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Ambiguity and macroeconomics: a rationale for price stickiness

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Abstract - This paper deals with the emergence of price stickiness, that is nominal price elasticity below one, in the wake of nominal shocks. The setting of analysis is a general equilibrium model with both ambiguity and rational expectations. Ambiguity and macroeconomics are linked exploiting a micro-founded framework. Ambiguity concerns the lack of knowledge of firms about the relationship between changes in the aggregated stock of money and in the money distribution across heterogeneous consumers in the economy. Ambiguity is represented through a multiple priors approach. It is shown that price stickiness can emerge even if a change in the money supply level does not alter the distribution of money across consumers (uniform monetary policy). The key assumption made in the paper is that attitude towards ambiguity of firms is asymmetric: ambiguity aversion towards uncertain positive outcomes (gains) and ambiguity seeking towards negative outcomes (losses). By focusing on the dynamics of beliefs following a change in the stock of money that does not alter the money distribution, it is shown that money neutrality remains true in the long run.

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Introduction

According to some empirical studies (i.e. Greenwald and Stiglitz 1989) price stickiness, that is price elasticity below one following aggregated nominal shocks, is a stylised fact. The theoretical puzzle (Farmer 1992) is how to reconcile that fact with a standard model based on agents' rational choices. The nominal rigidity topic is, of course, an old one, and has already been tackled in many ways: for example by introducing menu costs (Blanchard and Kiyotaky 1987), near rationality (Akerlof e Yellen 1985), multiple equilibria (Cooper and John 1988), staggered contracts (Fisher 1977), information incompleteness (Lucas 1972), and money social externalities (Farmer 1993).

This paper tries to solve this puzzle through an application of ambiguity theory to microfounded macroeconomics. Ambiguity is introduced in a general equilibrium framework, inspired by the Lucas's approach based on information incompleteness. It will be shown how it is possible to overcome a critique that, on the empirical ground, has been levelled against Lucas's model. It is argued that, because of readily available information about nominal aggregates, that model fails to explain the persistence of price rigidity which data point to (Romer 1996). In the present paper information incompleteness is referred to money distribution, that is a much more difficult to observe variable than the money stock aggregated level. It is assumed that rational firms face an ambiguous problem when they evaluate the impact of monetary policies on the distribution of nominal endowments across heterogeneous consumers. In this context, the approach of multiple priors is used to model the attitude towards ambiguity, that is firms are supposed to be unable to assign a fully reliable additive probability distribution to possible events because they are ambiguous. Hence firms have multiple additive priors on possible events and their preferences are compatible with either maxmin or maxmax expected utility decision rule.[‡]

The aim of this paper is to show that asymmetric attitude of firms towards ambiguity can explain a lasting phenomenon of prices stickiness even in presence of monetary policies that do not alter the nominal endowments distribution among agents.

The paper is organized as follows. The concept of a uniform monetary policy is introduced in Section 2. In Section 3 the economic framework is presented. Section 4 deals with the relationship between ambiguity and price stickiness. Section 5 and 6, respectively, describe the dynamics of money distribution and the dynamics of expectations. Concluding remarks are in Section 7.

2. The meaning of a uniform monetary policy

There are many conditions explaining why prices do not to react proportionally to monetary shocks even if agents are assumed to be rational. These conditions refer to the cases in which a change in the money stock is either not (believed to be) once for all, or is not immediately implemented, or is not fully observed, or does not distribute money in proportion to heterogeneous agents' initial nominal balances (Grandmont 1983). Moreover, creation of money to finance government spending in real goods (i.e. the construction of a bridge or a highway) changes the economy endowment, and therefore the new money is likely to affect relative prices and the real equilibrium. To avoid these issues, in what follows public expenditure is not considered (money is supposed to be distributed to consumers directly) and we concentrate on a specific kind of monetary policy: a once for all, announced, immediately implemented, observed (in its macro features) and proportionally distributed change in the exogenous stock of money. Such policy is labelled a "uniform monetary policy".

3. The economic framework

Our analysis rests on a very simplified economic framework, to focus on the effect of ambiguity about non observable macroeconomic variables on firms' pricing decisions. It is worth remarking that the result of price stickiness is does not depend on the simplifying assumptions made. We study a sequence economy of which the per period structure fully retains the standard

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‡ Maxmin (maxmax) expected utility postulates that firms with multiple priors consider the least (most) value of expected utility for any act and choose that act for which this least (most) value is greatest.

properties (homogeneity of demand and money neutrality under full observability) which should characterize our benchmark model to make the introduction of ambiguity significant.

At any time t population is constituted by a fix number $H = \{1 \ldots h \ldots H\}$ of people belonging to H different families. Each person lives for one period only and is replaced by another identical member of her family. On the supply side there is a fix number $J = \{1 \ldots j \ldots J\}$ of firms engaged in monopolistic competition. Production takes place freely (there are no inputs in the production function). Economic agents are subject to a cash-in-advance constraint: they must use money for transactions. Timing is as follows. Firms set prices on the basis of the general price level (taken as given: we consider a Nash-equilibrium in prices) as well as expected demand. Then demand is observed, goods are produced and sold, and profits are paid out. Expectations are assumed to be uniform and common knowledge across firms. We work directly with explicit aggregated demand functions; nominal demand for good j is given by:

$$p_j q_j = \frac{Q^2 - p_j^2}{P} + \frac{p_j}{P} n$$

where n represents the consumers' total nominal expenditure and P , Q are aggregate price level indexes that ensure the adding-up property of the demand function:

$$P = \sum_j p_j \qquad Q^2 = \frac{\sum_j p_j^2}{J}$$

Due to the cash-in-advance constraint, consumption is limited by the already accumulated monetary endowment. Consumers intertemporal consumption/saving decisions are modelled in a very simple way. We assume a specific form of paternalistic intergenerational altruism. At any period, the living member of family h leaves a bequest composed of two parts: the same portfolio of firms' shares she received and a fraction of her nominal endowment. Although this way of modelling the international linkages is somehow arbitrary[§], however it has some useful implications:

- under standard rational expectations money is neutral (there is no price stickiness), and therefore the emergence of nominal rigidities is not due to that simplifying assumption;
- market demand depends straightforwardly on money distribution;
- there is no market for shares;
- the analytics of the model is very simple

To be specific, each consumer *h* spends a constant fraction $\phi^h \in (0,1)$ ("disturbed" by a common i.i.d. random shock $\theta \in [0,1]$) of her initial monetary endowment, and she leaves the remaining part to the next member of her family. All ϕ^h s are known by firms. The total nominal demand of agent *h* is

$$n^h = \theta\phi^h M^h$$

where M^h s are the initial monetary endowments, not directly observable by firms.

Then, aggregate nominal expenditure ($n = \sum_h n^h$) depends on the money distribution index

$$\Omega = \sum_h \phi^h M^h$$

Given the of expected profits (i.e. revenues) function[**]

$$E\left[p_j q_j\right] = H\,\frac{Q^2 - p_j^2}{P} + \frac{p_j}{P} E[n] \qquad [1]$$

the optimal *j*-price is

$$p_j = \frac{E[n]}{2H} = \frac{E[\theta]E[\Omega]}{2H}$$

which, given the assumption of uniform expectations, is the same for each firm.

[§] Note that, if the population was constituted by a single person, this behaviour would be inefficient. In fact, any unit of money spent for consumption would be totally incorporated in profits and, therefore, it would be entirely available to the next component of the same family. Reducing current consumption would not raise the next member's utility. When there are different families, any unit of money saved is passed on to the next family member; if spent, it generates profits which are distributed to the next family member proportionally to her stock portfolio.

In the temporary equilibrium of the economy, therefore, the real production of each firm is given by

$$q = \frac{2H}{J} \frac{\theta\Omega}{E[\theta]E[\Omega]}$$

It is now clear that if we assume that expectations are rational (in the Lucas's sense) and, therefore, that $E[\Omega] = \Omega$, the result is that, abstracting from the effects of the purely stochastic disturbance θ, following a uniform monetary policy all nominal quantities change proportionally to the money supply level and real quantities are unaffected.

4. Ambiguity and price stickiness

While, for the sake of simplicity, it is assumed that the distribution of the i.i.d. shock (θ) is well known and therefore that expectations about it are formed in the standard way, we suppose that imposing standard rational expectations about the not observable impact of monetary policies on the money distribution index Ω is questionable. Rather, in the following we assume that agents are not ambiguity neutral and that Ω is an ambiguous variable whose value could be deduced only indirectly. Remarkably, all the observable signals reveal only $\theta\Omega$, and therefore firms cannot disentangle single values (learning about Ω cannot be immediate). In this way we introduce an endogenous dynamics originating from both the evolution of the money distribution (Ω) and its expected value ($E[\Omega]$). This issue will be dealt with later on. Now we concentrate on the implications of ambiguity with reference to the effects of a uniform monetary policy in the short run.

We use multiple priors to model ambiguity. Ambiguity is represented by a set of possible priors instead of a single one on the underlying state space. This means, as Ellsberg put it, that "each subject does not know enough about the problem to rule out a number of possible distributions" (Ellsberg 1961, 657). If an agent is ambiguity averse (seeking), she maximizes the minimum (maximum) expected utility with respect to each probability in the prior set, thus

[**] The specific aggregate demand function assumed guarantees the existence of a well defined maximim revenue being

exhibiting *maxmin* (*maxmax*) behaviour.[††] In the following, therefore, expectations about θ are intended to be formed according to a single probability distribution while $E[\Omega]$ is defined with respect to multiple priors.

Let $\Gamma \equiv \{f(\Omega)\}$ be the set of multiple probability distributions for Ω. An ambiguity averse (seeking) agent will choose optimising with respect to the distribution which minimizes (maximises) her payoff. In our case, the profit function is what should be maximised. From equation [1] it follows that the probability distribution $\hat{f} \in \Gamma$ which minimises (maximises) the expected profit function is simply the distribution which minimises (maximises) the expected value of Ω. Therefore an ambiguity adverse (seeking) agent will choose according to the probability distribution that minimise (maximise) the expected value of Ω.

Let us suppose that the economy is in a long run steady state. The constant (known) value of the money distribution index is Ω_0. At this point a uniform monetary policy is implemented, so that the new, constant, level of the stock of money becomes[‡‡] $M_1 = \lambda M_0$ and $\Omega_1 = \lambda \Omega_0$. As already stated, firms can only observe that $M = \lambda M_0$, and consider Ω_1 as an ambiguous variable, described by a set of multiple priors $\Gamma \equiv \{f_k(\Omega)\}$. Let $S(f_k)$ be the support of any f_k.

We make the following assumptions:

A1: if firms were ambiguity neutral, their unique probability distribution $f(\Omega_1)$ would be such that $E\lfloor \Omega_1 | f_k \rfloor = \lambda \Omega_0$

A2: an increase (reduction) in the money supply level does not reduce (increase) the initial money endowment of any agent.

A3: Γ will be such that $\exists k', k'' : E\lfloor \Omega_1 | f_{k'} \rfloor < \lambda \Omega_0 < E\lfloor \Omega_1 | f_{k''} \rfloor$

A1 guarantees that, in our framework, if agents are ambiguity neutral, money is neutral.

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concave in p_j (for given P and Q).

[††] See Gilboa and Schmeidler 1989.

[‡‡] Subscripts refer to time (before and after the uniform monetary policy is implemented).

A2 means that there is a direct relationship between the money stock and the money distribution index. It also implies that if $\lambda > 1$ ($\lambda < 1$) then $\Omega_0 < min\ S(f_k)\ \forall k$ ($\Omega_0 > max\ S(f_k)\ \forall k$) and, therefore $E\lfloor \Omega_1 | f \rfloor > \Omega_0\ \ \forall k$ ($E\lfloor \Omega_1 | f \rfloor < \Omega_0\ \ \forall k$). A2 makes it not necessary to deal with pathological cases in which an indirect relationship between the money supply level and aggregate nominal demand emerges, making it no longer true that an expansionary (contractionary) monetary policy can only be a good (bad) news for firms.

A3 is formulated in order made not to limit the model to polar relative to the benchmark one, that is not to reduce the central role of agents attitude towards ambiguity within the model.

Under these assumptions, it is firstly supposed that firms are ambiguity averse. We know from A3 that profits will be maximised with respect to a probability distribution such that $E\lfloor \Omega_1 \rfloor < \lambda\Omega_0$. Therefore, prices will change less than proportionally to the money stock level as a result of an expansive policy but they will change more than proportionally as a result of a restrictive one.

A further step is to be taken to explain the occurrence of price stickiness as a general result. In the rest of this Section we motivate the case in which the consequences of an expansionary or contractionary monetary policy are evaluated asymmetrically: according to ambiguity aversion or ambiguity seeking, respectively.

In a seminal paper, Kahnemann and Twersky (1979) shows that agents' preference between risky prospects are not linear in probabilities and violate the Expected Utility Theory. Agents tend to overweigh small probabilities and to underweigh large probabilities. Namely they transform priors into decision weights which measure both the perceived likelihood of beliefs (diminishing sensitivity-discriminability) and the preference for gambles (attractiveness).[§§] Kahnemann and Twersky pointed out this behaviour within the framework of a Non Expected Utility Theory called Prospect Theory. The core of prospect theory as well as its recent generalization-axiomatization called Cumulative Prospect Theory[***] is that agents evaluate possible losses and gains differently. Losses and gains are defined with respect to a reference point or neutral outcome. Agents show both the possibility effect (*lower subadditivity*) and the certainty effect (*upper subadditivity*). Agents make decisions based on changes of their monetary endowments rather than on total monetary outcomes, thus inducing a sign- and rank-dependent expected utility. As a result, agents have inverse-S-shaped utility functions: these are concave for small probabilities and convex for high probabilities. This result is consistent with a concave utility function for gains and a convex utility function for losses.

Since attitude towards ambiguity is sign- and rank-dependent, it is appropriate to focus on the distinction between good and bad uncertain outcomes, that is gains and losses. We argue that attitude towards ambiguity is asymmetric depending on which case prevails.

Plenty of experimental evidence suggests asymmetry in the attitude towards ambiguity. See Cohen et al. (1985), Einhort and Hogart (1990), Wu and Gonzales 1999, Abdellaoui 2000, Bleichrodt and Pinto 2000, Bleichrodt et al. 2001, Kilka and Webber 2001. All these papers reporting experimental studies indicate that agents treat gains and losses differently. A variety of parametric functions are used to elicit individual utility and probability weighing functions for represent their behaviour. The common feature of these experimental studies is that the elicited utility functions satisfy both upper and lower subadditivity and are consistent with ambiguity aversion for gains and ambiguity seeking for losses.

Because of A2, as long as $\lambda > 1$ ($\lambda < 1$) *ceteris paribus* profits are higher (lower); the extent of the variation depends on the actual value of Ω_1. Moreover, profits are still an increasing function of Ω even assuming that firms know the macro structure of the model and thus they can calculate the value of their profit function expecting that, in equilibrium, all firms will charge the same price,.

[§§] Discriminability and attractiveness, respectively, determine curvature (slope) and elevation (intercept) of the inverse-S-shaped utility function in the Cumulative Expected Utility.

[***] Tversky and Kahnemann 1992, Wakker and Tversky 1993, Chateauneuf and Wakker 1999.

Therefore, an expansionary (contractionary) policy represents a prospect of gain (loss) from the point of view of firms.

Thus, a tendency to show ambiguity aversion for prospective gains and ambiguity seeking for prospective losses suffices to bring about price stickiness in the context of a nominal uniform monetary policy. Moreover, such theoretical result seems to have some support from empirical investigations.

5. The dynamics of money distribution

As regards money distribution we observe that changes in agent *h*'s monetary endowment are given by (assuming that all consumers hold the same equity portfolio):

$$M_{t+1}^{h} = M_{t}^{h} - \theta_t \phi_h M_{t}^{h} + \frac{\Pi}{H}$$

(where Π are aggregate profits), from which, given that $\Pi_t = \theta_t \Omega_t$,

$$\Omega_{t+1} = \left(1 + \theta_t \phi_t\right)\Omega_t - \sum_h \left(\phi^h\right)^2 M_t^h$$

The dynamics of Ω_{t+1}, therefore, depends not only on Ω_t but also on the other money distribution index $\sum_h \left(\phi^h\right)^2 M_t^h$. To maintain analytics as simple as possible, we linearise $\left(\phi^h\right)^2$ around its mean value $\phi \equiv \frac{\sum_h \phi^h}{H}$: $\left(\phi^h\right)^2 \cong \phi^2 + 2\phi\left(\phi_h - \phi\right) = -\phi^2 + 2\phi\phi^h$, then

$$\Omega_{t+1} = \left(1 - \theta_t \phi\right)\Omega_t + \theta_t \phi^2 M_t \qquad [2]$$

Four observations follow equation (2):

Observation 1 The dynamics of Ω_t has a steady state (for a constant money supply) $\hat{\Omega} = \phi M$ that does not depend on θ and is proportional to the money supply level.

Observation 2 The constant in the linear relationship [2] is positive. The coefficient is positive and lower than 1. Therefore, despite the value of θ_t, Ω_t converges towards $\hat{\Omega}$ at any time *t*

Observation 3 The dynamics of Ω_t does not depend on expectations about Ω

Observation 4 Following a uniform monetary policy ($\forall h \; M^h \to \lambda M^h$) Ω jumps to its new steady state value.

6. The dynamics of expectations

Analysis of the dynamics of $E[\Omega]$ is more complex than that of its true value Ω. As indicated above, Ω is assumed to be an ambiguous variable, and agents' expectations are formed according to multiple probability distributions.

Each prior, say $\psi_t(\Omega_t)$, is updated separately using Bayes rule[†††], but the relevant posterior, say $\vartheta_t(\Omega_t)$, does not constitute a suitable new prior for Ω_{t+1} precisely because of the autonomous dynamics of Ω itself according to equation [2]. In fact, given $\vartheta_t(\Omega_t)$, Ω_{t+1} is a function of two (independent) random variables: Ω_t and θ_t. Therefore, the updating of $\psi_t(\Omega_t)$ is carried out in two steps: the first is being Bayesian updating of (each) $\psi_t(\Omega_t)$, the second pertains to the calculation of the relevant probability distribution of the dependent random variable Ω_{t+1}

Bayesian updating depends on the signal π_t (the firm's profits), on the basis of which it is possible to calculate $\psi_t(\Omega_t \mid \pi_t) = \dfrac{\psi_t(\pi_t \mid \Omega_t)\psi_t(\Omega_t)}{\psi_t(\pi_t)}$

To obtain the new prior $\psi_{t+1}(\Omega_{t+1})$, we need to translate the probabilistic assessment over Ω_t into one about Ω_{t+1}. We first exploit equation [2] (which we write $\Omega_{t+1} = \zeta(\Omega_t)$):

$$\psi_{t+1}(\Omega_{t+1} \mid \theta_t) = \eta(\theta_t)\vartheta_t\left(\zeta^{-1}(\Omega_{t+1})\right)\left|\frac{\partial \zeta^{-1}(\Omega_{t+1})}{\partial \Omega_{t+1}}\right|$$

where $\eta(\theta_t)$ is the probability distribution of θ_t.

Then, we integrate the last equation with respect to θ_t to obtain the marginal distribution of Ω_{t+1}:

[†††] We refer to Epstein and Schneider [2001].

$$\psi_{t+1}\left(\Omega_{t+1}\right)=\int_{\theta_t\in\Theta}\eta\left(\theta_t\right)\vartheta_t\left(\zeta^{-1}\left(\Omega_{t+1}\right)\right)\left|\frac{\partial\zeta^{-1}\left(\Omega_{t+1}\right)}{\partial\Omega_{t+1}}\right|d\theta_t \qquad [3]$$

Actually, a closer analysis of the dynamics of equation [3] is not needed. In view of our goals, it suffices to consider the dynamics that of the set of admissible values for Ω_t, according to agents' beliefs. Such range is updated according to the two-step procedure described above.

To be more specific, we now restrict our analysis to a case in which Ω has already converged to its steady state value $\hat{\Omega}$ (recall that this happens immediately if the perturbing shock is a uniform monetary policy). We do not assume, however, that agents has already learned that.

Let $\tilde{\Omega}_0=\left[\underline{\Omega_0},\overline{\Omega_0}\right]$ be the initial support of one of the multiple priors. Since the value of $\hat{\Omega}$ is always calculable, it must be $\hat{\Omega}\in\left[\underline{\Omega_0},\overline{\Omega_0}\right]$. Moreover it must hold that $\underline{\Omega_0}\geq\min_h\{\phi_h\}M$ $\overline{\Omega_0}\leq\max_h\{\phi_h\}M$. Then, $\tilde{\Omega}_0$ is first updated after the agents' observation of the signal $s_0\equiv\pi_0$. Since $s_0=\dfrac{\theta_0\Omega_0}{J}$ the new admissible range, say $\left[\underline{\Omega_0}(s_0),\overline{\Omega_0}(s_0)\right]$ is such that $\overline{\Omega_0}(s_0)=\overline{\Omega_0}$ and $\underline{\Omega_0}(s_0)=\max\{\underline{\Omega_0},Js_0\}$. Without loss of generality we assume $Js_0=\max\{\underline{\Omega_0},Js_0\}$, therefore $\tilde{\Omega}_0(s_0)=\left[Js_0,\overline{\Omega_0}\right]$

As for the second step equation [2] is applied to $\tilde{\Omega}_0(s_0)$ to obtain a new range, say $\tilde{\Omega}_1(\theta_0)$, expressed as a function of the (unknown) value[‡‡‡] of θ_0 given by

$$\tilde{\Omega}_1(\theta_0)=\left[(1-\theta_0\phi)\frac{s_0}{J}+\theta_0\phi^2M,\ (1-\theta_0\phi)\overline{\Omega_0}+\theta_0\phi^2M\right]$$

In general it is $\tilde{\Omega}_t(s_t)=\left[\max_{z\leq t}\{s_t\}J,\overline{\Omega_t}\right]$ and

$$\tilde{\Omega}_{t+1}(\theta_t)=\left[(1-\theta_t\phi)\max_{z\leq t}\{s_t\}J+\theta_t\phi^2M,\ (1-\theta_t\phi)\overline{\Omega_t}+\theta_t\phi^2M\right]$$

[‡‡‡] To fully define the evolution of the range of integration for $\tilde{\Omega}_1$, the max and min of $\tilde{\Omega}_1(\theta_0)$ can be calculated according to the possible values of θ_0; however, such operation is not needed for our purposes.

The following proposition shows that the admissible range Ω_t shrinks to the true value of Ω. That demonstrates that, in the limit, perfect learning is eventually achieved; in other words in the long run a uniform monetary policy is neutral.

Proposition 1 $\lim_{t \to \infty} \wp_t = \{\hat{\Omega}\}$

The proof is in the appendix.

Of course the speed of convergence of each single prior can be different.

7. Concluding remarks

In this paper we show that an asymmetric attitude of firms towards ambiguity is a sufficient condition to generate lasting price stickiness. We assume, on the basis of a growing body of theoretical literature and a large amount of experimental evidence, that firms are characterized by both lower and upper subadditivity. This assumption is consistent with the hypothesis of ambiguity aversion (seeking) with respect to random gains (losses). Such kind of asymmetric attitude towards ambiguity is enough to determine price stickiness following a nominal uniform monetary policy, since an expansionary (contractionary) policy represents a prospect of gain (loss) in terms of firms' profit.

APPENDIX

Proof of proposition 1

Upper limit

We simply observe that the dynamics of $\overline{\Omega}_t$ mimics that of Ω_t (see (2)), which converges to $\hat{\Omega}$. It should be added that $\overline{\Omega}_t$ moves towards $\hat{\Omega}$ from above since $\overline{\Omega}_0 > \hat{\Omega}$ and $\overline{\Omega}_t > \hat{\Omega} \Rightarrow \overline{\Omega}_{t+1} > \hat{\Omega}$

Lower limit

We observe that on the one hand $\max_{z \le t} \{s_t\}$ is a time-non-decreasing value, and, on the other, that at any time *t*, for given $\max_{z \le t} \{s_t\}$ $\underline{\Omega}_t$ moves towards $\hat{\Omega}$ (from below), due an analogous argument used for the upper limit.

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