РОССИЙСКАЯ ЭКОНОМИЧЕСКАЯ ШКОЛА

NEW ECONOMIC SCHOOL

Best student papers

Oleg Itskhoki

Asymmetric Price Rigidity and the Optimal Rate of Inflation

Working Paper # BSP/2004/075 E

This paper is based on the Master Thesis prepared at NES in 2004 in the framework of the research project "Monetary Policy in Transition Economies" under the supervision of prof. O.A. Zamulin (Ph.D., NES, CEFIR) and prof. K.A. Sosunov (Ph.D., NES, Institute for Open Economy).

The research was supported by Ford Foundation, World Bank, John D. and Catherine T. MacArthur Foundation.

The author is grateful to leaders (O. Zamulin and K. Sosunov) and all participant of NES research project on Monetary Policy, as well as to S. Anatolyev, V. Polterovich, N. Shagas, and A. Sotskov for useful comments and discussion.

Moscow
2004

Itskhoki, Oleg. Asymmetric Price Rigidity and the Optimal Rate of Inflation / Working Paper # BSP/2004/075 E. – Moscow, New Economic School, 2004. – 28 p. (Engl.)

This paper addresses the issue of optimal rate of inflation. Stable inflation at some optimal level is the long-term goal of monetary policy as opposed to short-term stabilization policy. In the paper it is argued that the optimal rate of inflation is positive due to a number of reasons.

The paper studies the relationship between long-run level of inflation and price stickiness. In particular the case of asymmetric price rigidity – a situation when prices are more rigid downwards than upwards – is analyzed. The idea of asymmetric price rigidity is not new for (New) Keynesian theories. However, formal analysis of asymmetric rigidity is far from being exhaustive. It turns out that asymmetric price rigidity may enhance the optimality of a positive inflation.

The paper studies a formal model of asymmetric rigidity and its implication. Some possible sources of asymmetry are identified. An attempt is made to find empirical support for the hypothesis of asymmetric rigidity.

Key words: New-Keynesian Theories, Sticky Prices, Asymmetric Rigidity, Optimal Inflation, Monetary Non-neutralities

Ицхоки О.Е. Асимметричная жесткость цен и оптимальный уровень инфляции / Препринт # BSP/2004/075 E. - М.: Российская Экономическая Школа, 2004. – 28 с. (Англ.)

Данная работа посвящена вопросу выбора оптимального уровня инфляции. Постоянная инфляция на некотором оптимальном уровне является долгосрочной целью монетарной политики, в отличие от краткосрочной стабилизационной политики. В работе утверждается, что оптимально выбирать положительную долгосрочную инфляцию.

В данной работе мы исследуем связь между долгосрочным уровнем инфляции и жесткостью цен. В первую очередь, нас интересует случай асимметричной жесткости цен. Под асимметричной жесткостью цен понимается ситуация, когда цены оказываются более жесткими при снижении, чем при росте. Идея асимметричной жесткости цен не является новой для (Ново-) кейнсианских теорий. Однако формальный анализ данной проблемы практически отсутствует. В работе мы показываем, что асимметричная жесткость цен может рассматриваться как еще один аргумент в пользу положительной долгосрочной инфляции.

В работе рассматривается формальная модель асимметричной жесткости цен, идентифицируются потенциальные источники асимметричной жесткости цен, проводится эмпирическая проверка гипотезы о наличии асимметричной жесткости цен в реальных данных.

Ключевые слова: Ново-кейнсианские тории, жесткие цены, асимметричная жесткость цен, оптимальный уровень инфляции, отсутствие нейтральности денег

ISBN

Contents

Contents 3

1. Introduction 4

2. Optimal Rate of Inflation 4

3. Asymmetric Rigidity 6

4. The Model of Asymmetric Price Rigidity 7

4.1. Set Up of the Model

4.2. Partial Equilibrium Analysis: The Firm's Problem

4.3. General Equilibrium of the Model

4.4. Optimal Rate of Inflation

4.5. Simulations Results

4.5.1. Partial Equilibrium and Optimal Rate of Inflation

4.5.2. General Equilibrium

5. Empirical Evidence 20

5.1. Univariate Approach

5.2 Multivariate Approach

6. Conclusion 24

Reference 25

Appendix 28

1. Introduction

This paper addresses the issue of optimal rate of inflation. Stable inflation at some optimal level is the long-term goal of monetary policy as opposed to short-term stabilization policy. In the paper it is argued that the optimal rate of inflation is positive due to a number of reasons.

Essentially, the arguments in favor of positive optimal inflation fall into three groups. Desirable level of inflation may be positive as a result of tax system optimization (i.e., seigniorage argument). However, this does not seem to be a sufficiently important reason for long-run monetary policy. The other two groups of arguments appear to be more relevant. Positive rate of inflation is desirable for the financial markets and the conduct of short-run macro-stabilization policy since this assures that nominal interest rates are positive. And, finally, trend-inflation alleviates price stickiness and contributes to business cycle stabilization.

In this paper we investigate the relationship between long-run level of inflation and price stickiness. In particular we analyze the case of asymmetric price rigidity – a situation when prices are more rigid downwards than upwards. The idea of asymmetric price rigidity is not new for (New) Keynesian theories. However, formal analysis of asymmetric rigidity is far from being exhaustive. It turns out that asymmetric price rigidity may enhance the optimality of positive inflation.

In the first part of the paper we discuss briefly certain arguments on optimal rate of inflation. The second part of the paper is devoted to asymmetric price rigidity, its possible sources and consequences. In the third part we present a formal model of asymmetric price rigidity, which is a slight modification of Ball and Mankiw (1994) model. And the final part provides some empirical evidence on asymmetric rigidity in real data.

2. Optimal Rate of Inflation

The issues connected with inflation have always been central to Macroeconomics. There is a wide consensus among the economists that high inflation affects negatively economic activity[1]. Two-digit inflation is virtually unacceptable for most developed countries.[2] At the same time monetary authorities of most countries seem to fear deflation much more than inflation of the equal size. This fear has recently become more obvious in the view of Japanese stagnation of the 1990's.

There exists an implicit agreement among the central bankers that slightly positive (about 2 or 3 percent) stable inflation is desirable. For example, this point of view is advocated by Lawrence Summers (1991). However, Alan Greenspan declares that his long-term monetary goal is stable prices and zero inflation.[3] Nevertheless, very few countries with good macroeconomic dynamics show close to zero or

[1] The mechanism of this phenomenon seems to be the following: higher inflation is always more volatile and unexpected; unexpected inflation distorts intertemporal decision and risk-averse agent cut down their transactions. One may think here of the Bruno and Fischer rule of 40% threshold level of inflation (Bruno and Fischer 1990). The other reason outlined by Summers (1991) is that nonzero inflation generates an inefficient rent-seeking process for deferred payment. This argument, however, needs further formalization.

[2] This may be not true, however, for developing countries, such as Russia, that face a substantial tradeoff between monetary stability and real growth. The real losses of bringing inflation down to one-digit level may be prohibitively high for these countries. Similar issues are discussed by Blanchard (2003).

[3] Greenspan defines price stability as a rate of inflation that can be not taken into account when forming long-term intertemporal expectations. Inflation measured by CPI is biased upwards due to substitution effect and quality

negative rates of inflation. David Romer (2000) argues that since World War II most countries have witnessed only periods of disinflation but not deflation. This can be treated as an implicit evidence of the fact that most central banks target a somewhat positive long-term rate of inflation.[4]

In theory there is no single leading point of view on this problem. The famous Friedman's rule (see, for example, Blanchard and Fischer, 1989, section 4.5) states that the optimal rate of inflation should be negative and equal to minus real interest rate not to distort the consumers' decision of allocation of their assets between money and bonds. However, most economists do not take this theoretical result too seriously. Summers (1991) notes that money in the utility-function models that generate this result are "almost completely irrelevant". Moreover, the doctrine of monetarism, developed in a large scale by Friedman himself, suggests an optimal rate of money growth to be slightly higher than real growth rate in order to give some flexibility to the economy (see for reference Sachs and Larrain, 1993, section 8.5).

On the other hand, there are a number of reasons in favor of a positive optimal rate of inflation. Essentially, there are three main groups of arguments. The first argument refers to the seignorage as a source of government revenue. Government tax optimization may imply positive inflation rates. However, the gains from optimal inflation tax in developed countries seem to be relatively small in comparison with overall monetary stability. As Summers (1991) argues, "optimal tax theory has little or nothing to do with sensible inflation policy". I support this point of view and, therefore, will not analyze this issue in more detail.

Secondly, positive inflation is needed for the proper functioning of financial markets and monetary policy. Romer (1996) argues that the risk free real interest rate in the United States has been negative in about one third of the years since World War II. Low or zero rates of inflation would mean that the nominal interest rate would have to become very close to zero or even negative which could lead to a collapse of the financial system. Moreover, the stimulating short-run monetary policy is impossible given very low or negative interest rates (one may refer to this situation as to Keynesian "liquidity trap"). The other point made by Fischer and Summers (1989) is that very low inflation targets by monetary authorities are not time consistent.

And, finally, the third argument in favor of positive inflation is that it may function as a lubricant for the economy by making nominal prices more flexible. Empirical research by Lucas (1973), Ball, Mankiw, and Romer (1988), and Kiley (2000) suggests that higher rates of inflation do, in fact, make prices more flexible and business cycle less persistent. As a consequence, relative prices are becoming more flexible as well. In other words higher inflation alleviates real rigidities as well as nominal. This allows the economy to go through the business cycle more smoothly with smaller volatility in the output gap. This discussion does

---

improvement. This bias is about 0.5-0.9%. According to Greenspan, Fed's long-term monetary goal is inflation within this interval (FOMC meeting transcripts, 1996). At the same time, Summers (1991) argues that "proposed zero-inflation amendment is a good idea if it is not taken too seriously or too literally, but is instead viewed as a device for strengthening the independence of the Federal Reserve System".

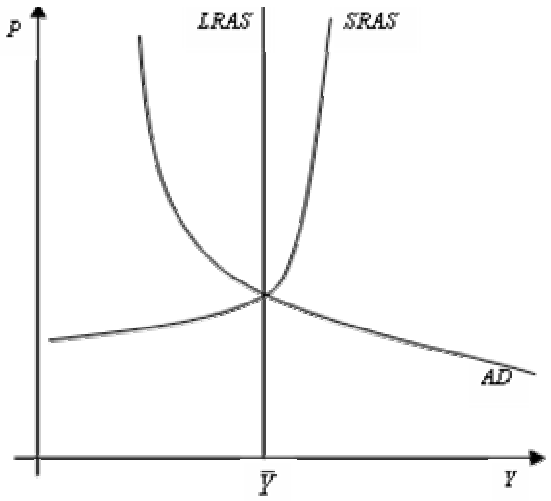
[4] I believe that there are endogenous mechanisms that prevent countries with a sound real sector from falling into deflation. The first mechanism is, of course, expectations and time inconsistency of low or negative inflation. Secondly, growing economies face constant structural changes that require fast relative price adaptation which, in its turn, demands some price level dynamics. And, thirdly, monetary authorities conduct their policies directly not observing their final targets (e.g., output gap). Therefore, they base their actions on available instrument such as past or current price level dynamics (Taylor, 1999), which may lead to endogenous inflation. However, all these arguments should be developed in further research.

not take into account the possibility of the asymmetric price rigidity and money illusion which was often assumed in Keynesian theories. We develop this point in more detail in the following section.

3. Asymmetric Price Rigidity

Asymmetric price rigidity in Keynesian and New Keynesian literature implies that prices are more rigid in the downward direction than in the upward direction. In other words, prices can easily go up, while they resist going down. This phenomenon usually appears in the introductory level textbooks on Macroeconomics in the form of asymmetric (convex) short run aggregate supply curve (see Figure 1). In this case positive aggregate demand shocks lead to insignificant output increases and substantial increases in price level, while negative aggregate demand shocks on opposite reduce output significantly and do not affect prices too much.

Figure 1. Asymmetric price rigidity in an AS-AD diagram.



The important consequence of asymmetric price rigidity is that the cost of business cycle becomes first order rather than second order since positive output gaps do not compensate for negative ones.[5]

The possible source of asymmetric price rigidity is labor market. Many economists (e.g., Tobin 1972 and Summers 1991) argue that nominal wages are extremely rigid downwards, while they can move upwards rather easily. In labor economics this phenomenon is called the *ratchet effect* and is a well studied empirical fact (see, for example, Ehrenberg and Smith 2000). However, rational foundations for it are not yet developed, neither in Labor Economics nor in Macroeconomics. One may think of a money illusion of workers as a natural explanation for the ratchet effect. It is very likely that people are not completely rational and, hence, some money illusion is natural in real life.

In the New Keynesian literature there has been a number of works that tried to investigate the asymmetric price rigidity. A work by Timur Kuran (1983) builds upon a somewhat artificial model. The asymmetry arises as a result of relationship between the discount factor and market growth rate of a firm that

[5] A good survey of the literature on this topic is provided in Ball, Mankiw, and Romer (1988), Ball and Mankiw (1994b), and Gordon (1990).

sets its price for two periods. Therefore, the asymmetry may be upward as well as downward conditional on the parameters values.

There is also a number of works in the spirit of Caplin and Leahy (1991), such as Caballero and Engel (1992) and Tsiddon (1993). This models rest upon state-contingent pricing and optimal sS-rules for the firms. The asymmetry is generated in these models by either trend inflation or asymmetric distribution of shocks. However, this models are very technical, overcomplicated, and in most cases intractable. The work that seems to be the most fruitful in this field is the paper by Ball and Mankiw (1994). The asymmetry arises endogenously in this model as a result of trend inflation. However, this is a weak point of this model since the asymmetry cancels out once there is no trend inflation and even becomes negative for negative trend inflation. The Ball and Mankiw model will be analyzed more closely in the following section.

It is worth noting that that there have been some empirical works on asymmetric effects of shocks. Cover (1992), De Long and Summers (1988), and Senda (2001) find some empirical evidence in favor of asymmetric responses of output to aggregate demand shocks. However, Bils and Klenow (2002) and Bils, Klenow, and Kryvtsov (2003) investigates the firm-level micro data on price adjustment and concludes that prices are as flexible downward as upwards. Therefore, asymmetric rigidity is not a well established empirical fact yet. We will address the issue of empirical verification of asymmetric price rigidity further on in the paper.

An intuitive way to model asymmetric price rigidity is to introduce asymmetric menu cost which is higher for downward adjustment than for upward adjustment. A rational explanation for this intuitive assumption is desirable. Unfortunately, it is very likely that one has to assume money illusion in order to get this result. However, both Tobin (1972) and Summers (1991) consider money illusion as a very plausible macroeconomic phenomenon.

Given a higher menu cost for downward adjustment the firms will bear higher costs if there are as many negative nominal (e.g., aggregate demand) shocks as positive ones. Therefore, positive rate of inflation is likely to reduce the costs for the firms and, hence, increase social well-being. Moreover, positive rate of inflation will render the prices more flexible and they will easier adjust to sectoral or firm-specific (idiosyncratic) shocks. Therefore, positive rate of inflation will contribute to smoothing the business cycle and reduce overall output variability. This affects may be seen in a model of the following section.

4. The Model of Asymmetric Price Rigidity

In this section we present a slight modification of the Ball and Mankiw (1994) model which takes into account the possibility of asymmetric price rigidity. The asymmetry is introduced into the model exogenously by simply setting different menu costs for upward and downward price adjustments (downward nominal price adjustment is more costly than upward). A separate model is needed in order to give rational foundations for the asymmetric menu costs. However, here the main objective is to look at the consequences of possible asymmetric price rigidity for the general equilibrium of the model.

4.1. Set Up of the Model

The set up of the model is the following. The aggregate demand (in logs) in the economy is

$$y_t = m_t - p_t, \tag{1}$$

where m is the money supply and p is the aggregate price level. The money supply follows a random walk with drift

$$m_t = \pi + m_{t-1} + \theta_t, \tag{2}$$

where π is "trend" money growth[6] and θ_t is a random zero-mean money supply shock at t independently and identically distributed according to cumulative distribution function (*CDF*) $F(\theta)$. θ may be treated more broadly as an arbitrary aggregate demand disturbance, in particular, a monetary shock.

There is a continuum of firms characterized by their menu cost C, which is distributed according to CDF $G(C)$ on $[0,\overline{C}]$:

$$\int_0^{\overline{C}} dG(C) = 1.$$

All firms are engaged in monopolistic competition in a market of diversified product. The optimal nominal price for each firm is simply the current money supply[7]

$$p_t^* = m_t = m_{t-1} + \pi + \theta_t. \tag{3}$$

If not for the menu cost, all firms would set their nominal prices at the optimal level. Therefore, potential output (defined as the level of output that corresponds to absolutely flexible prices) in the model is zero:

$$\bar{y} = m - p^* = m - m = 0.$$

The firm's loss from non-optimality of its price is quadratic, which may be interpreted as a second order approximation for a general loss function (see, for example, Ball, Mankiw, and Romer 1988):

$$Loss_t = (q_s - p_t^*)^2, \tag{4}$$

where q_s is the price set by the firm in period s (the price setting process described below is such that s can be either t or t–1). For convenience we denote by x_s the following expression

$$x_s = q_s - m_s, \tag{5}$$

where x_s may be interpreted as a "relative" price set by the firm.[8] Hence, the loss of the firm in period t=s (the period of price resetting) is simply x_t^2; the loss of the firm in period t=s+1 is $(x_{t-1} - \pi - \theta_t)^2$.

The crucial feature of the model is the price setting process, which combines both time and state contingency in price adjustment. A representative firm sets the price every two periods just like in Taylor model (see, Blanchard and Fischer 1989, section 8.2). However, its commitment to maintain the price fixed in the second period is not absolute. The firm may make an extra adjustment in the second period by paying

[6] Note that trend money growth and trend inflation are essentially the same since the economy will convergence eventually to its flexible price equilibrium where all money supply shocks translate one-for-one into price level changes. Therefore, inflation and money growth may differ in the short run, but not in the long run.

[7] Therefore, the model implies no strategic complementarity which is, of course, an oversimplification assumed in order to render the model tractable.

[8] *Relative* in the sense that it is a deviation from a long-term trend (or optimal price).

the menu cost. Clearly, the firm will do so if there is a large shock to its optimal price, so that the losses from non-optimality of its fixed price exceed the menu cost. Therefore, the model inherits the simplicity and tractability of time-contingent models (such as Taylor or Fisher), but it also allows for asymmetric reaction of the firm to different shocks just like in state-contingent models (e.g., Caballero and Engel).[9]

As it was shown by Ball and Mankiw, this model endogenously generates asymmetric price rigidity given non-zero trend inflation ($\pi \neq 0$). When trend inflation is zero, the asymmetry of price rigidity vanishes from the model. Moreover, the asymmetry becomes backward as trend inflation becomes negative. As a result, zero inflation is optimal from the social welfare standpoint. In this paper we challenge this result by introducing (exogenously) an asymmetric rigidity into the model. The firm has to pay a higher menu cost in order to reset its price downwards. If the menu cost for upward adjustment is *C*, the menu cost for downward adjustment is αC, where $\alpha > 1$. Hence, the firm will compare $Loss_t = (x_{t-1} - \pi - \theta_t)^2$ with *C* if $\theta_t > x_{t-1} - \pi$ and with αC otherwise.

4.2. Partial Equilibrium Analysis: The Firm's Problem

Let's first look at the firm's problem when it sets the price. We analyze the optimal decision of a firm with an arbitrary menu cost *C*. At period *t*–1 after the realization of the shock θ_{t-1} the firm sets x_{t-1} in order to minimize its two-period expected losses (there is no discount factor for the second period). In the second period the firm will choose to reset its price if $\theta_t > x_{t-1} - \pi + \sqrt{C}$ or $\theta_t < x_{t-1} - \pi - \sqrt{\alpha C}$. Clearly, it will set its relative price to a new optimum $\pi + \theta_t$ (in other words, its nominal price will equal $p_t^* = m_{t-1} + \pi + \theta_t$). Denote by $\underline{\theta}$ and $\overline{\theta}$ the upper and lower thresholds values of θ correspondingly

$$\begin{aligned} \underline{\theta} &= x_{t-1} - \pi - \sqrt{\alpha C}, \\ \overline{\theta} &= x_{t-1} - \pi + \sqrt{C}. \end{aligned} \tag{6}$$

Already at this stage one may see the asymmetry in the optimal response of the firm to different shocks. Firms will adjust to a much smaller positive shocks than negative shocks given $x_{t-1} > 0$, $\pi > 0$ and $\alpha > 1$. If we keep $\alpha > 1$, this asymmetry will remain even when $x_{t-1} = \pi = 0$. This feature of the model makes it fundamentally different from that of Ball and Mankiw.

The firm's problem in period *t*–1 may be formalized as

$$x_{t-1} = \arg\min_x \left\{ x^2 + \int_{\underline{\theta}}^{\overline{\theta}} (x - \pi - \theta)^2 \, dF(\theta) + C\left(1 - F(\overline{\theta})\right) + \alpha C F(\underline{\theta}) \right\}, \text{ given (6).}^{10} \tag{7}$$

[9] Clearly, there is little place for asymmetric price adjustment in pure time-contingent models. In such models a firm resets its price after a fixed or random number of periods and resets its price optimally. Therefore, there may be no asymmetry. However, recent New Keynesian theories on Sticky Information (e.g., Mankiw and Reis 2002) may generate asymmetric rigidity even given time-contingent pricing due to imperfect information of price setters.
On the other hand, pure state-contingent models lack tractability and there exhaustive analysis is impossible (as argued by Blanchard and Fischer 1989, section 8.3).

[10] Note that (6) already constitutes optimally chosen values of $\underline{\theta}$ and $\overline{\theta}$. More generally, one could omit restrictions (6) and optimize (7) with respect to *x*, $\underline{\theta}$, and $\overline{\theta}$. This will give the same results.

The first term in (7) reflects the loss from non-optimality of the price in period t–1 when the price is just set for two periods. The second term is the expected loss from non-optimality of the price in the second period given that the firm does not adjust its price.[11] And, finally, the third and the fourth terms stand for the menu cost borne by the firm when it increases and decreases its price respectively.

The solution to problem (7) will depend on the parameters of the problem α, π, and C:

$$x_{t-1} = x^*(C \mid \alpha, \pi), \quad \underline{\theta} = x^*(C \mid \alpha, \pi) - \pi - \sqrt{\alpha C}, \quad \text{and} \quad \overline{\theta} = x^*(C \mid \alpha, \pi) - \pi + \sqrt{C}.$$

While α and π are the same for all the firms, C is specific to each firm. Non-trivial distribution of C assures that for each shock θ_t some firms will bear the menu cost and reset the price and some will remain with their old price contributing to price stickiness in the economy.

The formal solution of (7) gives[12]

$$x^* = \frac{1}{1 + F(\overline{\theta}) - F(\underline{\theta})}\left[\pi\left(F(\overline{\theta}) - F(\underline{\theta})\right) + \int_{\underline{\theta}}^{\overline{\theta}} \theta dF(\theta)\right]. \qquad (8).$$

Along with (6), (8) gives us a system of three equations with three unknowns. Unfortunately, it is impossible to get a general closed form solution for this problem. However, one can find a numerical solution for specific distribution of θ (e.g., normal distribution).

The expression (8) is very intuitive. The firm sets its price in period t–1 as a weighted average of the (expected) optimal prices in period t–1 and t, where the weights are the probabilities that the price set by the firm will be in effect in the respective period. The optimal (relative) price in period t–1 is zero, while the probability that x_{t-1} will be in effect in this period is one. Further, the optimal price in period t is $\pi + \theta_t$. The conditional expectation of $\pi + \theta_t$ given that x_{t-1} is in effect is

$$E\left(\pi + \theta_t \mid \underline{\theta} < \theta_t < \overline{\theta}\right) = \pi + \int_{\underline{\theta}}^{\overline{\theta}} \theta dF\left(\theta \mid \underline{\theta} < \theta < \overline{\theta}\right) = \pi + \int_{\underline{\theta}}^{\overline{\theta}} \frac{\theta dF(\theta)}{F(\overline{\theta}) - F(\underline{\theta})},$$

while the probability of this event is $F(\overline{\theta}) - F(\underline{\theta})$. This result squares well with the fact that firms have quadratic loss functions. This implies that they set their prices as certainty equivalents, which is exactly what we observe in our case. Thus, the assumption of the quadratic loss function may be very restrictive. It is interesting to assess the robustness of the model to the relaxation of this assumption. However, the absence of certainty equivalence in price setting will render the model intractable and it will be impossible to solve it even numerically. We will turn back to other consequences of certainty equivalence in price setting later on in the paper.

[11] To be more specific, it is conditional expectation multiplied by the probability of the condition. In other words, it is the expected loss from non-optimality multiplied by the indicator function that equals one when the firm does not adjust.

[12] This can be obtained via direct partial differentiation of the objective function in (7) with respect to x. According to the envelop theorem, there is no need to take the full derivative and differentiate with respect to $\underline{\theta}$ and $\overline{\theta}$ since they are already chosen optimally. However, one may check it directly. The first order condition is sufficient for this problem since it is convex.

From (8) one can see that x^* is less than $\frac{\pi}{2}$, since $F(\overline{\theta}) - F(\underline{\theta}) < 1$ and $E\left(\theta_t \mid x_{t-1} - \pi - \sqrt{\alpha C} < \theta_t < x_{t-1} - \pi + \sqrt{C}\right)$ is negative due to asymmetry in price rigidity (see section 4.5.1 for a specific numerical example). It is worth noting, that for small trend inflation ($\pi \approx 0$) x^* will be negative, which contributes even more to the asymmetry. As a result, $|\underline{\theta}| > \overline{\theta} > 0$, which implies that firms would adjust to smaller positive shocks than negative shocks (recall equations 6).

Therefore, negative monetary shocks will contribute much more significantly to output declines than positive monetary shocks to output increases. In view of this, the idea that output gains and losses from business cycle generated by positive and negative aggregate demand shocks are of second-order becomes very questionable. However, this is a more sophisticated issue than it may seem. Below we address it in more detail.

We also note here that $x^*(C \mid \alpha, \pi)$ is not monotonic in π. If π becomes very high, the firm will more often adjust its price in the second period and, hence, it will set x^* closer to zero (i.e., first period optimal price). Therefore, higher inflation contributes to business cycle smoothening. This implication of the model is now a well studied phenomenon, both theoretically and empirically (see Lucas 1973, Ball, Mankiw, and Romer 1988 and Kiley 2000).

Let's now compare x^* with the optimal two-period relative price that would arise in the Taylor model, where firms do not have the option to reset their prices in the second period.[13] Clearly, it would be

$$\frac{1}{2}\left[\pi + \int_{-\infty}^{+\infty} \theta dF(\theta)\right] = \frac{1}{2}\left[\pi + E\theta_t\right] = \frac{\pi}{2} > x^*.$$

This means that firms will set the price in the first period lower than they would in the Taylor model. Therefore, initially the output will be higher and this may partially compensate for the adverse effects of asymmetric price rigidity in the second period. This is a very important observation and we shall return to it later on in the paper.

4.3. General Equilibrium of the Model

In this section we analyze the general equilibrium of the model for any given α and π. As in Taylor model it is assumed that half of all firms have their scheduled price changes in odd periods, while the other half does it every even period. We need to find the aggregate price level in the economy for any realization of θ in the second period. Given the money supply, the knowledge of the aggregate price level allows us to obtain the stochastic path of the output in the economy. Hence, this dynamic model reduces to one period problem since the solution to firm's problem (in relative terms) doesn't change with time. The lack of strategic complementarity and serial correlation of the aggregate demand disturbances makes the equilibrium path of output also serially uncorrelated. It means that output fluctuations are not persistent at all since they die out already in the next period. Clearly, this is a result of oversimplified assumptions of the model, which

[13] Note that Taylor model is a special (limiting) case of our model when $C \to \infty$. This implies that firms will never reset their prices in the second period.

were introduced to make the model tractable. The key implication of the model concerns the asymmetry of the one-period response of output to monetary shocks, but not the persistence of output fluctuations during business cycle. Therefore, these assumptions are justified.

The aggregate price level in the economy in period t is given by

$$p_t(\theta) = m_{t-1} + \frac{1}{2}\left[(\pi+\theta)G(\hat{C}) + \int_{\hat{C}}^{\bar{C}} x^*(C)dG(C) + \int_0^{\bar{C}} (x^*(C)+\pi+\theta)dG(C)\right], \quad (9)$$

where $\hat{C}$ is the threshold level for the value of the menu cost: all firms with $C \le \hat{C}$ will reset their prices given shock θ in the second period, while firms with $C > \hat{C}$ will keep their old prices. Hence, $\hat{C}$ solves the following equation:

$$\begin{matrix} \hat{C} = \left(x^*(\hat{C}) - \pi - \theta\right)^2 \\ \alpha\hat{C} = \left(x^*(\hat{C}) - \pi - \theta\right)^2 \end{matrix}, \quad \text{for} \quad \begin{matrix} \theta > 0 \\ \theta < 0 \end{matrix}. \quad (10)$$

Clearly, smaller number (measure) of firms will adjust to negative shocks. Equation (10) can be solved for every θ to obtain $\hat{C}(\theta)$.

Let's now interpret the elements in (9). The aggregate price level at t will be composed of pricing decisions of the firms in period t–1 and t. These pricing decisions already take into account all monetary shocks up to t–1. In other words, firms pricing decisions will rest upon the value of m_{t-1}. This explains the first term in (9). Note that this means that all shocks will have effect on the economy only for one period (as discussed above). We turn now to the elements in square brackets in (9). The factor of one half before the square brackets reflects the fact that there are two types of the firms: those that set prices at t–1 and t. The first term in square brackets corresponds to the firms that set price t–1 and reset at t: they choose the optimal price $\pi+\theta$ and the measure of such firms is $P\{C \le \hat{C}(\theta)\} = G(\hat{C})$. The second term corresponds to the firms that set the price at t–1 but do not reset it at t. And the final term reflects the price set by the firms at t.

Given $p_t(\theta)$, we may find now $y_t(\theta)$:

$$\begin{aligned} y_t(\theta) &= m_t - p_t(\theta) = \pi + \theta - \frac{1}{2}\left[(\pi+\theta)G(\hat{C}) + \int_{\hat{C}}^{\bar{C}} x^*(C)dG(C) + \int_0^{\bar{C}} (x^*(C)+\pi+\theta)dG(C)\right] = \\ &= \frac{1}{2}(\pi+\theta)\left(1 - G(\hat{C})\right) - \frac{1}{2}\left[\int_{\hat{C}}^{\bar{C}} x^*(C)dG(C) + \int_0^{\bar{C}} x^*(C)dG(C)\right]. \end{aligned} \quad (11)$$

Expression (11) is our final result. Unfortunately, there exists no closed form solution for output. However, one can numerically obtain the distribution of output given the distributions of monetary shocks and menu costs (see section 4.5). The intuition behind (11) is straightforward. The monetary shock $\pi+\theta$ has a positive effect on output given that some firms do not adjust, which is reflected by the first term in (11). However, the firms set their initial prices different from the current optimal level, which is reflected by the second term in (11).

Let us consider two special (limiting) cases now: the case of no menu cost (pure flexible prices) and the case of infinite menu cost (pure time-contingent pricing). If there were no menu cost ($C \equiv 0$), each firm

would (re)set its price to the optimal every period (i.e., $x^* = 0$ and $G(\bar{C}) = 1$). As a result, the output would always be at its potential, flexible-price, level.

With an infinite menu cost ($C \equiv \infty$) our model, as discussed above, transforms into Taylor model with no option for firm to reset their prices in the second period. In this setting the firms would set $x^* = \frac{\pi}{2}$ (which is average expected optimal price) and the share of firms resetting the price in the second period would be zero (i.e., $G(\bar{C}) = 0$). In this case, output equals $\frac{\theta}{2}$, which reflects the fact that half of the firms won't be able to adjust to the shock.

An important general result that one may expect to obtain here, is that expected output (with respect to distribution of shocks) will equal zero:

$$Ey = \int y(\theta) dF(\theta) = 0 . \tag{12}$$

This happens by virtue of two features of the model: the firms set their prices as certainty equivalents (i.e., the price set by a firm is an average of expected optimal price) and the problem of a firm is dynamically consistent. This result might seem rather surprising since we have asymmetric price rigidity in the model: the output increases less in response to positive shocks than it decreases in response to equivalent negative shocks. The intuition behind this result is the following: forward-looking firms initially set the price lower than they would in the model with symmetric price rigidity (when $\alpha = 1$ and $\pi = 0$); this pushes the level of output up so that on average output still equals zero. To make this point clearer, one may think of a situation when realization of the monetary shock was zero ($\theta_t = 0$). Let's assume that none of the firms would adjust to this shock (which is a reasonable simplification). Then

$$y_t = \frac{\pi}{2} - \int_0^{\bar{C}} x^*(C) dG(C) > 0 ,$$

since the firms initially set their prices lower than $\frac{\pi}{2}$ (as discussed above). This means that the output in this case will be above the natural rate. Therefore, an economy with shocks given that the realization of the shock is zero will have higher output than the (deterministic) economy without shocks. However, in the stochastic economy negative shocks will contribute more to output declines than positive shocks to output increases. As a result, the average output in the stochastic economy will "fall back" to its natural rate.

This result may be called a strong form of a natural rate hypothesis: the output will stay on its natural rate not only in the long run, but also it will on average equal the natural rate at every single period.[14] Unfortunately, this result will not hold if we relax the assumption that gives us certainty equivalence in the price setting (i.e., the quadratic loss function).[15] And it is not clear to what extent this assumption is consistent with empirics.

[14] Unfortunately, I cannot provide a formal proof of this result. However, simulations suggest that this result holds at least for some important special cases (i.e., normal distribution of monetary shocks and uniform distribution of menu cost) – see section 4.5.2.

[15] In Economics literature this issue was first raised by Miles Kimball (1989).

4.4. Optimal Inflation Rate

Finally, we turn to the question of socially optimal rate of inflation. To answer this question we first need to define how the social welfare is measured. We will assume that social welfare is inversely proportional to average firm's losses (i.e., the value of the objective function of a firm – see equation 7). This may be an oversimplifying assumption since social welfare clearly depends on the volatility of output, which we do not account for. There are two reasons to take this assumption. Firstly, firms are the only agents in the model. To include consumers into the measure of social welfare, we will need to complicate the model by introducing consumer's utility function and decision making process. Secondly, this assumption was taken in the original paper by Ball and Mankiw, and it will be desirable to compare the results.

As a first step, we find the optimal rate of inflation for a firm with menu cost *C*. To find it, we substitute the optimal decision of the firm into its loss function:

$$Loss = (x^*)^2 + \int_{\underline{\theta}}^{\bar{\theta}} (x^* - \pi - \theta)^2 \, dF(\theta) + C\left(1 - F(\bar{\theta})\right) + \alpha C F(\underline{\theta}). \qquad (13).$$

Now our goal is to find the global minimum of the loss function with respect to inflation rate. Clearly, this problem should have an internal solution since both very large positive and negative inflation is bad for the firm (it always bears the menu cost which is its guaranteed minimum). The first order condition for the minimization problem is presented below:[16]

$$\int_{\underline{\theta}}^{\bar{\theta}} (\pi + \theta - x^*) dF(\theta) = 0. \qquad (14)$$

Clearly, zero inflation will not deliver minimum to the problem since the asymmetric rigidity remains in our model even when there is no trend inflation. Given zero trend inflation ($\pi = 0$), the firm's optimal price would be

$$x^* = \frac{1}{1 + F(\bar{\theta}) - F(\underline{\theta})} \cdot \int_{\underline{\theta}}^{\bar{\theta}} \theta dF(\theta) < 0,$$

since $|\underline{\theta}| > \bar{\theta}$ due to asymmetric menu cost[17] and symmetric distribution of θ by our initial assumption. This implies that

$$\left.\frac{dLoss}{d\pi}\right|_{\pi=0} = \left[1 - \frac{F(\bar{\theta}) - F(\underline{\theta})}{1 + F(\bar{\theta}) - F(\underline{\theta})}\right] \cdot \int_{\underline{\theta}}^{\bar{\theta}} \theta dF(\theta) < 0,$$

which in its turn suggests that the optimal rate of inflation is positive.

To find the optimal rate of inflation we recall the first order condition for the firm's problem:

$$x^* = \int_{\underline{\theta}}^{\bar{\theta}} (\pi + \theta - x^*) dF(\theta). \qquad (15)$$

Combining (14), (15), and the firm's optimal price (8), yields the following simple result. The optimal rate of inflation for a firm with menu cost *C* is such that the firm sets its first period price to zero:

[16] To compute the F.O.C. one should take only partial derivative with respect to π. This is true by virtue of envelope theorem: all other elements (derivatives w.r.t. x^*, $\underline{\theta}$, and $\bar{\theta}$) will cancel out due to the F.O.C. in the firm's problem.

$$x^*(\pi^*) = \frac{1}{1+F(\overline{\theta})-F(\underline{\theta})}\left[\pi\left(F(\overline{\theta})-F(\underline{\theta})\right)+\int_{\underline{\theta}}^{\overline{\theta}}\theta dF(\theta)\right]=0. \tag{16}$$

This means that the optimal rate of inflation is

$$\pi^* = -\frac{1}{F(\overline{\theta})-F(\underline{\theta})}\cdot\int_{\underline{\theta}}^{\overline{\theta}}\theta dF(\theta) = -E\left(\theta \mid \underline{\theta}<\theta<\overline{\theta}\right)>0.^{18} \tag{17}$$

The intuition behind this result is rather straightforward. Positive rate of inflation will allow the firm to adjust more frequently to positive shocks than to negative shock, which is less costly by our assumptions. Moreover, the firm won't have to bear the costs of non-optimality of its price in the first period.

After we have found the optimal rate of inflation for a single firm with menu cost *C*, we turn back to the question of socially optimal rate of inflation. In the model the firms are heterogeneous and differ in their menu costs. Therefore, the optimal rate of inflation will be different for different firms. However, it is positive for every firm, which implies that the socially optimal rate of inflation will also be positive.[19]

4.5. Simulations Results

In this section we report the simulations results for one special case of the model.[20] Simulations contribute to better understanding of the mechanics of the model and make the results of the model more transparent.

As in Ball and Mankiw (1994), we specify $F(\theta)$ to be normal with zero mean and variance σ^2 and $G(C)$ to be uniform over $[0,\overline{C}]$[21]. According to Alan Blinder (1991), a median firm resets its price once a year. Therefore, a period in the model should correspond to six months. The standard deviation of θ is set to equal $\sigma = 0.025$. This implies that the standard deviation in the growth of nominal GDP is 3.5% per year, which is consistent with the US data. We set $\overline{C} = 0.02$, which implies that $\sqrt{\overline{C}} = 0.14$ and $E\sqrt{C} = \frac{2}{3}\sqrt{\overline{C}} = 0.094$. This means that an average firm will tolerate 9.4% deviation of its price from the optimal before making a special adjustment, while the firm with the highest menu cost will tolerate 14% deviation.[22] This setting seems to be plausible. And finally we set $\alpha = 1.3$, which implies that the cost of the downward adjustment for the firm is 30% higher than that of the upward adjustment.[23]

---

[17] The firm will set negative first period relative price in order to adjust to negative shocks more rarely not to bear the higher menu cost. The limiting case is the Ball and Mankiw model with $\alpha = 1$, where zero inflation is becoming optimal for all firms.

[18] Note that this is not a final result yet, this is only an equation from which one may find optimal rate of inflation as a function of the firm menu cost: $\pi^*(C)$.

[19] For example, one may think of a social welfare function in this model as a sum of firm's welfare across all firms.

[20] Simulations are conducted in GAUSS 4.0. The Code of the program is available in the Appendix to the paper.

[21] In the original paper Ball and Mankiw had uniform distribution in $\sqrt{C}$ rather than in *C*. However, this change does not make a significant difference. I use uniform distribution in *C* to make the numerical calculations slightly easier.

[22] Clearly, this concerns only upward adjustments.

[23] The results of the model are very similar for the values of α in the range [1.1;1.5].

Figure 2. Optimal price as a function of menu cost given different value of trend inflation

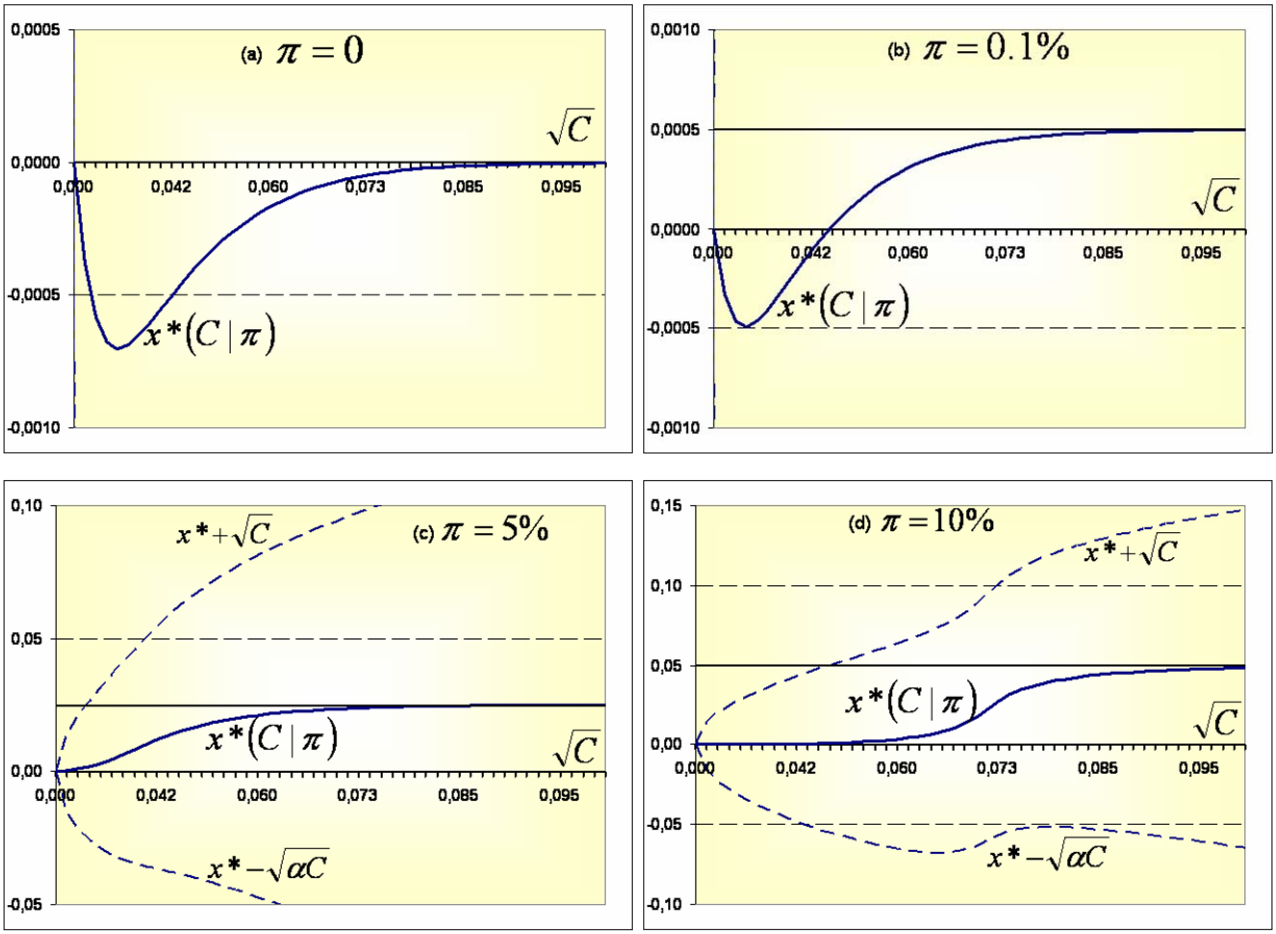
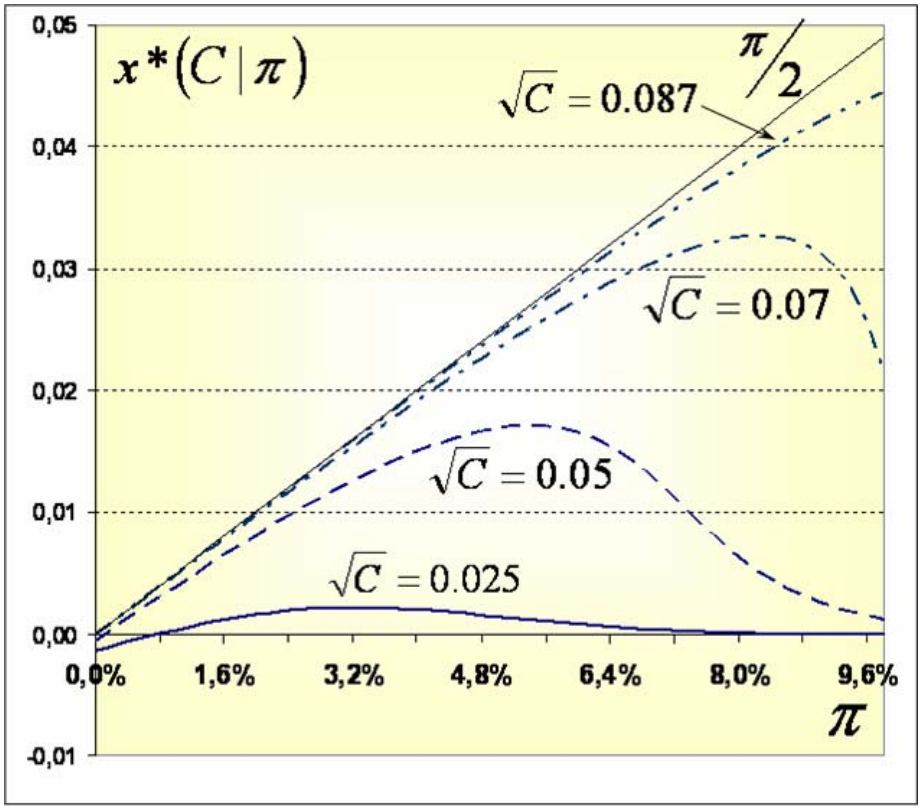


Figure 3. Optimal price as a function of trend inflation for different menu costs

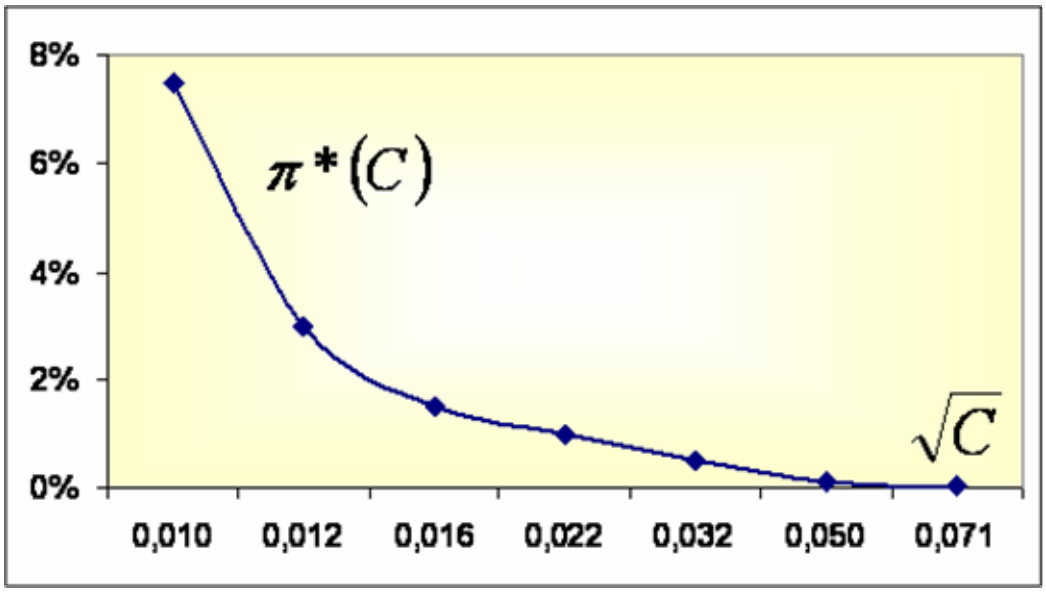


4.5.1. Partial Equilibrium and Optimal Rate of Inflation

In this section we look at the optimal price, set in the first period by a firm with menu cost *C* given trend inflation $\pi -$ $x^*(C \mid \pi)$. These results are presented in Figure 2 (a through d). In figures 2.a and 2.b one can see the optimal relative price for small trend inflation. In this case the optimal price is negative for small values of menu cost. For larger trend inflation (figures 2.c and 2.d) the optimal price is positive for essentially all values of menu cost. As menu cost increases and the model under analysis approaches standard Taylor model (see section 4.2 and 4.3), the optimal price converges to half of the trend inflation. In Figures 2.c and 2.d the dashed lines represent the bounds within which the firms will not adjust to the second period shock.

In Figure 3 we also present optimal two-period price now as a function of trend inflation given different menu costs. One can see that the optimal price is not monotone in trend inflation: as trend inflation increases the optimal price converges back to zero (see section 4.2). For small values of trend inflation optimal price is negative (see section 4.3). This effect is more obvious given smaller menu cost. Given larger menu cost, the optimal price is closer to half of the trend inflation, however, it is always smaller than it (see section 4.2).

Figure 4. Optimal rate of inflation for firms with different menu cost



And finally, we turn to the question of optimal rate of inflation. Recall the optimality condition from section 4.5. For a firm with a given menu cost *C* the optimal rate of inflation is such that this firm will set its two-period (relative) price to zero:

$$\pi^*: \qquad x^*(C \mid \pi^*) = 0 .$$

In Figure 4 we present optimal rates of inflation for firms with different value of menu cost. The optimal rate of inflation is higher for firms with smaller menu cost.[24] It is worth noting that firms with menu

[24] Note, however, that a firm with zero menu cost is indifferent between different values of trend inflation.

cost over 0.005 ($\sqrt{C} > 0.07$) prefer inflation rates that are very close to zero. The explanation is straightforward. These firms almost never adjust neither upward, nor downward. Therefore, they prefer zero inflation which at least makes their pricing optimal on average. This fact reveals the problem of our model. α in the range of [1;2] is too small to make a substantial difference for firms with high menu costs. It plays a role, however, for firms with lower menu cost.

If we want to estimate the optimal rate of inflation as an average over the firms, the upper bound for this estimate would be about 1-1.5%. Trend inflation of this size will bring down the weighted average menu cost across the firms. In the next section we analyze another implication of positive trend inflation – lower real output variability.

4.5.2. General Equilibrium

First we look at the response of the model economy to aggregate demand disturbances of different sizes and signs given certain level of trend inflation. These results are presented in Table 1.

Table 1. Output response to a monetary shock for different levels of trend inflation

θ Shock	Output y (%)			
	π=0%	π=1%	π=5%	π=10%
-3σ	-3,122	-3,219	-3,450	-2,390
-2σ	-2,300	-2,334	-2,225	-1,302
-1σ	-1,209	-1,200	-1,000	-0,461
0	0,016	0,042	0,130	0,232
1σ	1,221	1,200	1,010	0,661
2σ	2,185	2,083	1,542	0,600
3σ	2,690	2,470	1,350	0,388

Table 1 reveals the essentials of the asymmetry in the output response to different shocks. The response of the output to a negative shock is almost always larger than the response to a corresponding positive shock. The exceptions are shocks of very small magnitude. For example, the response of the output to a zero shock is positive at all levels of inflation, which reflects the intuition discussed in section 4.3. It is also worth noting, that the responses of the economy are not monotone in the size of the shock: they start to decline as shocks become larger since more and more firms are adjusting their prices.

Now we turn to the distribution of output for different levels of trend inflation. We are mainly interested in first three moments – mean, variance, and skewness. As discussed in section 4.3, we expect mean to equal zero, variance to decline with trend inflation and skewness to be negative. These statistics of the distribution are presented in Table 2.

All the results in Table 2 coincide with our expectations. The "strong form of natural rate hypothesis" (see section 4.4) holds in our numerical example. It is worth noting that output variation declines

significantly with trend inflation. It means that the increasing trend inflation may contribute to business cycle smoothening via smaller nominal rigidities. This result fits well empirical evidence on output-inflation tradeoff (see section 2 and 4.2) and can be treated as another argument in favor of positive trend inflation.

Table 2. Key output distribution statistics for different levels of trend inflation

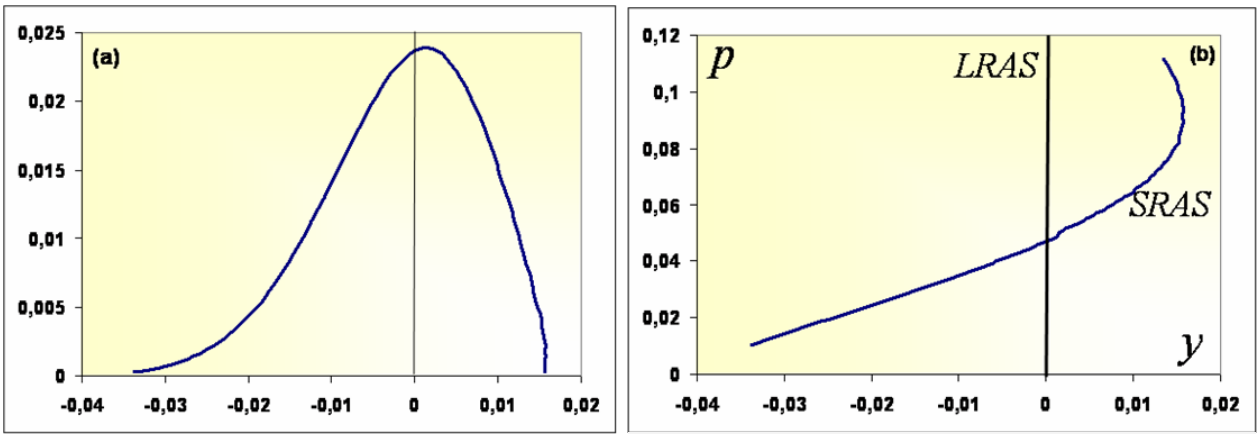
Output Distribution Statistic	Trend Inflation			
	π=0%	π=1%	π=5%	π=10%
Mean	0,000	0,000	0,000	0,000
St. Deviation (%)	1,145	1,133	0,957	0,539
Skewness	-0,014	-0,103	-0,483	-0,324

Given asymmetric price rigidity, the skewness of the output distribution is negative. However, it is not monotone in trend inflation. At first, it increases in absolute value, but as trend inflation becomes very high, the distribution of output shrinks and, therefore, skewness decreases in absolute value.

Tables 1 and 2 suggest two testable implications. In order to support asymmetric rigidity empirically, one may either look at the impulse responses of output to aggregate demand disturbances or at the skewness of detrended output distribution.[25] These issues are discussed in more detail in section 6.

And finally, we present the partial distribution function (pdf) of output in Figure 5.a. It summarizes the facts about output distribution in a very convenient visual way. The level of trend inflation is chosen to be 5%. The results for different levels of trend inflation are essentially the same. However, 5% trend inflation is large enough to emphasize all important implications of the model.

Figure 5. Output PDF (a) and SRAS curve (b) for 5% trend inflation



[25] Here *detrended* should be understood as "clear of aggregate supply disturbances".

Figure 5.b presents the short run aggregate supply (SRAS) in the model economy. As it was argued in the beginning of this paper (see section 3), SRAS has a "convex" form, which reflects asymmetric price rigidity. The level of trend inflation for Figure 5.b is also set at 5%.

5. Empirical Evidence

As it was mentioned in the beginning of the paper, empirical studies of asymmetric rigidity are very limited. There are two basic approaches. Cover (1992), De Long and Summers (1988), and Senda (2001) are examples of the first one. They analyze macro data to estimate the response of output to aggregate demand disturbances of different signs. Generally, these studies do find empirical support of asymmetric rigidity.

The second approach deals with firm-level micro data on price adjustment. Two papers of this kind are Bils and Klenow (2002) and Bils, Klenow, and Kryvtsov (2003). These authors show that at micro level prices are rather flexible in both directions. They challenge the empirical finding of Alan Blinder (1991), arguing that an average firm revises its price as often as once in four to six months and the chances of both price reduction and price increase are roughly the same. The authors also suggest that price stickiness (and in particular asymmetric rigidity) is only a macro phenomenon (if it is at all) which does not exist on the micro level. This means the identification of asymmetric rigidity on the macro level is not enough for a complete research. One should also provide some micro-level explanation for this phenomenon.

Nevertheless, in this paper we only make an attempt to analyze macro-level data on asymmetric rigidity. As it was underlined in section 4.5.2 there are two testable implications of the asymmetric price rigidity. The first implication is the response of output to aggregate demand shocks of different magnitudes and signs. The problem here is to get data on aggregate demand shocks. Usually, this requires a multivariate econometric model that takes account of simultaneity.[26]

The second implication is to estimate the distribution (and in particular skewness) of detrended (from aggregate supply stochastic path) output innovations. This approach does not demand data on aggregate demand disturbances, but instead it requires the decomposition of the output series into permanent (aggregate supply) and temporary (aggregate demand) components. The temporary component is sometimes also referred to as output gap. Therefore, one needs to look at the distribution of random innovation to output gap.

In the end both implications lead to the same thing: one needs to distinguish between aggregate supply and aggregate demand disturbances, which is a separate issue in empirical economics which has no definite solution so far. In the following sections we attempt to conduct a few econometric tests of asymmetric rigidity based on macroeconomic data.

5.1. Univariate Approach

In this section we apply univarite time-series models of output decomposition into trend and cyclical components. It is assumed that cyclical component represents the deviations from long-run tendency (aggregate supply evolution) caused by aggregate demand disturbances. The obvious advantage of this

[26] For example, consider the famous Blanchard and Quah (1989) decomposition within the VAR framework.

approach is that as an input it requires only output series. However, this has a direct limitation – oversimplifying assumptions usually lead to problems with verification of the results.

In this paper we apply two alternative techniques of output decomposition – first differencing and filtering. The first technique assumes that the permanent component of the output series is simply random walk. Therefore, first differencing leads to a stationary component of output which is assumed to be driven by aggregate demand disturbances.[27] The second technique applies stochastic filters (e.g., HP or Band-Pass) to output series to separate low and high frequency fluctuations. Low frequency fluctuations are then treated as a cyclical component of output. In this paper we will apply HP-filter[28] to get stationary cyclical component.

Given a stationary component of output, we fit an ARMA-process to get to aggregate demand disturbances, which we are interested in. Further we test the null hypothesis that skewness of aggregate demand innovations is zero versus the one-sided alternative that it is negative. The results of the tests are provided in Table 3.[29]

Table 3. Skewness of aggregate demand innovations and its 5% bootstrap quantiles

Country	First-differencing		HP-filter	
	Skewness	5% Bootstrap Quantile	Skewness	5% Bootstrap Quantile
Australia	0,237	-0,632	0,139	-0,696
Canada	0,239	-0,533	0,006	-0,462
France	0,486	-3,568	**-0,338**	-2,535
Germany	1,090	-1,580	0,560	-1,860
South Africa	0,116	-0,625	**-0,006**	-0,571
Spain	0,418	-1,665	1,215	-1,891
Switzerland	0,334	-1,587	**-0,782***	-0,740
United Kingdom	0,276	-0,993	**-0,620***	-0,619
United States	**-0,236**	-0,632	**-0,069**	-0,678

Table 3 suggests that there is no asymmetric response in the data. Skewness is negative only in one case out of nine for first-differencing technique and in five cases out of nine for HP-filtering technique. Moreover, it is significantly negative only in two cases – for Switzerland and United Kingdom. This can be rather treated as alpha-error since in other 16 cases skewness is insignificantly different from zero. However, this method is not absolutely reliable since it cannot distinguish to well between aggregate supply and aggregate demand disturbances. In the next section we turn to multivariate models to resolve this issue.

[27] This method is advocated by Campbell and Mankiw (1987).
[28] HP stand for Hodrick and Prescott, who suggested this famous filtering technique in 1980.
[29] We use quarterly output data on 9 countries, period 1957:1 through 2002:4. Source: IMF IFS 2003.
Negative skewness coefficients are in bold. Coefficients with the star * are significant at 5% significance level. The GAUSS 4.0 code for bootstrap quantiles is presented in Appendix 2.

5.2. Multivariate Approach

In this section we apply the most common approach in the field – VAR (Vector Auotoregressive model). VAR methodology was first applied to estimate asymmetric rigidity by Cover (1992) and De Long and Summers (1988). The most recent research that contains generalization of earlier works was conducted by Takashi Senda in 2001. As in this paper, Senda based his research on Ball and Mankiw (1994) model of asymmetric rigidity. He estimated the level of asymmetric rigidity for 10 developed countries and then conducted a cross-section regression of asymmetric rigidity on inflation and nominal aggregate demand variability. Overall, Senda finds support for Ball and Mankiw Model. In this paper I estimate a different specification of VAR model for a different set of countries and quarterly date (as opposed to annual data used by Senda).[30]

The specification of the model is the following:

$$\begin{cases} m_t = \alpha_0 + \alpha_1 y_t + \alpha_2 m_{t-1} + \alpha_3 y_{t-1} + \alpha_4 i_t + \varepsilon_t, \\ y_t = \beta_0 + \beta_1 m_t + \beta_2 y_{t-1} + \beta_3 m_{t-1} + \beta_4 u_t + \gamma_1^+ \varepsilon_t^+ + \gamma_1^- \varepsilon_t^- + \gamma_2^+ \varepsilon_{t-1}^+ + \gamma_2^- \varepsilon_{t-1}^- + \delta_t, \end{cases} \tag{18}$$

where m_t is the growth rate of money (M2), y_t is the growth rate of output (or, alternatively, change in log of output), i_t is nominal interest rate, u_t is unemployment rate, ε_t is a monetary shock, and δ_t is shock to output[31], $\varepsilon_t^+ = \max\{\varepsilon_t, 0\}$ and $\varepsilon_t^- = \min\{\varepsilon_t, 0\}$. Unemployment and nominal interest rate are included into the model for identification purposes. $\gamma_i^{\pm}$ measures the degree of asymmetric rigidity; to be more precise, the first candidate for the role of the measure of asymmetry is:

$$AM = \gamma_1^- + \gamma_2^- - \gamma_1^+ - \gamma_2^+. \tag{19}$$

Model (18) is estimated by instrumental variables (or TSLS, two-stage least squares). It is worth noting that regressors $\varepsilon_t^{\pm}$ are also endogenous.[32] Therefore, we use lags of $\varepsilon_t^{\pm}$ as valid instruments. The results of the estimation are presented in Table 4.[33] Only for three countries (Canada, Spain, and US) the measure of asymmetry (AM) is significantly different from zero. However, for all countries it is positive, which can be treated an informal argument in favor of existence of asymmetric rigidity. The difference of our results from those obtained by Cover (1992) and Senda (2001) are driven by the fact that we are not using current realizations of monetary shocks as exogenous variables; we treat them as exogenous and apply instrumental variables for consistent estimation. This approach seems to be more appropriate in our case.[34]

[30] I would like to note that I found the link to Senda's work already when this research was done.

[31] It is implicitly assumed here that ε captures aggregate demand innovations while δ stands for aggregate supply innovations. However, this may not be the case since we do not impose any restrictions on the cumulative response of the variables to these shocks. A more methodologically justified approach is that of Blanchard and Quah (1988), which restricts the long run effect of aggregate demand shocks to be zero.

[32] This fact is usually disregarded in empirical works. Cover (1992) and Senda (2001) are not exceptions.

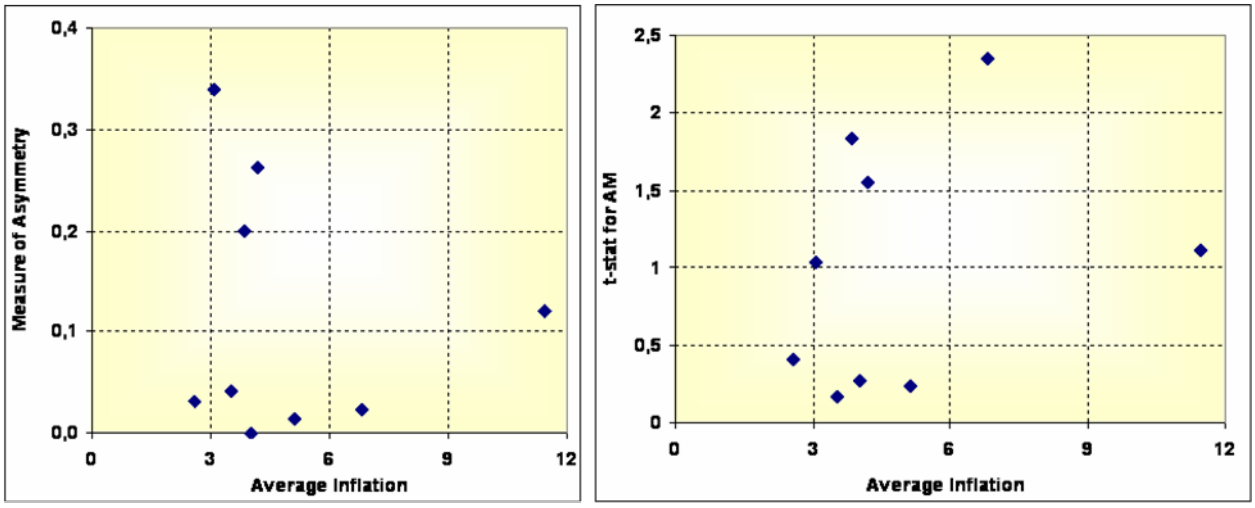
[33] Data source: IMF IFS 2003. Standard errors are in shaded area; Significant estimates at 10% confidence level are in bold.

[34] However, this approach may lead to "weak instruments problem". It is very likely that past monetary shocks and other variables used as instrument in our model weakly predict current monetary shocks. One option to improve the results is to use alternative asymptotics. Under alternative asymptotics our estimates are very likely to turn significant.

Table 4. Asymmetric Rigidity Estimation in a VAR Framework, model (18)

Country	Sample Period	Average Inflation	Nominal Demand Variability	γ_1^+	γ_1^-	γ_2^+	γ_2^-	AM
Australia	1982:3 2002:1	3,53	3,30	**0,610**	0,653	**-0,066**	**-0,067**	0,042
				0,305	0,521	0,019	0,020	0,247
Canada	1957:1 2002:3	4,2	2,52	1,110	1,135	-0,171	0,066	**0,262**
				1,420	1,411	0,114	0,162	0,169
France	1982:2 1998:4	5,13	4,54	**0,118**	**0,132**	**-0,029**	**-0,029**	0,014
				0,034	0,027	0,009	0,010	0,059
Germany	1982:2 1998:4	3,08	3,36	**1,768**	**1,937**	**-1,204**	**-1,033**	0,339
				0,344	0,316	0,212	0,211	0,328
South Africa	1966:2 2002:4	11,44	3,81	**0,235**	**0,331**	0,024	0,048	0,119
				0,066	0,085	0,193	0,145	0,107
Spain	1982:2 1998:4	6,8	2,96	**0,018**	**0,043**	-0,003	-0,004	**0,024**
				0,005	0,008	0,005	0,005	0,010
Switzerland	1980:2 2002:3	2,59	3,13	0,032	**0,137**	0,051	-0,022	0,031
				0,073	0,040	0,042	0,045	0,076
United Kingdom	1982:4 2002:3	4,03	2,99	**0,012**	**0,013**	-0,001	-0,002	0,000
				0,004	0,004	0,001	0,002	0,002
United States	1959:2 2002:3	3,85	2,07	**2,451**	**2,438**	-2,556	-2,345	**0,199**
				1,027	1,074	3,997	3,992	0,109

Figure 6. Measure of Asymmetry and its t-statistic against Average Inflation



In Figure 6 we present an informal graphical illustration of our results: we plot the measure of asymmetry and its t-statistic against average inflation. Figure 6 suggests that to some extent there exists positive correlation between trend inflation and asymmetric rigidity, which supports theoretical results of Ball and Mankiw model.

However, the empirical support of asymmetric rigidity presented in this paper is not solid enough to argue that asymmetric rigidity in fact exists in real data. A further research must be done to give a definitive answer to this question.

6. Conclusion

This paper investigated the issue of optimal long-run inflation from a standpoint of sticky prices models of macroeconomic fluctuations. It appears both theoretically and empirically that price stickiness emphasizes the optimality of long-run inflation.

The special case of asymmetric price rigidity is particularly interesting in this respect. As it was argued, positive trend inflation is desirable given asymmetry in price rigidity. Positive trend inflation alleviates price stickiness, contributes to business cycle smoothening and reduces the cost of adjustment for the firms.

It was also argued that asymmetric rigidity is endogenous to the economy. Trend inflation may only emphasize the effects of asymmetric rigidity but not generate them. It is very unlikely from the intuitive perspective that asymmetric rigidity would vanish given zero trend inflation and, moreover, would reverse given negative trend inflation. However, any rational explanation of exogenous asymmetric rigidity seems to fail. Therefore, it may be fruitful to consider behavioral foundations for asymmetric rigidity. Labor market is a potential source of asymmetry.

The paper provides some empirical evidence on asymmetric price rigidity. Empirical study suggests that asymmetric rigidity is likely to be present in the data. However, existing statistical methods are too imprecise to deal with such sophisticated issues. Further empirical research – both on macro and micro level – is needed to provide a more solid evidence on asymmetric price rigidity

This paper makes an attempt to introduce another scope for the analysis of optimal long-run inflation. However, the most challenging task is to estimate relative significance (in terms of some criterion) of different approaches to optimal long-run monetary policy.

Reference

1. **Ball, Laurence and Gregory Mankiw. 1994a.** Asymmetric Price Adjustment and Economic Fluctuations. *Economic Journal, Vol. 104, No. 423, pp. 247-261.*
2. **Ball, Laurence and Gregory Mankiw. 1994b.** A Sticky-Price Manifesto. *NBER Working Paper No. 4677.*
3. **Ball, Laurence, Gregory Mankiw, and David Romer. 1988.** The New Keynesian Economics and the Output-Inflation Trade-off. *Brookings Papers on Economic Activity, No. 1, pp. 1-65.*
4. **Bils, Mark and Peter Klenow. 2002.** Some Evidence on the Importance of Sticky Prices. *National Bureau of Economic Research Working Paper #9069. Forthcoming in the Journal of Political Economy.*
5. **Bils, Mark, Klenow, and Oleksiy Kryvtsov. 2003.** Sticky Prices and Monetary Policy Shocks. *Federal Reserve Bank of Minneapolis Quarterly Review, Vol. 27, No. 1, pp. 2-9.*
6. **Blanchard, Olivier. 2003.** Comments on "Inflation Targeting in Transition Economies; Experience and Prospects", by Jiri Jonas and Frederic Mishkin *in NBER's Inflation Targeting, forthcoming.*
7. **Blanchard, Olivier and Stanley Fischer. 1989.** Lectures on Macroeconomics. *Cambridge: MIT Press.*
8. **Blanchard, Olivier and Danny Quah. 1989.** The Dynamic Effects of Aggregate Demand and Supply Disturbances. *American Economic Review, Vol. 79, pp. 655-673.*
9. **Blinder, Alan. 1991.** Why Are Prices Sticky? Preliminary Evidence from an Interview Survey. *American Economic Review, Vol. 81, pp. 89-96.*
10. **Bruno, Michael and Stanley Fischer. 1990.** Seigniorage, Operating Rules, and the High Inflation Trap. *Quarterly Journal of Economics, Vol. 105, No. 2, pp. 353-374.*
11. **Caballero, Ricardo and Eduardo Engel. 1992.** Price Rigidities, Asymmetries, and Output Fluctuations. *NBER Working Paper No. 4091.*
12. **Cambell, John and Gregory Mankiw. 1987.** Are Output Fluctuations Transitory? *Quarterly Journal of Economics, Vol. 102, No. 4, pp. 857-880.*
13. **Caplin, Andrew, and John Leahy. 1991.** State-Dependent Pricing and the Dynamics of Money and Output. *Quarterly Journal of Economics, Vol. 104, pp. 683-708.*
14. **Clarida, Richard, Jordi Gali, and Mark Gertler. 1999.** The Science of Monetary Policy: A New Keynesian Perspective. *Journal of Economic Literature, Vol. 37, pp. 1661-1707.*
15. **Cover, James. 1992.** Asymmetric Effects of Positive and Negative Money-Supply Shocks. *Quarterly Journal of Economics, Vol. 107, No. 4, pp. 1261-1282.*
16. **De Long, Bradford and Lawrence Summers. 1988.** How Does Macroeconomic Policy Affect Output? *Brookings Papers on Economic Activity, Vol. 2, pp. 433-80.*
17. **Ehrenberg, Ronald and Ronald Smith. 2000.** Modern Labor Economics. *7th eds. Addison Wesley Longman.*
18. **Federal Open Market Committee (FOMC) Meeting Transcripts. 1996.** (*http://www.federalreserve.gov/fomc/transcripts/1996/19960703Meeting.PDF*)

19. **Fischer, Stanley and Lawrence Summers. 1989.** Should Governments Learn to Live with Inflation? *American Economic Review, Vol. 79, No. 2, pp.382-388.*
20. **Friedman, Milton. 1968.** The Role of Monetary Policy. *American Economic Review, Vol. 58, No. 1, pp. 1-17.*
21. **Gordon, Robert. 1990.** What is New-Keynesian Economics? *Journal of Economic Literature, Vol. 28, No. 3, pp. 1115-1171.*
22. **Hodrick, Robert and Edward Prescott. 1980.** Postwar U.S. Business Cycles: An Empirical Investigation. *Carnegie-Mellon University. Published in 1997 in Journal of Money, Credit and Banking, Vol. 29, pp. 1-16.*
23. **Kiley, Michael. 2000.** Endogenous price stickiness and Business Cycle Persistence. *Journal of Money, Credit and Banking, Vol. 32, No. 1, pp. 28-53.*
24. **Kimball, Miles. 1989.** The Effect of the Demand Uncertainty on a Precommitted Monopoly Price. *Economics Letters, Vol. 30, No. 1, pp. 1-5.*
25. **Kuran, Timur. 1983.** Asymmetric Price Rigidity and Inflationary Bias. *American Economic Review, Vol. 73, No. 3, pp. 373-382.*
26. **Lucas, Robert. 1973.** Some International Evidence on Output-Inflation Tradeoffs. *American Economic Review, Vol. 63, pp. 326-334.*
27. **Mankiw, Gregory and Ricardo Reis. 2002.** Sticky Information versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve. (*http://post.economics.harvard.edu/faculty/mankiw/papers/sticky10.pdf*)
28. **Romer, David. 1996.** Advanced Macroeconomics. *McGraw Hill.*
29. **Romer, David. 2000.** Keynesian Macroeconomics without the LM Curve. *Journal of Economic Perspectives, Vol. 14, No. 2, pp. 149-169.*
30. **Sachs, Jeffrey, and Felipe Larrain. 1993.** Macroeconomics in the Global Economy. *Prentice Hall.*
31. **Senda, Takashi. 2001.** Asymmetric Effects of Money Supply Shocks and Trend Inflation. *Journal of Money, Credit and Banking, Vol. 33, No. 1, pp. 65-89.*
32. **Summers, Lawrence. 1991.** Price Stability: How Should Long-Term Monetary Policy Be Determined? *Journal of Money, Credit and Banking, Vol. 23, No. 3, Part 2, pp. 625-631.*
33. **Taylor, John** *(edited by)***. 1999.** Monetary Policy Rules. *NBER – Business Cycle Series, Vol. 31, University of Chicago Press.*
34. **Tobin, James. 1972.** Inflation and Unemployment. *American Economic Review, Vol. 62, No. 1/2, pp. 1-18.*
35. **Tsiddon, Daniel. 1991.** On the Stubbornness of Sticky Prices. *International Economic Review, Vol. 32, pp. 69-75.*
36. **Tsiddon, Daniel. 1993.** The (Mis)Behaviour of the Aggregate Price Level. *Review of Economic Studies, Vol. 60, No. 4, pp. 889-902.*

Statistical Data: **International Monetary Fund (IMF), International Financial Statistics Database (IFS). 2003.** (*http://www.imf.org/*).

Appendix 1. Gauss Code for Simulations

```
new;
cls;
library pgraph nlsys;

/*Parameters*/
BB=100; /*number of repetitions*/
p=.05; /*trend inflation*/
a=1.3; /*asymmetric rigidity*/
s=0.025; /*st.dev. of AD disturbances*/
x0=0; /*initial value*/
CC=.02; /*upper bound for menu cost*/
d=0.00001; /*step*/

/*Partial Equilibrium: Plotting optimal price as a function of menu cost*/
xtics(0,.25,.05,2);
ytics(0,.1,.01,2);
xaxis=(cumsumc(ones(20,1))-1)/80;
yaxis=zeros(20,1);
i=1;
do while i<=20;
C=xaxis[i,1];
yaxis[i,1]=xo(C);
i=i+1;
endo;
xy(xaxis,yaxis);

/*General Equilibrium: computing y(t)*/
Data=zeros(BB,4);
j=1;
do while j<=BB;
t=rndn(1,1)*s;

C=0;
if t>0;
do while C<(p+t-xo(C))^2;
C=C+d;
endo;
z=C;

else;
do while a*C<(p+t-xo(C))^2;
C=C+d;
endo;
z=C;

endif;

SS=0;
C=0;
do while C<z;
C=C+d;
SS=SS+xo(C)*d/CC;
endo;

do while C<=CC;
SS=SS+2*xo(C)*d/CC;
C=C+d;
endo;

y=(p+t)*maxc(0|(1-z/CC))-SS;
y=y/2;
```

```
Data[j,.]=t~(p+t)~y~(p+t-y);

print j/BB;
j=j+1;
endo;

print Data;

/*Solution to the system*/
proc xo(z);
local x, fvp, jc, tcode;
{ x,fvp,jc,tcode } =  nlsys(&sysm,x0);
retp (x);
endp;

/*System of equations for firm's optimal price*/
proc(1)=sysm(x);
local l, tu, tl;
tu=(x-p+sqrt(C));
tl=(x-p-sqrt(a*C));
l=(p*(cdfn(tu/s)-cdfn(tl/s))+ intquad1(&m,tu|tl) ) / (1+cdfn(tu/s)-cdfn(tl/s))-
x;
retp (l);
endp;

/*Nonstandard Normal pdf*/
proc m(x);
retp (pdfn(x/s).*x/s);
endp;

proc eqn1(z);
retp ( p+t-xo(z)-sqrt(z) );
endp;

proc eqn2(z);
retp ( xo(z)-p-t-sqrt(a*z) );
endp;
```

Appendix 2. Gauss Code for Skewness and Bootstrap Quantiles

```
new;
cls;

load e[181,1]=c:\temp\data.txt; /*loading data – cyclical component*/

n=rows(e);

skew=sumc(e^3)/n / (e'*e/n)^(3/2) ; /*skewness*/

/*bootstrap*/
BB=1000;
boot=zeros(BB,1);
b=1;
do while b<=BB;
e_b=e[ceil(rndu(n,1)*n),1];
skew_b=sumc(e_b^3)/n / (e_b'*e_b/n)^(3/2) ;
boot[b,1]=skew_b-skew;
b=b+1;
endo;

boot=sortc(boot,1);

print skew boot[0.01*BB,1] boot[0.05*BB,1] boot[0.1*BB,1];
```