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## Sluggish information diffusion and monetary policy shocks

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## Abstract

The sticky-information model appeared in order to offer a more empirically consistent view on the effects of monetary policy than the one provided by the benchmark sticky prices setup. Such inattentiveness framework was built on the assumption that current decisions are mainly based on past expectations about the current state of the economy. In this note, we propose an explanation for information stickiness that goes beyond the simple idea of infrequent updating of expectations. The suggestive new feature is that contemporaneous decisions will depend on a process of information diffusion that is triggered by the relation between two rational players: the profit maximizing media industry and the private agents, who seek information in order to update prices.

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# 1 Introduction

This note reinterprets the sticky-information approach to monetary policy pioneered by Mankiw and Reis (2002). In the original framework, information is sticky because firms are heterogeneous in what concerns the time moment in which they collect information in order to recompute optimal prices. The proposed mechanism, based on an adjustment assumption according to which each firm has a same probability of being one of the firms updating information independently of the timing of the last update, implies that current prices are a weighted average of past expectations on the contemporaneous optimal price level. However, this stickiness framework is silent in what concerns the process through which individuals acquire information in specific time moments, i.e., the model postulates that information disseminates slowly throughout the population, without furnishing any clue on why this happens. Clearly, a black box exists in this reasoning and one needs to look inside it to gain further knowledge on the economic responses to monetary shocks.

Relying on the literature on technology diffusion, and more specifically on the analysis of Mukoyama (2006), we adapt the innovation diffusion mechanism to a setup of information dissemination where a permanent feedback between two entities exists: firms in the media industry intend to produce appealing and informative news in order to maximize audiences; the population desires to access relevant information and to remain attentive in order to decide about price updates. From this intertemporal interaction relation emerges an S-shaped diffusion process: on a first phase, the curve relating to the number of individuals accessing some new information exhibits increasing marginal increments; on a second stage, such increments become decreasing. At the end of the information dissemination process, a given share of the agents in the market or the whole market have accessed the new information.

The appealing set of results that the analysis will furnish relates to the ability of the diffusion setup in reproducing, for given parameter values, the same perturbations on inflation and output trajectories arising from various types of monetary policy changes that one finds in the information stickiness framework. Thus, the analysis adds value to the sticky information literature by presenting a reasonable explanation on how differences on the timing of information acquisition arise.

A work that has common traits with ours is the one by Carroll (2006). Such contribution also assumes that expectations are formed over information obtained through the news media. The main difference is that the referred paper models information dissemination exogenously as an infectious disease or an epidemic, without establishing the foundations under which information diffuses, which is precisely what we intend to do.

The note is organized as follows. Section 2 reviews the main features of the sticky-information model and the policy experiments developed in Mankiw and Reis (2002). Section 3 introduces the information diffusion mechanism. In section 4 information diffusion is attached to the formation of the next period's price level. Section 5 will then address the dynamics of the model, highlighting that the obtained results can accurately mimic the ones in the sticky-information formulation. Finally, section 6 concludes.

## 2 The Sticky-Information Setup

We consider an economy with many monopolistically competitive firms. The profit maximization behavior of the firms implies the following desired price for each firm (i.e., the price that maximizes profits at each time moment),[1]

$$p_t^* = p_t + \alpha y_t \tag{1}$$

In equation (1), $p_t$ and $y_t$ represent, respectively, the price level and the output gap (both measured in logs). Parameter $\alpha > 0$ is a measure of real rigidities; it indicates the degree of sensibility of desired prices relatively to the real performance of the economy. The intuition is straightforward: expansion phases of the business cycle imply increases in demand and the corresponding desire of firms in rising prices; recessions will lead to a desired contraction of prices relatively to the existing price level.

The sticky information model assumes that only a share $\lambda \in (0,1)$ of firms in the market will update prices at each time moment, following a Poisson distribution. Thus, the price level at time $t$ will correspond to

$$p_t = \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j} p_t^* \tag{2}$$

Equation (2) tells us that all firms intend to set prices at the desired level, however they collect information and form expectations about such desired price at different moments in the past. This equation can be transformed into a Phillips curve, where a positive contemporaneous relation between output and inflation becomes evident:

$$\pi_t = \frac{\alpha\lambda}{1-\lambda} y_t + \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-1-j} \left(\pi_t + \alpha g_t\right) \tag{3}$$

with $\pi_t := p_t - p_{t-1}$ the inflation rate and $g_t := y_t - y_{t-1}$ the growth rate of the output gap.

To address the dynamics of inflation and output, one needs to close the model with an equation representing aggregate demand. Letting $m_t$ denote money supply or, more broadly, the whole set of factors capable of shifting aggregate demand, one establishes the relation

$$m_t = p_t + y_t \tag{4}$$

The effects of monetary policy will be addressed by imposing exogenous changes to $m_t$, in order to explore the corresponding impact over $\pi_t$ and $y_t$. To make such relation more transparent, replace $y_t$ in (3) by the difference between money and prices (according to (4)), and apply first-differences, to obtain

$$\begin{aligned} \pi_{t+1} = {} & \alpha\lambda\Delta m + (1-\alpha\lambda)\pi_t + (1-\alpha)\lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t+1-j} \left(\pi_{t+1}\right) \\ & -(1-\alpha)\lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j} \left(\pi_t\right) \end{aligned} \tag{5}$$

[1] We avoid presenting the details of the optimization problem not only because of space limitations but also because this is a trivial problem in the literature. See Blanchard and Kiyotaki (1987) for details.

Expression (5) is a rule translating the motion in time of the inflation rate as the result of eventual changes in monetary policy (or demand conditions). The term $\Delta m$ corresponds to the rate of growth of money supply, $m_{t+1}-m_t$, which can be considered constant between monetary policy changes. Note that under a purely deterministic environment with expectations formed under perfect foresight, the model (i.e., equation (5)) may be reduced to relation

$$\pi_{t+1} = \lambda \Delta m + (1-\lambda)\pi_t \tag{6}$$

Because $\lambda \in (0,1)$, it is straightforward to characterize the dynamics of the model: the inflation path is stable, implying that for any $\pi_0$, the system will converge to the steady state outcome $\pi^* = \Delta m$. Parameter $\lambda$ will represent the velocity of convergence; the less attentive firms are, the slower will be the convergence towards the monetary steady state.

Relatively to the specified macro framework, Mankiw and Reis (2002) propose the following policy experiments:

(i) Permanent negative change in the level of aggregate demand, not known with anticipation. A 10% fall in the value of $m_t$ is considered at time $t = 0$. Previously to $t = 0$, $m_t = -\ln(0.9)$ and for $t \geq 0$, $m_t$ becomes equal to zero. Evaluating this experiment resorting to (5), one regards that inflation gradually falls but after a given length of time recovers its initial value. This policy measure is also contractionary in the sense that it produces a temporary fall in the output gap.

(ii) Unanticipated fall in the rate of money growth. A 2.5% per period fall in the value of $m_t$ is assumed for $t < 0$; for $t \geq 0$, the rate of growth of the money supply becomes equal to zero. This experiment reveals that the sticky information setting will again imply a gradual reduction in inflation, resting in the long run at the new level of demand growth (recall that in the steady state $\pi^* = \Delta m$). The output gap suffers a fall after the shock but its value returns gradually to zero.

(iii) The fall in the rate of money growth is the same as in the previous experience, however now such policy change is announced 8 periods before it effectively occurs (at $t = -8$). In this case, inflation falls but in a less pronounced way than in the surprise disinflation case, and the contractionary effect on the output gap is also less pronounced.

(iv) The change in money supply is modelled as a first-order autoregressive process: $\Delta m_t = \rho \Delta m_{t-1} + \varepsilon_t$, with $|\rho| < 1$ and $\varepsilon_t$ an eventual perturbation over the growth of money supply. The selected values are $\rho = 0.5$ and $\varepsilon_0 = -0.007$ ($\varepsilon_{t \neq 0} = 0$). Again, a contractionary effect on output and a fall in the inflation rate occur after the shock with the maximum effect happening only after some time periods. It is evident in this and in the previous experiments which is the main consequence of the formalized information sluggishness setup: an inertia effect arises, making the impact of monetary policy having its maximum strength some time after the disturbance takes place.

All the four experiments are developed by taking time periods of a quarter of a year and by assuming the following parameter values: $\alpha = 0.1$ (the degree of real rigidities is not too significant) and $\lambda = 0.25$ (firms update information once a year, on average).

# 3 The Process of Information Diffusion

Consider an economy where a single source of information exists (a news agency). After a given economic event (e.g., a shock on demand), a large number of media firms (newspapers, radios and TV stations) will resort to the information originating on the agency to produce news on the assumed specific subject. The number of media firms is $Z$. Some of these companies will produce accurate, self-contained and easily understandable information; others will convey news with some sort of inaccuracy or difficult to understand from the point of view of the interested audience. Thus, at a given time moment $t$ there are $X_t = \sum_{i=1}^{Z} x_t^i$ imprecise news on the event, if one defines

$$x_t^i = \begin{cases} 1 \text{ if the news are inaccurate / difficult to understand;} \\ 0 \text{ if the news are rigorous and precise.} \end{cases}, \quad i = 1, 2, ..., Z.$$

The number of agents attentive to the news at each time moment is $N_t$; the medium chosen to access the news is selected at random from set $Z$, with this random choice being independent across time and across individual agents in the economy. When the news are inaccurate or difficult to understand, this is reported back to the media (today this has become extremely common; the public interacts with the media through various channels: on-line discussion forums, e-mail messages and letters to the news offices, public opinion programs on radio and TV). The information producer will then improve the quality / readability of the contents and generate more accurate and reader / listener / viewer - friendly news that will reach a broader audience.[2]

Let $q_t := (Z - X_t)/Z$ define the degree of news informativeness; if $q_t = 0$, all news on the subject are uninformative; on the other extreme, $q_t = 1$ implies that the news are completely understandable and readily accessible to the whole of the potential audience. We also define $n_t := N_t/Z$ as the number of individual agents accessing, on average, the news of a specific single information source (the number of agents attentive to the contents of a specific medium).

If, at moment $t$, no one accesses the contents of the media company $i$ and they contain errors or are uninformative, this implies that the errors are not corrected and the information remains uninformative at time $t+1$. Thus, we can establish the probability

$$\Pr\left\{x_{t+1}^i = 1 |\ x_t^i = 1\right\} = \left(1 - \frac{1}{Z}\right)^{N_t}$$

or, considering simultaneously all the news that are uninformative,

$$E[X_{t+1}|X_t] = X_t \left(1 - \frac{1}{Z}\right)^{N_t}$$

From the previous expectation, one realizes that

$$E[q_{t+1}|q_t] = 1 - (1 - q_t)\left(1 - \frac{1}{Z}\right)^{Zn_t}$$

By assuming $Z \to \infty$ (i.e., a very large number of news media exists) and noticing that $\lim_{Z\to\infty} \left(1 - \frac{1}{Z}\right)^{Zn_t} = \exp(-n_t)$, we can present the following deterministic difference equation for

[2]We focus our attention on the receivers of the news and on how they react to incentives. Relatively to the producers of the news, media firms, we implicitly consider that they have an advantage in refining the quality of their output in order to maximize audiences. The maximization of the number of clients is a crucial feature of the information related industries, since the respective production process is typically associated to zero marginal costs and, thus, profit maximization requires placing special attention on the revenues side.

the motion of the news informativeness variable:

$$q_{t+1} = 1 - (1 - q_t)\exp(-n_t),\ q_0 \text{ given.} \tag{7}$$

Equation (7) establishes an intuitive relation between the informativeness of news and the number of agents accessing the news conveyed by each media firm. As one should expect, $\partial q_{t+1}/\partial n_t = (1 - q_t)\exp(-n_t) > 0$, i.e., the larger the number of agents accessing the news of given media, the faster dubious contents on the news are reported and the faster the quality of the news is improved (for the specific equation (7), the quality of news increases exponentially with the number of individuals accessing news). Note also that $\partial^2 q_{t+1}/\partial n_t^2 = -(1 - q_t)\exp(-n_t) < 0$; this derivative indicates that the rate of improvement in the news will be subject to decreasing marginal returns: as $n_t$ increases it becomes harder to find new 'bugs' on the conveyed information and therefore the quality improves at a slower pace.

The above reasoning indicates how the number of individuals accessing news influences the quality of news. We now need to look at the opposite direction: how the improved quality allows for an increase of agents being attentive to that specific news. It seems evident that the higher is the quality level of the news, the more agents will want to access them. To formalize this idea, consider that the utility of news for an agent $\ell$ is given by $u_t^\ell = u_\ell(1 - \kappa(1 - q_t))$, with $u_\ell > 0$ a parameter that will assume different values across agents; we also consider $\kappa > 0$. The presented expression translates the idea that the larger is the quality of news, the larger will be the degree of utility agent $\ell$ withdraws from the news. Let the cost of acquiring news be $c$. The news will be acquired if $u_t^\ell \geq c$. If $u_\ell$ follows a Pareto distribution of the type $D(x) = 1 - b/x$ with $b$ a parameter such that $x \geq b$, then the number of agents accessing the news at time $t$ is:

$$n_t = 1 - D\left(\frac{c}{1 - \kappa(1 - q_t)}\right) = \widetilde{n}(1 - \kappa(1 - q_t))$$

with $\widetilde{n} := b/c$ the maximum number of agents that can access a given news source. The larger is the overall quality of the news, the larger will be the share of individuals accessing a given medium, relatively to its potential demand: $\partial n_t/\partial q_t = \widetilde{n}\kappa > 0$. Replacing $q_t$ by $\frac{n_t}{\widetilde{n}\kappa} + \frac{\kappa - 1}{k}$ in equation (7), one obtains the following rule of motion for the number of agents accessing news of a given source:

$$n_{t+1} = \widetilde{n} - (\widetilde{n} - n_t)\exp(-n_t),\ n_0 \text{ given.} \tag{8}$$

# 4 Price Dynamics under Information Diffusion

In this section, we explain how the information diffusion process can be used in order to address the macroeconomic response to demand / monetary policy shocks. Agents that have already accessed the information on the shock and have understood it will form expectations $p_{t+1}^I := E_t p_{t+1}^* = p_{t+1}^*$ (expectations are rational) for the price level in $t + 1$, with $p_t^*$ the desired price defined in equation (1). The agents that do not have yet accessed or processed the news on the change of demand conditions will select a price that is equal to the previous price plus the growth rate of money supply that existed previously to the disturbance. Let $\Delta m|_{\Omega_t < 0}$ be this growth rate with $\Omega_t < 0$ the set of information known prior to the announcement of the shock. Type II agents will select the following price for $t + 1$: $p_{t+1}^{II} := p_t + \Delta m|_{\Omega_t < 0}$.

Therefore, prices at $t+1$ will be given by a weighted average:

$$p_{t+1} = \frac{n_{t+1}}{\widetilde{n}} p^*_{t+1} + \frac{\widetilde{n} - n_{t+1}}{\widetilde{n}} \left(p_t + \Delta m|_{\Omega_t<0}\right) \tag{9}$$

Given the definition of desired price in equation (1), one is able to rewrite (9) under the form of a Phillips curve,

$$\pi_{t+1} = \alpha \frac{n_{t+1}}{\widetilde{n} - n_{t+1}} y_{t+1} + \Delta m|_{\Omega_t<0} \tag{10}$$

The Phillips curve in (10) reveals the usual positive contemporaneous relation between income / output and the inflation rate. Note that the larger is the number of agents that already accessed the information, the larger is the impact of the output gap over price changes. In the limit case $n_{t+1} = \widetilde{n}$, we are in the steady-state position, where we regard that $y^* = 0$.

Combining (10) with the market clearing condition (4) and applying first differences, one obtains the following expression reflecting the motion in time of the inflation rate:

$$\begin{aligned} \pi_{t+1} \quad = \quad & \frac{1}{\widetilde{n} - (1-\alpha) n_{t+1}} \cdot \\ & \left\{ \frac{(\widetilde{n} - n_t) n_{t+1}}{n_t} \pi_t + \alpha n_{t+1}\, \Delta m|_{\Omega_t \geq 0} - \frac{\widetilde{n}(n_{t+1} - n_t)}{n_t}\, \Delta m|_{\Omega_t<0} \right\} \end{aligned} \tag{11}$$

The main point this paper wants to stress is that inflation difference equation (11) combined with the information diffusion rule (8) is capable of generating the exact same results as the sticky-information model when the same policy experiments are undertaken. Before addressing such experiments in the next section, note the main features of system (8)-(11):

1. The steady-state of the system is $(n^*, \pi^*) = (\widetilde{n}, \Delta m|_{\Omega_t \geq 0})$, i.e., all agents have access, sooner or later, to the relevant information about the policy measure and, in the long-run, inflation will be equal to the rate of growth of money supply that prevails after the shock.

2. Considering exclusively a deterministic interpretation of the referred system, one encounters a local stability result. To confirm this, compute derivatives in the vicinity of the steady-state for equation (11),

$$\begin{aligned} \left.\frac{\partial \pi_{t+1}}{\partial \pi_t}\right|_{(n^*,\pi^*)} \quad &= \quad 0; \\ \left.\frac{\partial \pi_{t+1}}{\partial n_t}\right|_{(n^*,\pi^*)} \quad &= \quad \frac{(1-\alpha)\exp(-\widetilde{n}) - 1 + \alpha\widetilde{n}}{\alpha\widetilde{n}}\, \Delta m|_{\Omega_t \geq 0} - \frac{\exp(-\widetilde{n}) - 1}{\alpha\widetilde{n}}\, \Delta m|_{\Omega_t<0} \end{aligned}$$

The following linearized system characterizes the local dynamics of the model,

$$\begin{bmatrix} n_{t+1} - \widetilde{n} \\ \pi_{t+1} - \Delta m|_{\Omega_t \geq 0} \end{bmatrix} = \begin{bmatrix} \exp(-\widetilde{n}) & 0 \\ \left.\frac{\partial \pi_{t+1}}{\partial n_t}\right|_{(n^*,\pi^*)} & 0 \end{bmatrix} \cdot \begin{bmatrix} n_t - \widetilde{n} \\ \pi_t - \Delta m|_{\Omega_t \geq 0} \end{bmatrix}$$

The eigenvalues of the Jacobian matrix in the above system are $e_1 = \exp(-\widetilde{n})$ and $e_2 = 0$. Because $|e_i| < 1, i = 1, 2$, for any positive $\widetilde{n}$, stability holds.[3]

[3] Local stability indicates that for any $\pi_0$ in the vicinity of $\pi^*$, the trajectory in time followed by the inflation rate is a trajectory of convergence towards $\pi^*$. Furthermore, since $n_t \in (0, \widetilde{n})$, equation (11) also provides the information that the basin of attraction of the steady-state is the whole universe of potential levels of $\pi_t$ and, thus, stability is global. Any numerical example can confirm this.

# 5 Policy Experiments

As mentioned earlier, the policy experiments we undertake are exactly the same ones as in Mankiw and Reis (2002). We consider the same level of real rigidities, $\alpha = 0.1$, and now the degree of sticky-information no longer applies. Instead, one needs to define the value of $\widetilde{n}$ and the initial value $n_0$. Recall $\widetilde{n}$ defines the percentage of individuals that potentially access a given information source, while $n_0$ is the percentage of agents that effectively resort to the information source in the precise moment in which the news about the monetary policy measure are generated for the first time (the group of exceptionally attentive agents). We take $\widetilde{n} = 0.22$ and $n_0 = 0.05$. Under a complete diffusion process, $n_t$ will converge from $n_0$ to $\widetilde{n}$; for the selected values, the convergence process is relatively fast: after 20 periods the information has asymptotically reached all the population; after 6 periods, 50% of the population has already accessed and processed the news. If one is considering quarterly data, this implies that it takes one and a half year for the monetary policy measure to be spread by one half of the price setting agents.

We recover the policy experiments:

(i) Non anticipated 10% fall in the level of aggregate demand. Figure 1 presents the effects of such shock, occurring at time $t = 0$, for the selected parameter values.[4] Panel A concerns the impact of the perturbation over the output gap (the shock has an evident contractionary effect); panel B respects to the reaction of the inflation rate (the strongest effect is felt after 9 to 10 periods, given the sluggishness introduced by the diffusion process). Once the disturbance takes place, the diffusion of information begins from $n_0 = 0.05$ to $\widetilde{n} = 0.22$; this process obeys to the motion rule (8), i.e., to the S-shaped process of information dissemination. The information diffusion process that begins with the disturbance occurring in the economy implies that it will take time for all the agents to access the new information, what justifies the shape of both the output gap and the inflation rate trajectories.

(ii) Non anticipated fall in the rate of money growth at date $t = 0$, from 2.5% per quarter to 0%. For this case, figure 2 illustrates the impact over output and inflation. Inflation falls from the first to the second equilibrium point, but with this process involving a contractionary effect: in the transition phase, inflation falls below zero. The output gap also falls below zero but it returns precisely to this same value in the long-run. The diffusion process is the same and it begins at the same moment as in the first experiment.

(iii) Anticipated fall in the rate of money growth, announced at $t = -8$ to occur at $t = 0$ (again, the change is from 2.5% growth per quarter to 0% growth per quarter). Figure 3 reveals that the fall in the output gap is less pronounced than in the previous case, while the contractionary effect over the price level is again felt only after $t = 0$ but with a reduced impact. In this case, we are considering the exact same diffusion process as in the previous experiments, but now it starts at $t = -8$, instead of beginning at $t = 0$.

(iv) Finally, we consider an AR(1) process for the money supply evolution in time with a negative shock ($\varepsilon_0 = -0.007$) occurring at $t = 0$. In this case, the economy will again experience a relatively sluggish decline in both the output gap and the inflation rate and a re-establishment of the equilibrium after around 20 periods. Again, the shock triggers the same type of diffusion process as in the previous cases, and it will be this process that shapes the evolution of $y_t$ and $\pi_t$ observed in figure 4.

[4]All figures are presented at the end of the paper.

# 6 Conclusion

Given zero marginal costs, firms in the media industry will have an incentive to maximize audiences. They achieve this goal through a process of refinement of the quality of news. Such process allows price setting firms to access relevant economic information that they can use to update their expectations. Because agents are heterogeneous with respect to the capacity to absorb information, any policy disturbance affecting the economy will imply a gradual departure from the steady-state. The steady-state is recovered as price-setters gradually access news and update expectations accordingly. An inertia effect then characterizes the response of the economic system to shocks that will eventually occur.

Figures 1 to 4 are identical to the ones presented in Mankiw and Reis (2002), for the exact same policy experiments. Thus, it is reasonable to conclude that information stickiness can be explained through a process of information dissemination, which arises from the coexistence in the society of agents requiring information and media companies that desire to maximize revenues for a given cost structure.

# References


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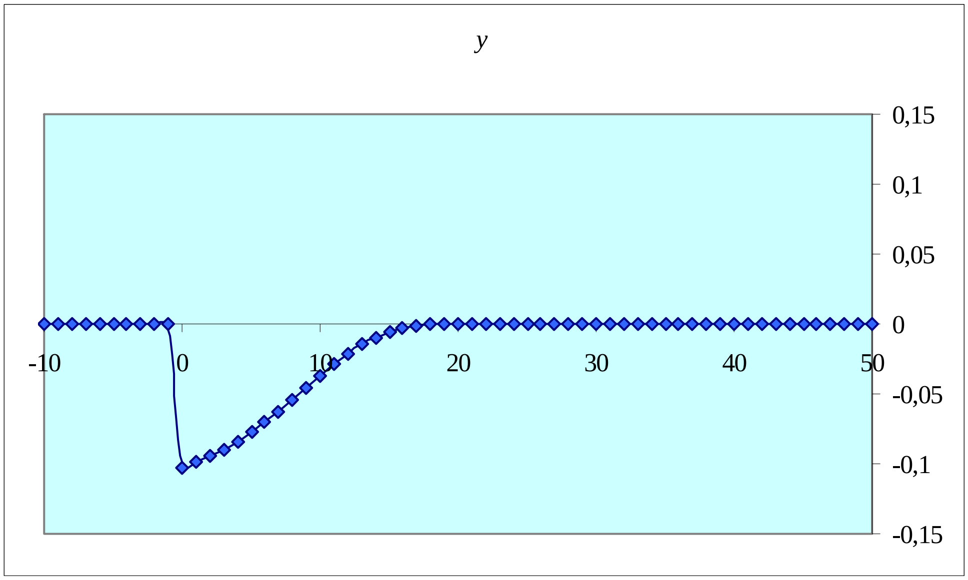
# Fig. 1 – Effects of policy experiment I

**Panel A:**




**Panel B:**

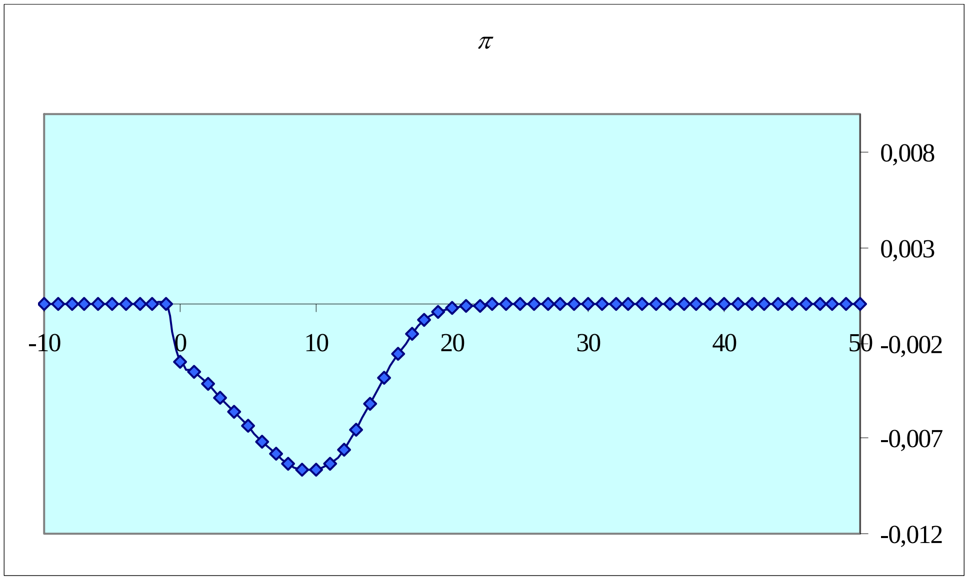
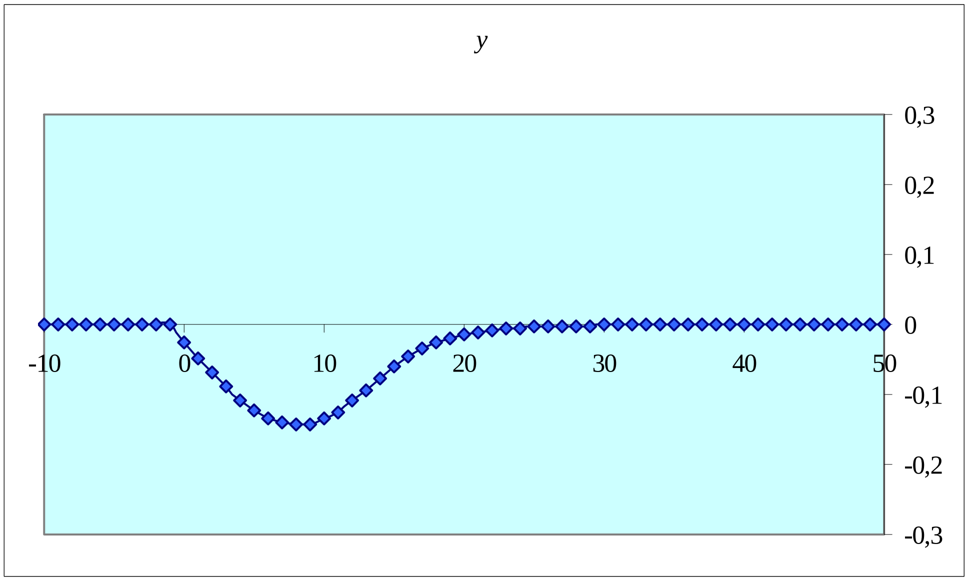


**Fig. 2 – Effects of policy experiment II**

**Panel A:**

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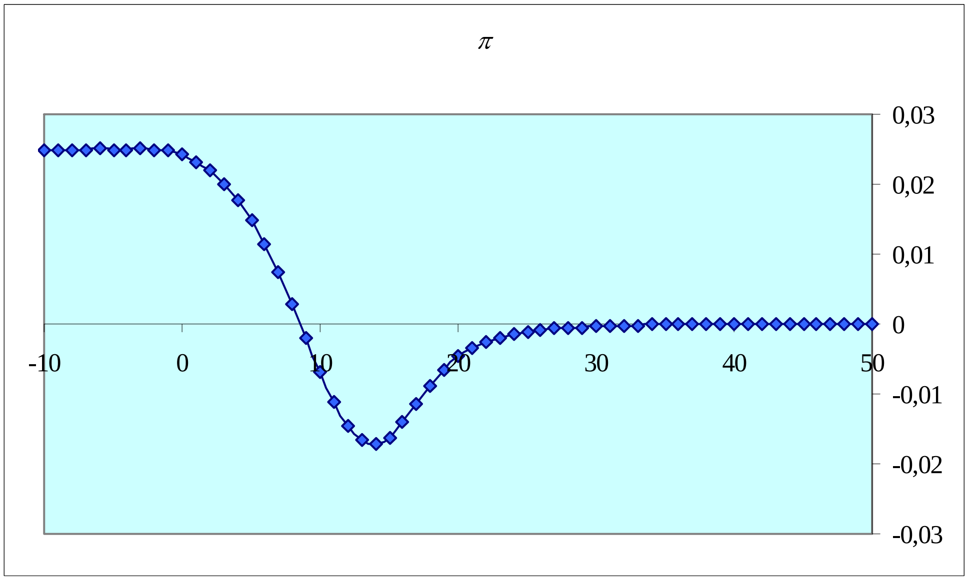
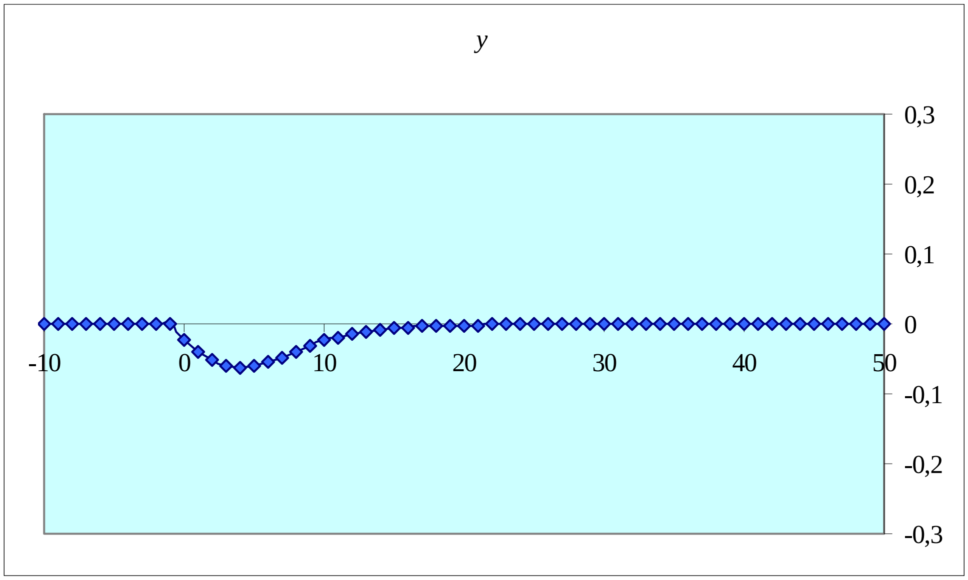


**Fig. 3 – Effects of policy experiment III**

**Panel A:**

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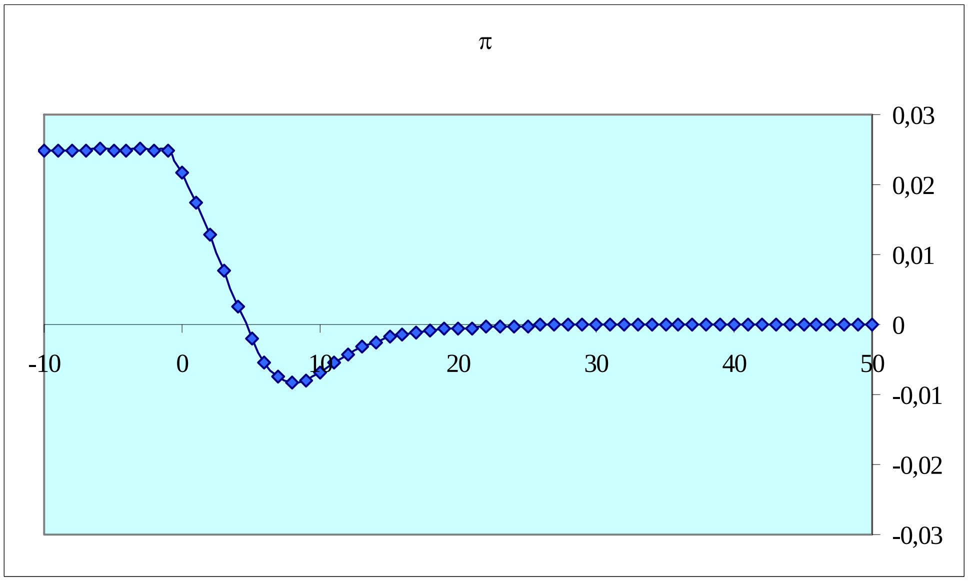
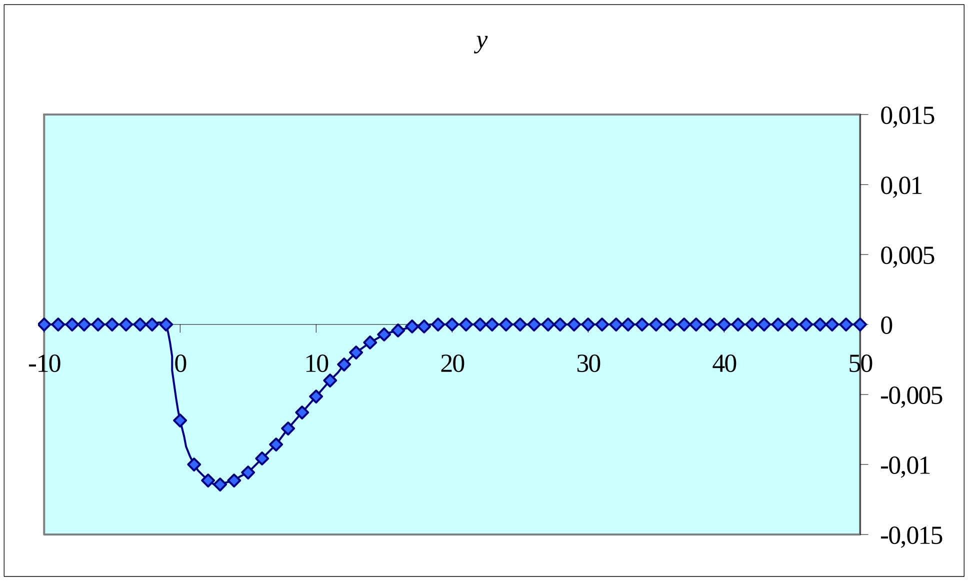


**Fig. 4 – Effects of policy experiment IV**

**Panel A:**




**Panel B:**