a simple stochastic sticky price model for a small open economy which is similar to the New Keynesian closed economy model popularized by Clarida, Gali and Gertler (1999).

The *demand side* of an economy is represented by a forward-looking IS-type equation of the following form:

$$y_t = E_t[y_{t+1}] - b(i_t - E_t[\pi_{t+1}]) + cE_t[\Delta q_{t+1}] + \varepsilon_t, \quad (1)$$

where  $y_t$  is the output gap,  $i_t$  is the nominal interest rate,  $q_t$  is the real exchange rate, an increase in which means real depreciation of the domestic currency,  $\varepsilon_t$  is a demand shock (e.g. government expenditure shock), which is assumed to be normally distributed with the mean of zero, and  $a$ ,  $b$  and  $c$  are positive coefficients.

The IS curve has survived the New Keynesian revolution and is nowadays derived from maximization of expected discounted utility function by a representative consumer. For microfounded derivation of the IS curve similar to (1) see Gali and Monacelli (2005), where parameters  $a$ ,  $b$  and  $c$  are functions of the primitive parameters of their model. If parameter  $c$  equals zero, equation (1) corresponds to the closed economy version of IS curve, which is used in Clarida, Gali and Gertler (1999) and its step-by-step derivations are available in, for example, Woodford (1996) and Bernake, Gertler and Gilchrist (1998). Such New Keynesian IS curve is different from a traditional one since current output depends positively on expected future output due to consumption smoothing and negatively on real interest rate due to intertemporal substitution of consumption. Since net export is another component of aggregate demand in an open econo-

my, output gap also depends on expected changes in the real exchange rate.

The *supply side* of the economy is presented by a New Keynesian Phillips curve. In order to derive it, we distinguish between two types of firms in the economy.

Firms of the first type are importing firms and they set prices according to the Law of One Price:

$$P_{it} = P_{it}^* S_t \quad (2)$$

where  $P_{it}$  and  $P_{it}^*$  are domestic and foreign prices of the  $i$ -th import good respectively and  $S_t$  is the nominal exchange rate. Aggregating (2) over all such firms and log-linearizing, we obtain the following relationship for the inflation in this “full pass-through” (FPT) sector of the economy:

$$\pi_t^{FPT} = \pi_t^* + \Delta s_t \quad (3)$$

Firms of the second type are either local firms or importing firms, which adopt a pricing-to-market strategy. This means that the pricing decisions of these firms are not affected by exchange rate considerations, implying zero pass-through, but are affected solely by local economic conditions. We assume that these firms set prices in a staggered fashion a la Calvo model (1983). This time-dependent modelling has become very popular in derivation of New Keynesian Phillips curve mainly because it allows obtain explicit analytical solution to firms’ profit maximization problem. The model assumes that every period each firm receives a signal with some probability  $\theta$  that it should keep its price fixed in this period and with probability  $1 - \theta$  that it should adjust. Hence, the average time over which a firm’s price is fixed is  $1/(1 - \theta)$ . The higher is  $\theta$ , the higher is the degree of price stickiness in an economy. Aggregating the pricing decisions of the firms of the second type and log-linearizing about the steady state, we obtain the relationship for inflation in this “pricing-to-market” (PTM) sector of the economy:

$$\pi_t^{PTM} = E_t[\pi_{t+1}] + dy_t + \omega_t \quad (4)$$

where the parameter  $d$  is positive, depends negatively on  $\theta$  and captures the degree of price stickiness in the economy. Equation (4) is usually called the New Keynesian Phillips curve and its step-by-step derivation can be found in, for example, Gali and Monacelli (2005). It is different from a traditional Phillips curve because here inflation depends on the expected future inflation and not on the expected current inflation. In our case this relationship is valid for the second-type firms only and it shows that their inflation depends on the expected overall inflation, the current output gap and a random supply shock, which is assumed to be normally distributed with the mean of zero.

To derive a Phillips curve for our economy with two types of firms we assume that there is a share  $e$  of the firms of the first type and a share  $1-e$  of the firms of the second type. Then the overall inflation is:

$$\pi_t = e\pi_t^{FPT} + (1-e)\pi_t^{PTM} \quad (5)$$

Substituting (3) and (4) into (5) and using the following relationship for the real exchange rate:

$$Q_t \equiv \frac{S_t P_t^*}{P_t} \text{ or } \Delta q_t \equiv \Delta s_t + \pi_t^* - \pi_t$$

we obtain the following version of a New Keynesian Phillips curve for the economy:

$$\pi_t = \frac{e}{1-e} \Delta q_t + E[\pi_{t+1}] + dy_t + \omega_t \quad (6)$$

This Phillips curve is different from the ones used in the literature since it explicitly shows the degree of pass-through onto consumer price inflation, measured by the coefficient  $e/(1-e)$ . The higher is the share of first-type firms  $e$ , the higher is the pass-through effect in an economy. Our model assumes  $e$  to be exogenous, but in reality it may vary depending on economic conditions. For example, Devereux and Yetman (2003) model pass-through effect to be endogenous to local monetary policy. They claim: “‘Looser’ monetary policy, which implies a higher mean inflation and a higher volatility of the exchange rate, will lead to more frequent price changes and a higher rate of pass-through”.

So, there are two reasons for price stickiness in our model: incomplete pass-through measured by parameter  $e$  (the higher is  $e$ , the further the curve shifts as a result of exchange rate changes) and staggered pricing measured by parameter  $\theta$ , which in turn depends on parameter  $\theta$  (the higher is  $\theta$ , the flatter is the Phillips curve).

The equilibrium in the economy is described by the system of the IS and the Phillips curves holding simultaneously.

To complete the model, we assume that the real exchange rate follows non-stationary AR(1) process (a random walk):

$$q_t = q_{t-1} + \eta_t \quad (7)$$

where  $\eta_t$  is a normally distributed shock with the mean of zero. Such exchange rate behaviour is often observed in the real life in countries with the flexible exchange rate regime.

### 3.2. The Optimal Monetary Policy under Discretion

As has become common in the literature on optimal monetary policy, we assume that the monetary authority minimizes the following loss function:

$$L_t = (\pi_t - \pi^T)^2 + \lambda y_t^2 \quad (8)$$

Such a loss function is not *ad hoc* and can be derived by second order approximation of the utility losses by a representative consumer (see Rotemberg and Woodford, 1999 and Woodford, 2003).

Substituting the Phillips curve (6) into the loss function (8) and making use of (7) and minimizing with respect to  $\pi_t$  we obtain the following reaction function of optimal inflation to expected inflation:

$$\pi_t = \frac{d^2}{d^2 + \lambda} \pi^T + \frac{\lambda}{d^2 + \lambda} E[\pi_{t+1}] + \frac{e\lambda}{(1-e)(d^2 + \lambda)} \eta_t + \frac{\lambda}{d^2 + \lambda} \omega_t \quad (9)$$

Taking expectations of the both sides of (9), solving for the expected inflation and substituting it back into the reaction function, we obtain the expression for the equilibrium inflation, which minimizes the losses of society:

$$\pi_t = \pi^T + \frac{e\lambda}{(1-e)(d^2 + \lambda)} \eta_t + \frac{\lambda}{d^2 + \lambda} \omega_t \quad (10)$$

We see that in order to minimize the social losses, domestic inflation should be adjusted to exchange rate and supply shocks. It should be noticed that there is no dynamic inconsistency here since the expected inflation equals the target inflation and there is no incentive to deviate from this target unless there are some unexpected shocks.

Substituting (10) into (6) we find the equilibrium output gap:

$$y_t = -\frac{ed}{(1-e)(d^2 + \lambda)} \eta_t - \frac{d}{d^2 + \lambda} \omega_t \quad (11)$$

The final step is to derive the optimal instrument rule where the real interest rate serves as the instrument for the monetary policy. To do this we substitute (11) into the IS curve (1) and solve for  $r$ :

$$r_t^{opt} = \frac{a}{b} + \left[ \frac{ed}{b(1-e)(d^2 + \lambda)} \right] \eta_t + \frac{d}{b(d^2 + \lambda)} \omega_t + \frac{1}{b} \varepsilon_t \quad (12)$$

or, for the sake of simplicity,

$$r_t^{opt} = r_0 + A\eta_t + B\omega_t + C\varepsilon_t, \quad (13)$$

where A, B and C are positive coefficients. This rule states that in order to minimize the social losses the real interest rate should respond to all types of shocks in the economy: real exchange rate shocks, supply shocks and demand shocks — with positive coefficients. This means, for example, that positive shocks, being inflationary, should be accompanied by a contractionary monetary policy, leading to negative output gap and lower equilibrium inflation, than what would be without intervention.

Figure 1 illustrates the optimal reaction of the real interest rate to a positive real exchange rate shock  $\eta_t$ , assuming that demand and supply shocks equal zero.

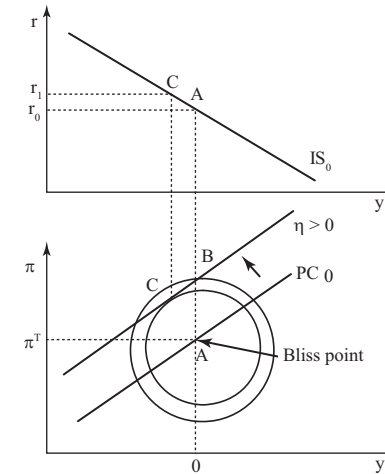


Figure 1. Monetary policy reaction to a positive exchange rate shock

Assume that initially the economy is at point A with the target inflation and zero output gap. The corresponding interest rate is  $r_0$ . An unexpected positive exchange rate shock (depreciation of the domestic currency) shifts the Phillips curve upwards due to the pass-through effect. If the interest rate is not adjusted, the economy will move to point B with an inflation rate higher than the target. The corresponding social losses can be illustrated by the circle coming through point B. We can see that in order to minimise the social losses the interest rate should be increased to  $r_1$  so that the economy comes to point C with a negative output gap and an inflation rate closer to the target than would be otherwise. Such an increase in the interest rate will also make the depreciation of the domestic currency less pronounced, reducing pass-through. So, a contractionary monetary policy is desirable in case of depreciation of the domestic currency.

By the same logic, a negative exchange rate shock should be accompanied by a reduction in the interest rate meaning expansionary monetary policy.

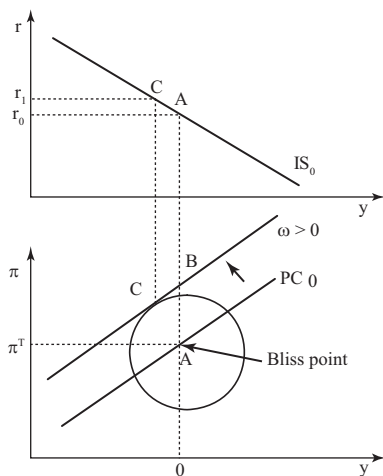
**Proposition 1.** *The optimal monetary policy should react to the exchange rate movements and should counteract the exchange rate changes reducing pass-through onto domestic prices. The adjustment in the interest rate should be more significant if:*

- *pass-through effect is higher (parameter  $e/(1-e)$  is higher)*
- *prices are less sticky (parameter  $d$  is higher, provided that  $d < \sqrt{\lambda}$ )*
- *the elasticity of consumption with respect to the interest rate is lower (parameter  $b$  is lower)*
- *the government cares less about the output gap (parameter  $\lambda$  is lower)*

**Proof.** To prove this we differentiate A with respect to each of the parameters and determine the signs of the corresponding derivatives. The expressions for the derivatives and their signs are presented in Appendix 1.

The finding that the higher is pass-through effect the higher should be the optimal adjustment in the interest rate is in line with Devereux and Engel (2000) who claim that although under low pass-through freely floating exchange rate (a monetary policy in which exchange rates are not a consideration) may be optimal in some circumstances, this is never true in case of producer currency pricing leading to full pass-through.

In the environment of highly volatile oil and other resource prices, it is important to analyse the optimal response of the monetary policy to supply shocks. Figure 2 illustrates the optimal interest rate reaction to a positive supply shock  $\omega_t$ .



**Figure 2.** Monetary policy reaction to a positive supply shock

A positive supply shock shifts the Phillips curve upwards. Because of the trade-off between inflation and the output gap, the social losses are minimised at point C with higher interest rate, inflation higher than the target and negative output gap. To obtain the target inflation, the interest rate would need to increase further, but this would lead to high negative output gap, which is costly. So, an adverse supply shock should be accompanied by contractionary monetary policy, while a favourable one by expansionary monetary policy. This finding is rather standard for Keynesian literature on optimal monetary policy.

**Proposition 2.** *The optimal interest rate response to a supply shock should be more significant if:*

- *prices are less sticky (parameter  $d$  is higher, provided that  $d < \sqrt{\lambda}$ )*
- *the elasticity of consumption with respect to the interest rate is lower (parameter  $b$  is lower)*
- *the government cares less about the output gap (parameter  $\lambda$  is lower)*

**Proof.** We differentiate B with respect to each of the parameters and determine the signs of the corresponding derivatives. The expressions for the derivatives and their signs are presented in Appendix 1.

The analysis of a demand shock  $\varepsilon_t$  is straightforward. Since such a shock does not create any trade-off between the targeted parameters the task of the optimal monetary policy is simply to adjust the interest rate along the IS curve in order to bring the economy back to the bliss point. Therefore, the magnitude of the interest rate adjustment does not depend on the parameters of the model except for the elasticity of consumption to the interest rate  $b$  (the slope of the IS curve).

The above analysis assumes that prices are symmetrically rigid upwards and downwards. But the empirical evidence described in section 2.2 suggests convincingly that prices are more rigid downwards than upwards. Such asymmetric price rigidity can be captured by two parameters in our model:  $d$  and  $e$ . First, parameter  $d$  may be higher for upward changes in prices than for downward ones. This will result in a kink of the Phillips curve at the zero level of inflation. Secondly, the pass-through effect may be lower in cases of appreciation of the domestic currency than in cases of its depreciation (as reported in Dobrynskaya and Levando, 2005) as more firms may adopt pricing-to-market strategy instead of reducing their prices. Also the model of Devereux and Yetman (2003) suggests that lower pass-through is associated with higher price stickiness and visa versa. Asymmetric pass-through will result in unequal shifts of the Phillips curve due to a positive and a negative exchange rate shocks of the same size.

So, the expression for the Phillips curve under asymmetric price rigidity will be the following:



$$\pi_t = \begin{cases} \frac{e_1}{1-e_1} \Delta q_t + E[\pi_{t+1}] + \hat{d}y_t + \omega_t, \Delta q_t > 0 \\ \frac{e_2}{1-e_2} \Delta q_t + E[\pi_{t+1}] + \hat{d}y_t + \omega_t, \Delta q_t < 0 \\ e_1 > e_2 \end{cases} \quad (14)$$

where

$$\hat{d} = \begin{cases} d_1, \pi_t > 0 \\ d_2, \pi_t < 0 \\ d_1 > d_2 \end{cases}$$

It should be noted that the asymmetric price rigidity, captured by parameter  $\hat{d}$ , appears when we compare cases of positive versus negative inflation and not when we compare cases of inflation versus disinflation. Therefore, the Phillips curve has a kink at the zero level of inflation and not at the target level of inflation if it is positive.

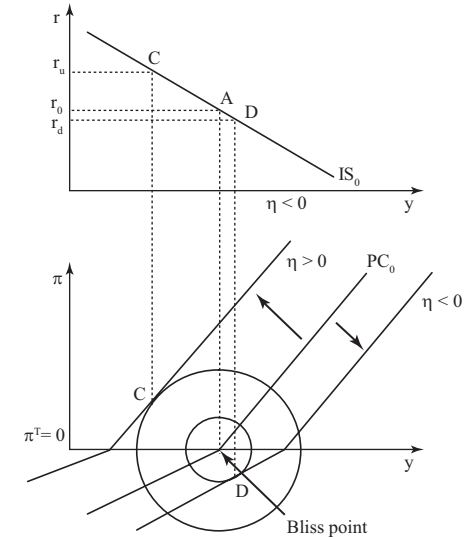
Minimizing the social loss function (8) subject to the Phillips curve (14) and using the IS curve (1) we obtain the following optimal interest rate rule assuming zero target inflation:

$$r_t^{opt} = \begin{cases} \frac{a}{b} + \left[ \frac{e_1 d_1}{b(1-e_1)(d_1^2 + \lambda)} \right] \eta_t + \frac{d_1}{b(d_1^2 + \lambda)} \omega_t + \frac{1}{b} \varepsilon_t, \pi_t > 0 \\ \frac{a}{b} + \left[ \frac{e_2 d_2}{b(1-e_2)(d_2^2 + \lambda)} \right] \eta_t + \frac{d_2}{b(d_2^2 + \lambda)} \omega_t + \frac{1}{b} \varepsilon_t, \pi_t < 0 \end{cases} \quad (15)$$

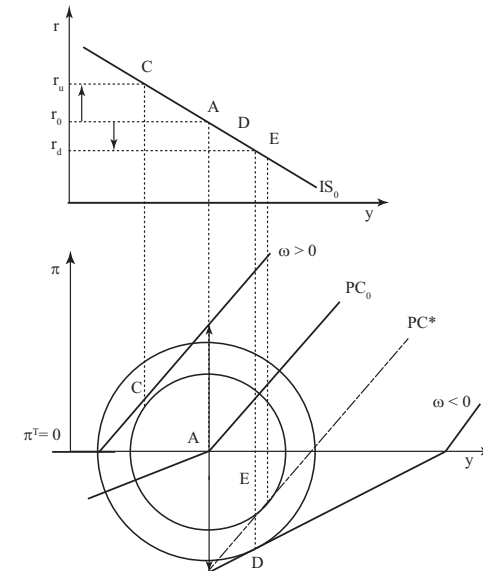
Figure 3 analyses the optimal monetary policy in cases of a positive and a negative exchange rate shocks of the same size assuming asymmetric price rigidity.

The kinked Phillips curve shifts further as a result of a positive exchange rate shock than a negative one due to asymmetric pass-through effect. In case of a positive shock the loss minimizing point is point C, which corresponds to an increased interest rate to  $r_u$ . In case of a negative shock the optimal point is point D. To reach this point the interest rate should be reduced, but the magnitude of the change should be much less. The same conclusion will be true for a positive target inflation, although the difference in the required interest rate changes will be less significant.

Figure 4 analyses positive and negative supply shocks of the same size assuming asymmetric price rigidity.



**Figure 3.** Monetary policy reaction under asymmetric price rigidity (exchange rate shocks)



**Figure 4.** Monetary policy reaction under asymmetric price rigidity (supply shocks)

A negative supply shock shifts the kinked Phillips curve downwards by the same magnitude as a positive one. If prices were symmetrically rigid, the optimal points in cases of a positive and a negative shock would be points C and E respectively. In order to reach these points, the interest rate should be adjusted by the same absolute value. But since prices are assumed to be more sticky downwards than upwards, the optimal point in case of the negative supply shock is point D, which is to the left of point E. This means that the optimal interest rate rule is to adjust less in response to a negative supply shock than in response to a positive one. But this asymmetry in monetary policy reaction would disappear had the target inflation been high enough to overweight the negative supply shock.

**Proposition 3.** *Under some conditions, the optimal monetary policy should be asymmetric depending on the sign of a real exchange rate or a supply shock. The optimal degree of the interest rate adjustment should be higher in case of positive shocks than in case of negative ones due to higher downward price rigidity and lower downward pass-through.*

**Proof.** Recall from the proofs of propositions 1 and 2 that the derivative of A with respect to pass-through effect ( $\epsilon/(1-\epsilon)$ ) is positive and the derivatives of A and B with respect to price flexibility ( $d$ ) are also positive, provided that  $d < \sqrt{\lambda}$ . Since it is assumed that pass-through effect and price flexibility are higher in case of an inflationary shock than in case of a deflationary one, the adjustment in the interest rate should also be higher.

This result is new to the Keynesian literature and has interesting practical implications for the conduct of monetary policy. It predicts that in order to minimise the social losses, the monetary authority should determine not only the direction of the required policy instrument change, but also its magnitude depending on the sign of a shock. If the monetary policy rule is specified so that it does not take into account such asymmetries, then following this rule may result in the equilibrium inflation and output gap, which are far from optimal. For example, if there is high upward pass-through but zero downward pass-through in an economy, while it may be optimal to increase the interest rate significantly as a result of a sharp depreciation of the domestic currency, it may also be optimal not to respond to the domestic currency appreciation at all. Then following the rule of a significant change in the interest rate due to an exchange rate shock will lead to higher social losses in case of an appreciation of the domestic currency than would be without monetary policy reaction.

#### 4. Conclusion

In this paper we build a simple general equilibrium sticky price model of a small open economy where real exchange rate behaves like a random walk. Using quadratic loss function as an approximation of the social utility losses,

we find that the optimal monetary policy rule is to adjust the interest rate in response to exogenous exchange rate, supply and demand shocks with positive coefficients. We claim that the optimal degree of such adjustment depends positively on pass-through effect and negatively on price stickiness in an economy.

Since the numerous empirical evidence speaks in favour of asymmetric price rigidity, in our theoretical model we assume lower degree of pass-through and price flexibility in case of downward price adjustments, resulting from deflationary exchange rate or supply shocks. Under this assumption, the optimal monetary policy should be different in cases of positive and negative shocks. We claim that negative shocks such as the domestic currency appreciation or a reduction in raw materials prices should be accompanied by a smaller adjustment in the interest rate than positive ones of the same size since prices are more sticky downwards.

Our findings show that in order to design the optimal monetary policy it is important to know the parameters of the economy, such as upward and downward price stickiness, upward and downward pass-through, the relative weights of the inflation and the output gap in the social loss function and others. It is especially important to check whether the assumption that  $d < \sqrt{\lambda}$  is satisfied, since in the other case the conclusions of our model may be reversed. Therefore, further empirical research is required to estimate the above parameters. Further research could also concentrate on the analysis of monetary policy rules under asymmetric price rigidity and cross-country comparisons of monetary policy practice.

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## Appendix 1

### Proof of proposition 1

Parameter	$e(1-e)$	$d$	$b$	$\lambda$
$\frac{\partial A}{\partial(\text{Parameter})}$	$\frac{d}{b(d^2 + \lambda)}$	$\frac{e(\lambda - d^2)}{(1-e)b(d^2 + \lambda)^2}$	$\frac{-ed}{(1-e)(d^2 + \lambda)b^2}$	$\frac{-ed}{(1-e)b(d^2 + \lambda)^2}$
Sign	+	+ if $d < \sqrt{\lambda}$	—	—

### Proof of proposition 2

Parameter	$d$	$b$	$\lambda$
$\frac{\partial B}{\partial(\text{Parameter})}$	$\frac{\lambda - d^2}{b(d^2 + \lambda)^2}$	$\frac{-d}{(d^2 + \lambda)b^2}$	$\frac{-d}{b(d^2 + \lambda)^2}$
Sign	+ if $d < \sqrt{\lambda}$	—	—

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Тел.: (495) 772-95-71; 772-95-73