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# Monetary Policy as a Process of Search

By ANDREW CAPLIN AND JOHN LEAHY \*

*Monetary policy makers are uncertain about the state of the economy and learn from the economy's reaction to policy. Private agents, however, anticipate any systematic attempt to incorporate this information into future policy. We analyze this feedback in the context of a monetary authority's attempt to stimulate an economy in recession. We show that modest stimuli may prove ineffectual. If small reductions in interest rates are unlikely to promote a response, then they may be followed by further cuts. A vicious circle develops in which the expectation that the policy could fail leads investors to delay investment thereby promoting failure.*  
(JEL E50)

Monetary policy makers face a difficult task. They must steer a course between inflation and unemployment, and they must do so with only limited information concerning the state of the economy and its reaction to the tools of policy. The ignorance and uncertainty that surrounds the conduct of policy was central to the monetary policy literature of the 1960's and early 1970's. Milton Friedman (1968) argued that "long and variable lags" in the economy's response to policy justify fixing the growth rate of the money supply. William C. Brainard (1967) studied policy making by authorities that do not know how a policy target will react to changes in policy instruments. William Poole (1970) asked whether a policy maker who cannot continuously observe output should use the money supply or the interest rate as an intermediate target.

In this paper, we return to the old idea that policy makers are ignorant, while incorporating the more recent notion that private agents react to policy rules.<sup>1</sup> We focus on

one aspect of this ignorance, namely a policy maker's ignorance concerning agents' reactions to policy initiatives. Our approach is motivated by the experience of many countries during the 1990–1992 recession, most notably the United States and Germany. Here policy makers, confronted by economies in recession, attempted to stimulate economic activity by lowering interest rates, but, fearful of renewed inflation, were very cautious in their actions. These policy makers appeared to be searching for the optimal stimulus. They would lower interest rates somewhat, then wait to see how the economy responded. If the recession continued, they lowered rates again. If signs of recovery became apparent, they held steady and turned their attention towards inflation.

The problem that confronts policy makers in their search for the optimal stimulus is that any systematic search behavior could itself influence the response of private agents to policy. If agents are aware that authorities will lower interest rates further should the recession persist they may be tempted to postpone action in the hopes of benefiting from these lower rates. This is most likely to be the case for cyclically sensitive sectors such as investment and consumer durables.

The policy maker's optimal search rule will need to take into account these reactions. We

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<sup>1</sup> The pioneering papers in the literature on monetary policy games are Finn E. Kydland and Edward C. Prescott (1977) and Robert J. Barro and David B. Gordon (1983).

See Kenneth S. Rogoff (1989) for a survey. For a recent discussion of the uncertainty policy makers face see Benjamin M. Friedman (1993).

show that this has implications for the optimal pace of monetary expansion. In particular, very gradual reductions in interest rates may prove ineffectual in stimulating economic activity. This is because small reductions in interest rates are less likely to promote a response, and hence more likely to be followed by further cuts. A vicious circle develops in which cautious policy is unsuccessful not only because it is cautious, but also because investors anticipate the greater possibility of failure and delay investment. In contrast, aggressive policy initiatives, because they are more likely to be successful and hence temporary, create a climate of urgency that promotes a more immediate response.

In the next section we present a simple model that illustrates these issues. The model consists of a government and a group of agents with investment projects. We assume that the economy is initially in recession and that the government manipulates interest rates in an effort to end the recession. The difficulty that the government faces is that it does not know the agents' valuations of their projects and hence how the economy will respond to policy. If the government cuts rates too quickly, too many agents might invest, leading to a rise in inflation. If the government is too cautious the recession will continue. The government's optimal policy is to set a sequence of interest rates which balance the possible losses due to recession and inflation. This sequence must take into account agents' reaction to policy.

After presenting and discussing the basic model we present two extensions in Section III. The first extension involves the introduction of external economies of scale. The effect of external economies is to further reduce the relative potency of gradual interest rate cuts. The reason is that small reductions in interest rates are unlikely to entice many agents to invest. This lowers the probability that agents will benefit from the external economies, decreasing the returns to immediate investment and increasing the incentive to wait.

The second extension supposes that agents care about the state of the economy when they invest in addition to the level of interest rates, and that they learn about the state of the economy from its reaction to monetary policy. To see how this channel might affect policy, suppose that the monetary authority gradually re-

duces interest rates to avoid inflation. Each time the economy fails to respond to a small cut in interest rates, policy makers learn that the economy is slightly worse off than they had previously believed, and that they can make another small cut in interest rates without too much fear of overstimulating the economy. The problem that arises is that private agents learn this information as well. With each failure of the economy to respond to monetary policy, agents learn that the economy is slightly worse off than they had previously believed, and with this knowledge they become less likely to respond to the next reduction in interest rates. The presence of learning therefore means that the failure of past policy initiatives is likely to dampen the economy's reaction to current ones.

These results, that gradual rate reductions may provide little stimulus and that past policy failures may reduce the potency of current policy initiatives, may provide some insight into the apparent failure of monetary policy to end the recent recession in the United States in spite of a reduction in the discount rate in excess of 400 basis points. In this case interest rates were reduced gradually. In the two years between December 1990 and December 1992, for example, the Federal Reserve cut the discount rate an average of 57 basis points on seven separate occasions, with an average of three months separating each decision. The cautious approach to expansion and its initial failure may have combined to slow the pace of recovery.

The organization of the paper is as follows. Section I presents a simple model of policy under uncertainty. We analyze the main properties of the model in Section II. Section III contains extensions including external economies and learning. Section IV contains a discussion of related literatures. Section V concludes.

## I. The Model

The purpose of this section is to create a model that embodies the major features of the recent policy making environment. At the center of our approach are three ideas: the policy maker is uncertain about the state of the economy, the policy maker learns about the state of the economy from the economy's reaction

to policy, and any systematic search strategy that the policy maker employs to learn about the state of the economy affects the economy's reaction to policy. All other aspects of the model are kept as simple as possible.

The setting is an economy in recession. There is a group of agents endowed with investment projects that are unprofitable given current economic conditions. The monetary authority controls some variable which affects the cost of capital. We shall refer to this variable as the interest rate.<sup>2</sup> The monetary authority must decide on a path for interest rates that will promote economic activity without igniting inflation. In the model this corresponds to prompting some, but not all, agents to invest. The problem that the authority faces is that it does not know exactly how unprofitable agents' investment projects are. If it lowers interest rates too slowly, no one will invest and the recession may persist, whereas if it lowers rates too quickly, too many will invest igniting inflation. In this setting the monetary policy maker must search for the optimal stimulus. This search, however, affects investment strategies.

#### A. Description of the Model

Following the recent theoretical literature on monetary policy, we treat the formulation of policy in this environment as a game between the government and the private agents. Let  $r_t$  denote the instrument of policy, in this case interest rates. We assume that time is discrete to reflect the fact that there are delays in the economy's response to policy and that governments collect and disseminate data at discrete intervals.<sup>3</sup> For simplicity we assume that at any point in time the economy is in one of three states: a recessionary state, an inflationary state, or a state of full employment and stable prices.

<sup>2</sup> In the model we assume that the monetary authority directly controls the real interest rate. We do not model the channel by which changes in short-term nominal interest rates feed into the real interest rate.

<sup>3</sup> If time were continuous, then it might be possible for the authority to lower interest rates continuously until it achieved the desired level of activity. This sort of precise control seems unrealistic.

The economy begins in the recessionary state, and the monetary authority lowers interest rates in an effort to push the economy towards full employment without entering the inflationary state. In order to focus on the policy maker's efforts to end the recession, we assume that both the full-employment stable-price state and the inflationary state are absorbing. The game ends once the economy enters either of these states.<sup>4</sup>

The policy maker's preferences over inflation and unemployment will influence the speed with which the policy maker lowers interest rates. The policy maker chooses the path of interest rates that minimizes the expected loss from inflation and unemployment. We assume that for each period in which the economy remains in recession the policy maker receives a payoff in terms of period zero utility of  $-\rho'\alpha$ , where  $\rho$  is the policy maker's discount rate and  $\alpha$  is the policy maker's disutility of unemployment. Upon entering the inflationary state in period  $t$  the policy maker receives a payoff of  $-\rho'\beta$ .<sup>5</sup>

The policy maker faces no disutility in the full-employment stable-price state. For simplicity, we normalize  $\beta$  to 1, since it is only the relative value of  $\alpha$  and  $\beta$  that affects the policy maker's decision.

The other influence on the speed with which the policy maker lowers interest rates will be the policy maker's beliefs concerning the economy's reaction to policy. We assume that policy makers are uncertain how many agents will invest in response to a given decline in interest rates. For simplicity we assume that there are two agents in the economy. This corresponds with the previous assumption of three states. If neither agent invests then the economy remains in recession. If both agents invest then the economy enters the inflationary state. If one agent invests the economy reaches full employment with price stability.

<sup>4</sup> The assumption that the full-employment stable-price state is absorbing is innocuous. It will become clear below that if the game were to continue in this case, the policy maker would be able to prevent further investment (see footnote 8). We discuss the assumption that the inflationary state is absorbing in Section III.

<sup>5</sup>  $\beta$  represents the present value of entering the inflationary state and is therefore likely to be much larger than  $\alpha$  which represents the flow cost of high unemployment.

Agents' investment decisions are endogenous and depend on the costs and benefits of investing. We index each agent by  $i \in \{1, 2\}$ . Each agent is characterized by a parameter  $\pi_i$  which reflects the profitability of the agent's investment project. Higher  $\pi$  correspond to more profitable investments. If the agent chooses not to invest in period  $t$ , then the agent receives nothing in that period, but retains the option of waiting to invest in the future. If an agent invests in period  $t$ , then the agent receives a payoff of  $\delta^t(\pi_i - r_t)$  in terms of period zero profits where  $\delta$  is the agent's discount rate. Increases in  $\pi_i$  and reductions in  $r_t$ , therefore, increase the payoff to investing in period  $t$ . For simplicity we have assumed that government policy affects this payoff linearly. Nothing special is involved in this. The important point is that government policy affects the profitability of investment. The sign of the effect is meant to suggest the effect of an interest rate. Each of the  $\pi_i$  is independently drawn from a uniform distribution on  $[0, 1]$ . This distribution is known to all three players, but the actual realization of  $\pi_i$  is known only to agent  $i$ . Agents invest only once, and choose the time of investment to maximize the expected value of payoffs.<sup>6</sup>

The game takes place over several periods, but the basic structure of the game is the same each period. In any given period  $t$ , the government first announces its interest rate  $r_t \in [0, 1]$ . The agents then simultaneously decide whether or not to invest. The agents and the government then receive their payoffs. Finally, if no investment occurs in period  $t$ , the game proceeds to period  $t + 1$ , and the government uses the information revealed by the agents' lack of response to set  $r_{t+1}$ .

### B. Equilibrium

We look for a symmetric perfect Bayesian equilibrium to our game. In such an equilibrium players follow history contingent strategies that satisfy three properties. First, the strategy of each player is a best response to

those of the other players. Second, players' beliefs concerning the profitability of other agents' projects,  $\pi_i$ , are updated using Bayes' rule and the equilibrium strategies.<sup>7</sup> Third, the strategies are a Bayesian equilibrium for all continuation games. We assume that agents 1 and 2 follow symmetric strategies for the sake of simplicity.

History in period  $t$  of our game consists of all previous government strategies, as well as the fact that the game has continued until period  $t$ . A strategy for agent  $i$  is a function that determines the probability that the agent will invest given the history of government offers and the agent's profitability  $\pi_i$ . A strategy for the government is an initial choice  $r_1$  and a function that determines  $r_t$  as a function of the history of past offers in the event no one invests.

Proposition 1 states that there is a unique equilibrium of the game and that this equilibrium takes a very simple form.

**PROPOSITION 1:** *There exists a unique perfect Bayesian equilibrium. This equilibrium is characterized by a unique pair  $\eta, \nu \in (0, 1)$  such that if the game is still continuing in period  $t$ :*

- (i) *agents invest if and only if  $\pi_i \in (\eta^t, \eta^{t-1}]$ .*
- (ii) *the government sets an interest rate  $r_t = \eta^{t-1}\nu$ .*

Proposition 1 says that agents' strategies are characterized by a sequence of cutoff rules,  $\bar{\pi}_t = \eta^t$ , that are decreasing with  $t$ . If the game has continued through period  $t$  then agents invest if  $\pi > \bar{\pi}_t$ . The proposition also states that both the cutoff  $\bar{\pi}_t$  and the interest rate  $r_t$  are proportional to the previous period's cutoff  $\bar{\pi}_{t-1}$ . Hence the characterization of equilibrium comes down to solving for two constants of proportionality  $\eta$  and  $\nu$ .  $\eta$  is the probability that an agent waits. It characterizes the effect of policy. An  $\eta$  close to 1 implies that agents

<sup>6</sup> We have assumed that each agent's payoff is independent of the actions of the other agent. We relax this assumption in Section IIIA.

<sup>7</sup> In general it is not possible to use Bayes' rule in the aftermath of probability-zero events. Fortunately, the only probability-zero event in the current model is that no agent responds to a zero offer, and this event is easily interpretable.

are very cautious.  $\nu$  characterizes policy setting. A  $\nu$  close to 1 implies that the government is very cautious.

The structure of the equilibrium presented in Proposition 1 conforms with our intuition that uncertainty concerning the state of the economy and the inflationary consequences of policy would lead the government to lower interest rates gradually and search for the optimal stimulus. The government lowers interest rates, waits and watches for the economy's response. If the economy fails to recover, then the monetary authority lowers interest rates again. If agents invest and the recession ends, then policy makers turn their attention to other issues such as inflation.

The proof of the proposition is contained in the Appendix. The intuition behind the form of the equilibrium is simple. Since agents discount the return to investing in the future both by  $\delta$  and by the possibility that the game might end, a marginal increase in the profitability of agent  $i$ 's project,  $\pi_i$ , increases the return to investing today more than it does the return to investing in future periods. This implies that if an agent with  $\pi_i = c$  would choose to invest today then so would any agent with  $\pi_i > c$ . Hence there exists a sequence of cutoff rules  $\{\bar{\pi}_t\}$  such that an agent invests the first period in which  $\pi_i$  exceeds  $\bar{\pi}_t$ . The simplicity of the rule makes the evolution of beliefs particularly simple: if the game continues until period  $t$ , the posterior distribution of  $\pi_i$  is uniform on the interval  $[0, \bar{\pi}_{t-1}]$ . This implies that the structure of the economy is essentially the same in each period. Only the support of the distribution of beliefs changes from one period to the next. This stationarity explains why the choices of  $r_t$  and  $\bar{\pi}_t$  are proportionate to  $\bar{\pi}_{t-1}$ .<sup>8</sup>

### C. Solution to the Model

It remains to solve for the parameters  $\eta$  and  $\nu$ .<sup>9</sup> Optimization by the government deter-

<sup>8</sup> It is now easy to see that if the game were to continue after one agent invested in period  $t$ , the optimal policy for the government would be to set  $r_s \geq \bar{\pi}_t$  for all  $s > t$  in order to discourage further investment. All other aspects of the model would remain unchanged.

<sup>9</sup> What follows is an informal derivation of the two parameters. A more formal treatment is contained in the Appendix.

mines  $\eta$ , the probability that an agent waits. The government targets the value of  $\eta$  that minimizes the relative costs of recession and inflation. Optimization by the agents determines the degree of caution in policy setting,  $\nu$ , that elicits the desired degree of caution on the part of agents,  $\eta$ .

We represent the optimization problem of the government as a dynamic program. Given the stationarity of the equilibrium the value of the government's optimal policy will be the same in each period in which the game continues. Denote this value by  $v$ . The government chooses  $r_t$  to maximize  $v$  given the cutoff level of investment in period  $t - 1$ ,  $\bar{\pi}_{t-1}$ , and the relation between the cutoff in period  $t$  to the interest rate,  $\bar{\pi}_t(r_t)$ :

$$v = \max_{r_t} (\rho v - \alpha) \left( \frac{\bar{\pi}_t(r_t)}{\bar{\pi}_{t-1}} \right)^2 - \left( \frac{\bar{\pi}_{t-1} - \bar{\pi}_t(r_t)}{\bar{\pi}_{t-1}} \right)^2.$$

The first term on the right-hand side of this equation gives the cost of continued recession,  $\rho v - \alpha$ , weighted by the probability that neither agent invests,  $(\bar{\pi}_t/\bar{\pi}_{t-1})^2$ . The second term represents the cost of igniting inflation times the probability that both agents invest,  $[1 - (\bar{\pi}_t/\bar{\pi}_{t-1})]^2$ . Since  $\eta = \bar{\pi}_t(r_t)/\bar{\pi}_{t-1}$ , the Bellman equation may be rewritten as

$$v = \max_{\eta} (\rho v - \alpha)\eta^2 - (1 - \eta)^2.$$

The first-order condition for an optimal response determines  $\eta$  as a function of  $v$ ,

$$\eta = \frac{1}{\alpha + 1 - \rho v}.$$

Using both equations to eliminate  $v$ , we arrive at an expression for  $\eta$ :

$$(1) \quad \eta = \frac{\alpha + \rho + 1}{2\rho} - \sqrt{\left( \frac{\alpha + \rho + 1}{2\rho} \right)^2 - \frac{1}{\rho}}.$$

Agents' optimal choice of  $\bar{\pi}_t$ , given  $\bar{\pi}_{t-1}$  and  $r_t$ , determines the degree of caution in policy setting,  $\nu$ , necessary to achieve the targeted probability of waiting,  $\eta$ . An agent with  $\pi = \bar{\pi}_t$  must be indifferent between investment in period  $t$  and investment in period  $t + 1$ . This indifference may be expressed as follows:

$$(2) \quad \bar{\pi}_t - r_t = \delta \frac{\bar{\pi}_t}{\bar{\pi}_{t-1}} (\bar{\pi}_t - r_{t+1}).$$

An agent that invests in period  $t$  receives  $\pi - r_t$ , whereas an agent that waits and invests one period later receives  $\pi - r_{t+1}$ . The latter amount, however, must be discounted by  $\delta$  and by  $\bar{\pi}_t/\bar{\pi}_{t-1}$  which is the probability that the other agent also chooses to wait beyond period  $t$  to invest.

Dividing both sides of equation (2) by  $\bar{\pi}_{t-1}$ , and solving for  $\nu = r_t/\bar{\pi}_{t-1}$  yields  $\nu$  as a function of  $\eta$ :

$$(3) \quad \nu = \frac{\eta - \delta\eta^2}{1 - \delta\eta^2} \in (0, 1).$$

Together equations (1) and (3) determine  $\eta$  and  $\nu$ . This completes the presentation and solution of the model.

**II. Properties of Equilibrium**

We now discuss the properties of the equilibrium of our model. The first thing to note is that the evolution of the real economy depends only on the probability that an agent chooses to wait,  $\eta$ . Higher values of  $\eta$  increase the likelihood of recession in any given period,  $\eta^2$ ; decrease the likelihood of inflation in any given period,  $(1 - \eta)^2$ ; and increase the likelihood that the economy will eventually land in the full-employment stable-price state,  $2\eta/(1 + \eta)$ .

The government targets the level of  $\eta$  that it desires. This target is given by equation (1). The comparative statics of this choice are straightforward. Governments with relatively high values of  $\alpha$ , those that are more concerned with unemployment than inflation, will target low values of  $\eta$  in order to encourage immediate investment. As  $\alpha$  approaches  $\infty$ , the targeted level of  $\eta$  approaches 0 and the probability that the recession will end immediately approaches 1. Conversely, inflation-

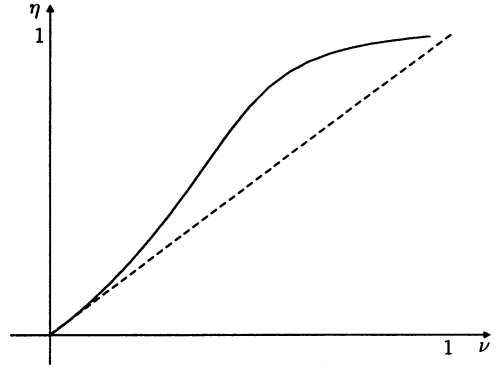


FIGURE 1. EQUATION (3) FOR  $\delta = 0.9$

averse governments with relatively low values of  $\alpha$  will attempt to discourage investment by targeting high values of  $\eta$ . As  $\alpha$  approaches 0, the targeted level of  $\eta$  approaches 1 and the probability that the recession ends in the current period falls to 0. Finally, as  $\rho$  falls the government becomes more concerned with the present. In the limit as  $\rho$  approaches 0, the targeted level of  $\eta$  approaches the static optimum  $1/(\alpha + 1)$ .<sup>10</sup>

The government chooses  $r_t$ , or equivalently  $\nu = r_t/\bar{\pi}_{t-1}$ , in order to target  $\eta$ . From equation (3) we see that the probability of waiting,  $\eta$ , is monotonically increasing in  $\nu$ , so that raising  $r_t$  discourages investment in period  $t$ . Inflation-averse governments will therefore behave cautiously and choose high values of  $\nu$ , whereas unemployment-averse governments will cut interest rates more aggressively and choose low values of  $\nu$ .

Figure 1 graphs the relationship between  $\nu$  and  $\eta$  for  $\delta$  equal to 0.9. The figure illustrates several general properties of equation (3). First, note that  $\eta$  is always greater than  $\nu$ . It follows that  $\bar{\pi}_t > r_t$ . Whereas it is profitable for all agents with profitability  $\pi > r_t$  to invest, only agents with profitability  $\pi > \bar{\pi}_t$  choose to do so. Agents with  $\pi$  between  $r_t$  and  $\bar{\pi}_t$  choose to wait in order to take advantage of the prospect of lower interest rates the next period. Taking account of the intertemporal context of policy, therefore, makes the government act more ag-

<sup>10</sup> As  $\beta$  represents the present value of entering the inflationary state, it should depend on  $\rho$  as well.

gressively than it would in a static context. In a one shot game an interest rate of  $r_t = \bar{\pi}_t$  would encourage all agents with  $\pi > \bar{\pi}_t$  to invest. Here the government must set  $r_t < \bar{\pi}_t$  in order to promote the same amount of investment since some agents with profitable investment projects choose to wait. Policy therefore needs to be more aggressive than the reaction it seeks to elicit. Even cautious policy makers who abhor inflation will move more aggressively once they take into account the dynamic implications of their policy.

A second feature of Figure 1 is the hump that appears when policy setting is cautious ( $\nu$  close to one). It is easy to show from equation (3) that  $\eta$  is concave in  $\nu$  for high  $\nu$ , and convex for low  $\nu$ . This shape reflects the balance between two conflicting influences on the firm's investment decision: the desirability of waiting for a better offer in the future and the possibility that the other firm might invest today. If policy setting is sufficiently gradual, the possibility that the other firm will invest is relatively low. In this case reductions in  $\nu$  increase the desirability of waiting because future offers become more attractive. The result is that cutoff for investment falls by less than the reduction interest rates;  $\eta$  falls by less than  $\nu$  for high  $\nu$ . Gradual policy initiatives may therefore elicit very little reaction. Because small interest rate cuts are unlikely to end the recession, agents feel safe waiting for rates to fall again. For low  $\nu$ , the probability that the other firm might invest is much higher. While a less cautious policy still increases the attractiveness of waiting for lower interest rates, the probability that the recession will last falls. In order to receive something, agents choose to invest immediately, so that  $\eta$  falls by more than the reduction in  $\nu$  for low  $\nu$ . The interaction between the two forces therefore lessens the marginal effect of cautious policy and enhances the marginal effect of aggressive policy.

One other property of the equilibrium deserves note: the current offer  $r_t$  is not a sufficient statistic for the state of the economy. According to equation (2), two additional pieces of information are necessary: last period's investment cutoff,  $\bar{\pi}_{t-1}$ , and the prospective policy of the government,  $r_{t+1}$ . Last period's cutoff determines agent's beliefs concerning the profitability of other agents investment projects. The policy of the govern-

ment helps determine expectations concerning the value of waiting.

### A Numerical Example

A simple numerical example will illustrate many of the properties of the equilibrium. Suppose that the private agents' discount rate,  $\delta$ , is equal to 1 and consider two different economies whose governments have different disutility from recession,  $\alpha$ . In the first case  $\alpha$  is equal to  $^{100}/_{11}$ . The government sets the interest rate so that  $\nu = ^{1}/_{12}$  in order to target a probability of waiting,  $\eta$ , equal to  $^{1}/_{11}$ . Such a policy implies that in the first period  $r_1 = ^{1}/_{12}$  and  $\bar{\pi}_1 = ^{1}/_{11}$ . The second government has a lower  $\alpha$  and is therefore relatively more concerned about inflation. It has an  $\alpha$  of  $^5/_3$  and chooses  $\nu' = ^{1}/_4$  in order to target  $\eta' = ^{1}/_3$ . This leads to a sequence  $(r'_1, \bar{\pi}'_1) = (^{1}/_4, ^{1}/_3)$  and  $(r'_2, \bar{\pi}'_2) = (^{1}/_{12}, ^{1}/_6)$ .

Note that the more inflation averse government is the less aggressive it is in cutting interest rates, but both governments are more aggressive than they would be in a one-shot game.  $r_t < \bar{\pi}_t$  in all cases, reflecting the agents' option to wait for lower interest rates in the future.

The response to the interest rate  $r = ^{1}/_{12}$  in the two economies is very different. In the first economy all agents with profitability  $\pi > ^{1}/_{11}$  invest, whereas in the second all agents with profitability  $\pi \in (^{1}/_9, ^{1}/_3]$  invest in direct response to the interest rate  $^{1}/_{12}$  and all agents with  $\pi > ^{1}/_9$  have invested by the time the government sets this interest rate. The difference in response arises because agents' beliefs concerning the probability that the other agent will invest differ in the two economies. In the first economy, agents believe that the profitability of the other agent may lie anywhere in the interval  $[0, 1]$ , whereas in the second economy it is known from the fact that no agent invested in the previous period that the profitability of the other agent lies in  $[0, ^{1}/_3]$ . The knowledge that  $\pi_t \notin (^{1}/_3, 1]$  in the second case reduces the probability that the interest rate  $^{1}/_{12}$  will stimulate investment. This lowers the cost of waiting and reduces the effectiveness of policy.<sup>11</sup>

<sup>11</sup> Note that expectations of future policy do not explain the difference in response. In the first economy, if the

### III. Extensions

To this point the only interaction between the private agents has been the probability that the game might end. We now consider two other potential interactions and their effect on the government's optimal policy. We first consider what happens when agents' payoffs depend on the number of agents that invest. We then consider what happens when investment conveys information about the profitability of investment. We also consider the effect of introducing credit controls and of relaxing the assumption that there are only two private agents and consider extending the model to both inflationary and recessionary periods.

#### A. Interactions Between the Payoffs of Agents

There are many reasons that an agent's payoff might depend on the number of agents that invest. Decreasing returns would suggest that  $\pi$  would fall as investment rises, whereas external economies might yield a rise in  $\pi$ .

One simple way to capture these payoff interactions is to alter the payoff function of each agent so that the return to agent  $i$  from investing in period  $t$  depends on whether the other agent invests. Let  $\chi(i, t)$  denote the return to agent  $i$  from investing in period  $t$ :

$$\chi(i, t) = \begin{cases} \psi_1 \pi_i - r_t, & \text{if only agent } i \text{ invests,} \\ \psi_2 \pi_i - r_t, & \text{if both agents invest.} \end{cases}$$

Increasing returns result if  $\psi_1 < \psi_2$ , and decreasing returns if  $\psi_1 > \psi_2$ .<sup>12</sup>

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current offer fails to elicit a response the government will set the interest rate to  $\nu \bar{\pi}_1$  or  $1/121$  in the next period. In the second economy the government will set the interest rate to  $1/36$  in the next period. The gain from waiting is lower in the second case so that if all else is equal investment should be higher, but this is not the case. In the current example the effect of beliefs dominates the effect of expectations. The possibility that the investment opportunity might disappear if the other agent invests has more influence on the investment decision than the possibility that the government might significantly lower interest rates in the future should no one invest.

<sup>12</sup> Note that  $\psi_2 = 0$  would provide an alternative justification of the assumption that the game ends upon investment.

Incorporating interactions in this way raises the possibility of multiple equilibria should  $\psi_2$  be much greater than  $\psi_1$ . It is easy to see, however, that if the equilibrium is unique then Proposition 1 will still describe the form of the equilibrium, and that equation (1) will still describe the government's optimal target for  $\eta$ . Neither of these results depended on the form of the agents' payoff except in so far as the equilibrium was symmetric. What does change is the relationship between government policy and agents' actions as described in equation (3). Retracing the arguments that led to equation (3) we have in this case:

$$(4) \quad \hat{\nu} = [\psi_1 \eta + \psi_2 (1 - \eta)] \left( \frac{\eta - \delta \eta^2}{1 - \delta \eta^2} \right).$$

Aside from the term  $\psi_1 \eta + \psi_2 (1 - \eta)$ , which represents the relative weighting of  $\psi_1$  and  $\psi_2$  in an agent's calculation of expected revenue, equation (4) is identical to equation (3).<sup>13</sup>

In comparing  $\hat{\nu}$  in equation (4) to  $\nu$  in equation (3), it is useful to choose  $\psi_1$  and  $\psi_2$  so that  $\psi_1 \eta + \psi_2 (1 - \eta)$  is equal to one for some  $\eta_0 \in [0, 1]$ , so that the two curves cross at  $\eta_0$ . In this case, it is easy to show that the two curves cross only once, and if  $\psi_1 < \psi_2$  then  $\nu > \hat{\nu}$  for  $\eta > \eta_0$ .

The effect of increasing returns is, therefore, to lower the  $\nu$  that the government must set to target an  $\eta > \eta_0$  and raise the  $\nu$  that the government must set to target an  $\eta < \eta_0$ . In other words, external economies reduce the effectiveness of cautious policies (high  $\nu$ ) and enhance the effectiveness of aggressive policies (low  $\nu$ ). The intuition behind this result is that a gradual policy makes it less likely that both agents will invest together and benefit from the external economies. This reduces the return to investment and increases the incentive to wait. Decreasing returns have the opposite effect.

<sup>13</sup> If  $\psi_2$  is much greater than  $\psi_1$  then agents' response to a given policy initiative may not be unique; a certain  $\nu$  may be consistent with two or more levels of  $\eta$ . The reason for this multiple equilibrium is that if each agent believes that the other is likely to wait then the return to investment will be low and each will want to wait, but if each agent believes that the other is likely to invest then the expected return to investment will be high and each will likely invest.

### B. Information Externalities

The second interaction among agents that we consider concerns the aggregation of information across agents. It might be the case that  $\pi_i$  reflects private information that agent  $i$  possess about factors that affect the profitability of investment for both agents. In such a situation each agent's opinion of the profitability of their own project will depend on the investment decisions of the other as in Caplin and Leahy (1993, 1994). Investment by one signals optimism and makes the other more optimistic.

To see how these informational spillovers affect the equilibrium of Section I, we amend the payoff function once again. Suppose that the payoff to agent  $i$  is simply the average of the two agents' types less the level of government policy:

$$\chi(i, t) = \frac{1}{2}(\pi_i + \pi_{-i}) - r_t,$$

where  $\pi_{-i}$  is the type of the other agent. Agent  $i$  can not directly observe  $\pi_{-i}$ , but can infer  $\pi_{-i} < \bar{\pi}_{t-1}$  if agent  $-i$  has not invested as of period  $t$ . The expected return to investing in period  $t$  for agent  $i$  is therefore

$$(5) \quad E_t \chi(i, t) = \frac{1}{2}\pi_i + \frac{1}{4}\bar{\pi}_{t-1} - r_t.$$

In this formulation each agent knows something about the return to investing, but not everything, and each agent possesses information about the return to investment that is valuable to the other.

Once again this amendment does not alter the form of the equilibrium as set out in Proposition 1 nor does it alter the derivation of  $\eta$ . Its only effect is on the relationship between  $\eta$  and  $\nu$ , which becomes

$$\nu = \frac{\frac{1}{4} + \frac{1}{2}\eta - \frac{1}{4}\delta\eta^2}{1 - \delta\eta^2}.$$

The inclusion of the information spillover adds a new channel by which the past affects the trade-off between investing and waiting.  $\bar{\pi}_{t-1}$  not only affects the probability that the other agent will invest, it also directly enters the expected return to investment in equation (5). The lower is  $\bar{\pi}_{t-1}$  the lower is an agent's expectation of the other's profitability, and the lower the likelihood of investment.

This effect of beliefs on the returns to investment means that the failure of a monetary expansion to stimulate the economy in the past reduces the effect of current policy. This might provide one possible explanation for the weak performance of monetary policy in the recent recession in the United States. Policy makers reduced interest rates gradually believing that the recession was weak. The failure of the economy to respond, however, revealed that the economy's troubles were somewhat deeper. Analysts began pointing to consumers' debt burden, bad bank loans, and the need for businesses to restructure. This increase in pessimism then reduced the likelihood that further monetary policy expansion would stimulate the economy.

### C. Many Private Agents

The assumption that there were only two private agents in the economy greatly simplified the derivation of the equilibrium of the model. If there had been  $N$  agents and the government had desired to prompt  $M$  of them to invest, then we would have had to calculate continuation games for scenarios in which 0 to  $M - 1$  had already invested.

The economic importance of the assumption of two agents, however, derives not from the fact that there are few agents, but from the fact that the government and the agents themselves are uncertain how the economy will respond to any given offer. If, instead, there were a continuum of agents all with  $\pi_i$  independently drawn from a known distribution, then there would be no such uncertainty; the government would be able to calibrate its offer so that only the desired proportion invested and the game would end in the first period. If, on the other hand, there were a continuum of agents but their distribution was unknown, then, even though there were a continuum of agents, the government and the agents would face a situation quite similar to that modeled in Section I. The government would face a trade-off between overstimulating and understimulating the economy. The agents would face a trade-off between earning sure profits today and waiting for potentially larger but more uncertain profits tomorrow. Having two agents is therefore not crucial to the results, but it makes modeling distributional uncertainty relatively easy.

### D. Credit Controls

It might seem that the obvious solution to the policy maker's dilemma is to introduce credit controls. These would allow the policy maker to target the number of agents who respond to a given policy initiative. In fact, David H. Romer and Christina D. Romer (1993) argue that credit controls are an important policy tool.

The obvious answer to such concerns is that credit controls are subject to much the same sort of uncertainty as other tools of policy (see Paul A. Volker and Toyoo Gyohten [1992 p. 172] for anecdotal evidence). How will the economy respond to the credit controls? How tight or loose should they be to produce the intended results? To what extent do firms have access to other sources of credit? Conceptually, it would be a simple matter to extend the model to include credit controls, so long as policy makers are still uncertain as to exactly how much credit is desirable to promote growth without inflation.

### E. A Repeated Game

We assumed that the game ended when the economy entered the inflationary state. One particularly simple way to endogenize the future is to use the formulation of payoffs described in Section IIIA and to assume that  $\psi_2$  is equal to 0 and that once inflation starts the monetary authority immediately creates a recession and starts the game over with a new draw on the agents' projects.<sup>14</sup> In this case  $\nu = \psi_1 \eta^2 (1 - \delta \eta) / (1 - \delta \eta^2)$ , and the monetary authority, who because of the stationarity of the problem effectively faces a series of one-period games that end with full employment and stable prices, targets the myopic value of  $\eta = 1 / (1 + \alpha)$ . Note the main properties of the model survive in this repeated setting. The fact that  $\nu < \psi_1 \eta$  reflects that fact that the monetary authority still cuts interest rates more aggressively

than it would if it ignored the dynamic setting. Also  $d\eta/d\nu$  is less than  $\psi_1$  for high  $\eta$  and greater than  $\psi_1$  for low  $\eta$ , so that the interaction between the agents' desire to wait for lower rates and agents' fear that the other might invest still lessens the marginal effect of cautious policy and enhances the marginal effect of aggressive policy.

## IV. Literature Review

As stated in the introduction, policy makers' ignorance was central to the theoretical discussion of policy in the 1960's. In contrast, the more recent theoretical literature has generally ignored the ignorance of policy makers. Following Robert E. Lucas Jr.'s (1976) critique of econometric policy evaluation, this literature has focused almost exclusively on incorporating the endogenous reaction of private agents into monetary policy models. In doing so it has generally presumed that authorities have enough knowledge and information to control the economy subject to the constraints imposed by the economy's reaction. Ironically, several recent papers have stood the issue of ignorance on its head, studying not the ignorance of policy makers but the ignorance of the private sector concerning the policy maker's initiatives (see, for example, Matthew B. Canzoneri, 1985; and Alex Cukierman and Allan H. Meltzer, 1986). One purpose of this paper has been to combine these two strands of literature by considering simultaneously a policy maker's search for the optimal policy and private agents' response to their search strategy.

Because the monetary authority learns from the response to its actions, our model bears some relationship to models of Bayesian learning such as Philippe Aghion et al. (1988) in which a monopolist searches for the best price or Joseph Zeira (1987) in which a firm searches for the capacity of the market. The main difference between these models and our model is that in most Bayesian learning models the results of search, while uncertain, are exogenous. In our policy game, the triggers that the monetary authority is trying to learn about respond to the search strategy.<sup>15</sup>

<sup>14</sup> Congressional testimony in July 1991 by Federal Reserve Chairman Alan Greenspan seems to support this form of the repeated game. He stated that the Federal Reserve had two policy goals: "first, to help bring the economy out of the recession; and, second, to avoid setting the stage for the next recession, which would follow if we allow inflationary imbalances to develop in the economy" (Alan Greenspan, 1991 p. 112).

<sup>15</sup> Graziella Bertocchi and Michael Spagat (1993)

Because of this feedback our model also bears a close relationship to models of the Coase conjecture. In fact, the model of Section I is in many ways similar to Joel Sobel and Ichiro Takahashi's (1983) model of sequential bargaining with one-sided offers. In this model, a monopolist offers a decreasing sequence of prices in the hope that consumers with higher valuations will purchase the monopolist's product at the higher prices. The ability of the monopolist to discriminate among consumers, however, is limited by consumers' ability to wait until the monopolist lowers its price. This ability to wait is similar to the ability of investors to wait in our model. There are, however, important differences. In the model of Section I, investors are not only competing against the government, they are competing against each other since if the other agent invests the government ceases to make offers. By increasing the size of offers, the government increases the probability of investment and thereby increases the competition between agents. This is the reason that even in the case in which the investors do not discount the future the government is able to make nonzero offers, a possibility that would not exist in the model of Sobel and Takahashi. In the Sobel and Takahashi model the goods are not scarce, so there is no competition among buyers.

The analogy to many buyers chasing few goods suggests a resemblance to Jeremy Bulow and Paul D. Klemperer's (1994) auction model. In both our model and the Bulow-Klemperer model, agents balance accepting a current offer against waiting for a better offer and risking that someone else will move in the meantime. Our central focus, however, is on the strategic role of the policy maker. The analogue to our policy maker in the Bulow-Klemperer story is their auctioneer. Their auctioneer, however, plays a trivial role in their model. Since the model is effectively a continuous-time model, the auctioneer simply lowers the asking price continuously until all items are sold. In our discrete-time model the policy maker faces a nontrivial decision about how far to lower the interest rate.

Another related literature concerns the dynamics of markets in which frictions impede the flow of information. Papers by Rafael Rob (1991), Caplin and Leahy (1993, 1994), and Christophe Chamley and Douglas Gale (1994) analyze situations in which agents with irreversible investment projects learn from others' investment decisions. In this paper, the trigger strategies hide information concerning agent's willingness to invest. This paper can therefore also be viewed as an analysis of policy making in an environment with imperfect information and inertia.

## V. Conclusion

This paper begins with the observation that policy makers are uncertain about the state of the economy and its reaction to policy. Because of this uncertainty not all policy initiatives are effective. Policy makers must instead search for the appropriate policy in any given circumstance. They will try one policy and if that does not yield desired results they will try again. An optimal search strategy, however, is a rule, and is therefore likely to influence private agents' responses to policy.

We analyze this search process in the context of a monetary authority that is lowering interest rates in an attempt to end a recession without igniting inflation. We derive three general lessons for policy makers. First, policy needs to be more aggressive than the reaction it seeks to elicit. This is because agents know that if a reduction in interest rates fails to stimulate growth, policy makers will be forced to reduce rates again. Agents therefore have an incentive to wait. Second, gradual policy initiatives may elicit very little reaction. This is because gradual policy initiatives are more likely to fail, and hence agents have a greater incentive to wait. Finally, policy failure may reduce the probability of future policy success. This is because the failure of an interest rate reduction to stimulate growth demonstrates that the economy is in fact weaker than previously believed. Agents incorporate this new information in subsequent decisions.

Although monetary policy is the focus of our story, we hope that the discussion sheds some light on policy decisions in other settings. Almost any time that there is uncertainty about the effect of policy, there will be uncertainty about

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present a Bayesian-learning model of monetary policy, but do not consider the reaction of private agents to the monetary authority's search strategy.

the future course of policy and private agents will have an incentive to wait to see what direction policy takes. It is clear that other policy instruments such as fiscal policy or investment tax credits could easily replace monetary policy in the analysis. Also the analogy with the seller of a scarce durable good might be worth pursuing. The seller of a home also faces many of the same issues when deciding on a pricing strategy. If the seller reduces the price of the house only slightly, buyers may decide that the probability that the house will sell is quite small and wait for the price to fall again. If a price reduction fails to result in a sale, buyers may take this as a signal that other buyers are uninterested and reduce their own valuation of the property, again increasing their desire to wait for price to fall further.

APPENDIX: PROOF OF PROPOSITION 1

Three lemmas establish Proposition 1. In the process we also solve for the parameters  $\eta$  and  $\nu$ .

**LEMMA 1:** *There exists a sequence  $\{\bar{\pi}_t\}$  such that agents invest in period  $t$  if and only if  $\pi_t \in (\bar{\pi}_t, \bar{\pi}_{t-1}]$ .*

**PROOF:**

We show that a cutoff rule is optimal for the first period and then argue by induction that it is optimal in all subsequent periods.

Consider the first period. If it is not optimal for an agent to invest in the first period for any  $\pi$ , then  $\bar{\pi}_1 = 1$ . If the agent would strictly prefer investment for some  $\pi$ , let  $\Pi$  denote the set of all  $\pi$  for which the agent strictly prefers investment to waiting. Since  $\Pi \subseteq [0, 1]$ ,  $\Pi$  has a greatest lower bound  $\hat{\pi}$ . Because the payoffs to investing in any period are continuous in  $\pi$ , an agent with  $\pi = \hat{\pi}$  is indifferent between investing and waiting. Since  $\hat{\pi}$  is the greatest lower bound to  $\Pi$ , for any  $\varepsilon > 0$  there exists  $\tilde{\pi} \in (\hat{\pi}, \hat{\pi} + \varepsilon)$  such that an agent with  $\pi = \tilde{\pi}$  strictly prefers investment in the first period. Now consider an agent with  $\pi > \tilde{\pi}$ . If such an agent invests in the first period, the agent receives  $\pi - \tilde{\pi}$  more than does an agent with  $\tilde{\pi}$ . By waiting the agent with  $\pi$  also receives  $\pi - \tilde{\pi}$  more than does the agent with  $\tilde{\pi}$  if the game continues. This future return is also discounted. Hence the agent with  $\pi$  has less of an incentive to wait than does the agent with  $\tilde{\pi}$  so

that all agents with  $\pi \geq \tilde{\pi}$  strictly prefer investment in the first period. Taking the limit as  $\varepsilon$  approaches 0, all agents with  $\pi > \hat{\pi}$  strictly prefer investment in the first period. Hence  $\bar{\pi}_1 = \hat{\pi}$ . The argument extends by induction to all subsequent periods. This completes the proof.

**LEMMA 2:**  $\bar{\pi}_t = \eta^t$ .

**PROOF:**

Let  $r^t = (r_1, r_2, \dots, r_t)$ .  $r^t$  describes the history of the economy if the game continues until period  $t + 1$ . Let  $v_t(r^{t-1})$  denote the value of an optimal policy for the government given that it has set interest rates  $r^{t-1}$  in previous periods. The Bellman equation for the government's optimization problem is

$$(A1) \quad v_t(r^{t-1}) = \max_{r_t} \left( \frac{\bar{\pi}_t(r^t)}{\bar{\pi}_{t-1}(r^{t-1})} \right)^2 \times (\rho v_{t+1}(r^t) - \alpha) - \left( \frac{\bar{\pi}_{t-1}(r^{t-1}) - \bar{\pi}_t(r^t)}{\bar{\pi}_{t-1}(r^{t-1})} \right)^2.$$

Note that if the game continues the government faces essentially the same trade-off between inflation and unemployment for every  $r^t$ . Hence  $v_t$  is constant and equal to  $v$  for all  $t$  and  $dv_{t+1}/dr_t = 0$ . It follows from the first order condition that  $\eta = \bar{\pi}_t/\bar{\pi}_{t-1}$  is given by equation (1). The proof is completed by observing that, since agents are initially distributed on  $[0, 1]$ ,  $\bar{\pi}_0 = 1$ .

**LEMMA 3:**  $r_t = \nu \bar{\pi}_{t-1}$ .

**PROOF:**

An agent that acts in period  $t$  receives  $\pi_t - r_t$ . Assuming that the other agent follows the presupposed sequence of cutoff rules and that the government follows strategy  $\{r_t\}$ , an agent that waits receives  $\delta\eta(\pi_i - r_{t+1})$ . In a symmetric equilibrium, these returns will be equated at  $\bar{\pi}_t$ . Note that  $\pi_t$  depends on the agents' expectation of  $r_{t+1}$ . In equilibrium this expectation will be correct.

We derive the agents' reaction function  $\bar{\pi}_t$  as a function of  $\bar{\pi}_{t-1}$ ,  $r_t$  and expectations of  $r_{t+1}$  from equation (2):

$$(A2) \quad \bar{\pi}_t = \frac{r_{t+1}}{2} + \frac{\bar{\pi}_{t-1}}{2\delta} - \sqrt{\left(\frac{r_{t+1}}{2} + \frac{\bar{\pi}_{t-1}}{2\delta}\right)^2 - \frac{r_t \bar{\pi}_{t-1}}{\delta}}$$

(A2) specifies how the agents will react to any given offer  $r_t$  including deviations from equilibrium behavior.

There is only one sequence of  $r$ 's that is stable and remains within the interval  $[0, 1]$ . That sequence is of the form  $r_t = \nu \bar{\pi}_{t-1}$  where  $\nu$  satisfies equation (3). To see this suppose the government makes an initial offer of  $r_1 = \nu + \varepsilon$ . Given this initial offer the only way for  $\bar{\pi}_1$  to equal the desired level  $\eta$  is for both agents to expect an offer of  $r_2 = \nu\eta + (\varepsilon/\delta\eta)$  in period two. In general in order for  $\bar{\pi}_t = \eta^t$ , the government must offer the sequence

$$r^t = \nu\eta^{t-1} + \frac{\varepsilon}{(\delta\eta)^{t-1}}$$

The requirement that  $r^t \in [0, 1]$  then requires that  $\varepsilon$  equal 0.<sup>16</sup> This completes the proof of the lemma.

Together Lemmas 1 through 3 establish Proposition 1.

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<sup>16</sup> This requirement may be thought of as a "no bubbles" condition, justified by the (unmodeled) cost of extreme policies.

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