Rush, Delay and the Money Burning Refinement in Political Signalling Games

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Abstract

We consider an equilibrium refinement in signalling games by allowing agents to perform costly tests of beliefs by burning money. We apply the refinement in a model where the public is unsure about the ability of an agent, such as a government, to foresee the effects of long-term decisions. Agents with much information about the consequences of decisions should invest either immediately or never. Poorly informed agents should wait for better information. We identify pooling equilibria in which excessive rush or waiting occurs. The burning money refinement eliminates rash and waiting distortions, but it implies wasting money and, for high discount factors, a decrease in welfare. We also identify the conditions under which the public should allow the agent to burn the public's money.

Keywords: Rush and delay, money burning refinement, belief tests, signalling in politics

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1 Introduction

There is a large literature on refinements of the Bayesian equilibrium notion. [Cho and Kreps 1987, Kreps and Sobel 1994, Fudenberg and Tirole 1992, Umbhauer 1994 and Mailath, Okuno-Fujiwara and Postlewaite 1993]. We consider a further refinement of the equilibrium notion that seems to be especially well-suited for political races where candidates can use money to advertise at any point in time. The refinement is based on burning money to influence beliefs and works as follows. Suppose that an informed player assumes that a particular type of the pooling equilibria is being played. Then an agent can incur costs to test out-of-equilibrium beliefs. Such costs could simply be burning money or utility through uninformative advertising or the costs could involve costly polls to review the beliefs of the public.

We apply the refinement in a simple model. We look at a single decision maker, such as a government, that cares about both the returns from any investment he makes as well as about the public's perceptions of his ability. The crucial features of our model are the following: First, we allow different levels of the government's ability to judge the impact of long-term investments. Moreover, governments that are very uncertain about the consequences of investment projects have the possibility to wait for better information in the future. Second, we assume that the public can not observe the ability of governments to foresee the consequences of long-term decisions.

We shall determine the signalling equilibria under which excessive or insufficient waiting occurs. The rash and waiting pooling equilibria in our model satisfy the intuitive criteria and, at least for certain parameter values, the Consistent Forward Induction Equilibrium Path concept of Umbhauer and the similar undefeated equilibrium concept of Mailath, Okuno-Fujiwara and Postlewaite.

By introducing the equilibrium refinement based on costly belief tests, pooling equilibria can be eliminated and we identify cases of governments burning money for belief tests. However, the opportunity of costly polls decreases overall welfare if discount factors are large. We also identify the conditions under which the public should allow the agent to burn the public's money.

Our model can explain why governments invest in excessive and costly tests of the beliefs of the public about their competence. Governments frequently test how the public would react to certain decisions and "fly a kite or a trial balloon".

The money burning refinement introduced in this paper may be useful for other signalling games, since the opportunity to burn money or utility is a natural way for players to broaden their strategy space. We expect that the burning money opportunity will generally lead to separating equilibria in signalling games. As shown in the application in this paper, however, welfare may be negatively affected.

2 Relation to the Literature

In our model we combine the desire to signal ability with the option of waiting for better information and the opportunity to test beliefs. Our model is thus related to three different branches of literature.

2.1 Option Values and Delay

The first element of our model is related to the option value (see Pindyck (1991) and Dixit (1992)), which gives an explanation why a decision-maker should delay decisions even if the net present value of the project today is positive. Consider a project that costs a fixed and sunk amount in the current period and generates an uncertain benefit in the future. If the firm makes such an irreversible investment, it gives up the possibility of waiting for new information to arrive that might affect the desirability and the timing of an investment. This lost option value is an opportunity cost that must be included as part of the cost of investment. Hence, traditional net present value rules must be modified to include the option value, i.e., the value to wait an hence the value of keeping the investment option alive.[1]

Often, governments delay not only for reasons of economic efficiency, but also for political reasons. The literature exploring such delay is sparse. Alesina and Drazen (1991) explain delay in macroeconomic stabilization with a model of attrition: any stabilization policy will harm some group, so each group wants to force a policy that protects its interests. Van Wijnbergen (1992) shows that gradual decontrol of prices may induce hoarding; the induced political pressures make continuation of decontrol less likely, and therefore make immediate decontrol more attractive.[2] In our model, politicians rush towards a decision or delay it excessively in order to avoid being recognized as incompetent.

2.2 Herd behavior

Recent work offers novel and interesting explanations for why numerous economic agents may ignore their private information and, as in a herd, imitate others and may pursue unwise policies. Two types of arguments appear in the literature. First, rational Bayesian decision makers will ignore their private information and instead mimic the actions of other economic agents (see Banerjee (1992); Bikhchandani, Hirshleifer, and Welch (1992)). Second, and directly relevant to our purposes, managers may mimic others in order to signal their ability (see Scharfstein and Stein (1990)).

1 In a related analysis, Gersbach (1993) considers the incentives of a majority to gather further information. For collective decisions, the value of the flexibility of waiting for better information may be negative for some or even a majority of voters.

2 Delay may also appear in bargaining. The seminal article is by Rubinstein (1982). Baron (1989) and Harrington (1990) apply such a model to legislatures. In different models, Admati and Perry (1987) and Cramton (1992) show that a bargainer may delay with the goal of communicating his relative strength.

2.3 Equilibrium Refinements

There is a large literature on refinements of the Bayesian equilibrium notion. [Cho and Kreps 1987, Kreps and Sobel 1994, Fudenberg and Tirole 1992]. The rash and waiting pooling equilibria in our model satisfy the intuitive criteria and, at least for certain parameter values, the Consistent Forward Induction Equilibrium Path concept of Umbhauer and the similar undefeated equilibrium concept of Mailath, Okuno-Fujiwara and Postlewaite.

We introduce a further refinement of the equilibrium notion that seems to be especially well-suited for political races in which candidates can use money to advertise at any point in time and hence can broaden their strategy space whenever it is optimal for them. The refinement is based on costly tests of beliefs and works as follows. Suppose the agent assumes that a particular type of pooling equilibria is being played, say a rash pooling equilibrium. Then, an agent can test the out-of-equilibrium beliefs of the public about his competence in the pooling equilibrium he is considering by incurring costs. Such costs could be a simple burning of money through uninformative advertising or could occur when extensive and costly polls to review the public's belief about the competence are conducted. Such belief tests destroy rash and waiting pooling equilibria, but imply inefficient money burning in the remaining separating equilibria.

Money burning has been addressed in a variety of other circumstances. Ben-Porath and Dekel (1988) and van Damme (1989) have discovered the power of forward induction in games in which players can "burn utility". Milgrom and Roberts (1986), Kihlstrom and Riordan (1984), Hertzendorf (1993), and Bagwell and Ramey (1994), Prat (1998) have examined the possibility to signal information through non-directly informative advertising in commercial and political settings. In our game, burning money is used as a vehicle to eliminate pooling equilibria and thus burning money can provide a refinement to the standard Bayesian equilibrium concept where the Intuitive Criterion and other refinements have no bite.

3 Model and Assumptions

We analyze a dynamic game of incomplete information considering both signaling and information gathering. There are two periods. For simplicity, we assume that the manager (or agent) whose decisions we analyze is risk neutral. The costs and benefits of a policy are measured in dollars. The game is given as follows:

Period 0: Nature determines the type of the agent, denoted by η. The type η can be either good (G) or bad (B). The a priori probability that $\eta = G$ is g_0 and that $\eta = B$ is $1 - g_0$. Each agent knows his own type.

Period 1: The agent must decide whether to invest. The investment yields a net return beginning in the next period. Its present value is V_i, with i either High (H) or Low (L). The a priori probability for value V_i is π_i. The agent, but not the public, observes a noisy signal S_j about the return from the project. The signal is either high (S_H) or low (S_L). The probability that an agent of type η receives a correct signal (that is, observes S_j when the project has return j) is t_η. Hence, $t_\eta = \text{pr}\{S = S_H | V = V_H\} = \text{pr}\{S = S_L | V = V_L\}$.

The agent decides whether to invest immediately or to postpone the decision. The public observes the agent's decision and forms a posterior estimate of the probability that the agent is good. The public's belief that the agent is good is denoted by g_1; with probability $1-g_1$ it thinks he is bad.

We often use the notation $\mathrm{pr}(G/I)$, $\mathrm{pr}(G/NI)$, $\mathrm{pr}(B/I)$, $\mathrm{pr}(G/NI)$ to describe the beliefs of the public after having observed investment (I) or waiting (NI).

Period 2: All remaining uncertainty about the project is resolved. An agent that postponed the project has a second chance of adopting it. Benefits and costs of the project are discounted by the factor $\delta < 1$.

Note that the public only has an apriori probability concerning the returns of the projects. The additional information an agent receives depends on his competence to judge situations and his ability to generate information about the consequences of the project. We make the following additional assumptions:

$$1 = t_G > t_B \geq 1/2. \tag{1}$$

Hence, the probability of an agent of type η receiving a correct signal (that is, observing S_j when the project has return j) depends on his type. For simplicity, we assume that a good agent receives a correct signal with probability 1: he is perfectly informed about the consequences of the project. A bad agent receives a noisy signal, as reflected by a value of $t_B < 1$.

The agent's utility increases in both social welfare and in the public's beliefs about his ability. The second element of the agent's utility reflects the desire of the agent to be elected. If the public believes that the agent is of high competence, he is more likely to be elected and thus his utility increases. The first element of the utility function follows the assumption of Rogoff (1990) that a politician cares about the success of a program. It is justified by the desire of the politician to be perceived as highly competent in the future.

We concentrate on the agent's utility in period 1. Utility increases with the probability that the public believes the agent is good as well as with the present value of the expected net returns from the investment. Expected net returns are denoted by R. If the investment is not made in either period, the net return is zero. Of course, R will vary with the information the agent obtains and with the period in which the project is implemented. For simplicity, we let utility be

$$U = mR + (1-m)g_1. \tag{2}$$

The parameter m, with $0 < m < 1$, is the weight the agent assigns to investment returns compared to the weight he assigns to the public's beliefs about his ability. We shall examine expected utility at the end of period 1. A weight m close to 1 means that the agent is mainly motivated by policies he implements. A low value of m corresponds to an agent mainly concerned about winning elections.

We denote the expected value of the project if no information signals have been received by EV_0 . We assume that the investment should not be made if no further information is received, or that

$$EV_0 = \pi_H V_H + (1-\pi_H)V_L < 0. \tag{3}$$

Consider an agent of type η who observed signal S_j. His posterior estimate of the expected return from the project is called $EV^{\eta}_{S_j}$. Obviously, an economic problem exists only if the project should be adopted in the good state and rejected in the bad state, i.e., if

$$V_H > 0, V_L < 0. \tag{4}$$

4 Socially optimal solution

We first characterize the socially optimal solution in which the public has perfect information about the agent's type, and signaling is irrelevant. Since the type η is given, the agent's decision is reduced to maximizing expected net benefits from the project. An agent who received a signal in period 1 uses Bayes's theorem to evaluate the probability that the project has a high return. Suppose the agent observed signal (S_H). Then the posterior probability that the project has a high return is

$$pr_\eta(V_H|S_H) = \frac{t_\eta \pi_H}{t_\eta \pi_H + (1-t_\eta)(1-\pi_H)} \tag{5}$$

$$pr_\eta(V_L|S_H) = \frac{(1-t_\eta)(1-\pi_H)}{t_\eta \pi_H + (1-t_\eta)(1-\pi_H)} \tag{6}$$

Note that $pr_\eta(V_H|S_H)$ is strictly monotonically increasing in t_η with

$$pr_G(V_H|S_H) = 1 \tag{7}$$

$$pr_B(V_H|S_H) = \pi_H \quad \text{for} \quad t_B = \frac{1}{2} \tag{8}$$

Similarly, the posterior probability $pr_\eta(V_H|S_L)$ is given by:

$$pr_\eta(V_H|S_L) = \frac{(1-t_\eta)\pi_H}{(1-t_\eta)\pi_H + (1-\pi_H)t_\eta} \tag{9}$$

Suppose that S_H has occurred. If the agent invests, then the expected value of social welfare is

$$V_H \frac{t_\eta \pi_H}{t_\eta \pi_H + (1-t_\eta)(1-\pi_H)} + V_L \left(1 - \frac{t_\eta \pi_H}{t_\eta \pi_H + (1-t_\eta)(1-\pi_H)}\right) \tag{10}$$

Suppose, instead, that the agent delays the decision for one period. Since all uncertainty is resolved in period 2, the assumptions imply that if the project's returns turns out to be high the agent who did not invest in period 1 will invest in period 2. Thus,

Proposition 1
If the agent observes S_L in period 1, neither a good nor a bad agent should invest in period 1. If the agent observes S_H, a unique critical value t_B^* exists, with

$$1/2 < t_B^* < 1, \tag{11}$$

such that a bad agent should wait until period 2 with the project decision if and only if $t_B \leq t_B^*$. A good agent should immediately invest.

Proof :
Notice that if S_L was observed, then

$$EV^G_{S_L} = V_L < 0$$

$$EV^B_{S_L} < \pi_H V_H + (1-\pi_H) V_L < 0$$

and neither type of agent would invest immediately.

If S_H was observed, we would obtain

$$EV^G_{S_H} = V_H > \delta V_H > 0 \tag{12}$$

Hence, a good agent should invest immediately.

For a bad agent, we obtain

$$EV^B_{S_H} = V_H \frac{t_B \pi_H}{t_B \pi_H + (1-t_B)(1-\pi_H)} + V_L \left(\frac{(1-t_B)(1-\pi_H)}{t_B \pi_H + (1-t_B)(1-\pi_H)} \right) \tag{13}$$

If a bad agent waits, his expected benefits are

$$\frac{t_B \pi_H}{t_B \pi_H + (1-t_B)(1-\pi_H)} \delta V_H > 0 \tag{14}$$

For $t_B = 1$, $EV^B_{S_H}$ equals V_H; waiting yields only δV_H. For $t_B = 1/2$, $EV^B_{S_H}$ equals $EV_0 < 0$ and hence waiting will be preferred. Since the difference between $EV^B_{S_H}$ and the expected profits from waiting increase strictly monotonically in t_B, the mean value theorem establishes the existence of t^*_B.

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5 Equilibria

In the following, for simplicity of presentation, we assume $1/2 = t_B < t^*_B$[3]. Thus, under complete information about his type, a bad agent waits with the project decision until period 2. For simplicity of presentation, we have assumed that the signals S_H and S_L are completely uninformative for the bad agent. A good agent invests immediately, if and only if, he observes S_H. Under incomplete information about the type of agent we must solve the corresponding signaling game and determine the perfect Bayesian equilibria of the game.

In order to derive the equilibria we first eliminate two configurations that cannot occur in equilibrium. First, if G does not invest in equilibrium knowing S_H, B does not invest either. Second, if B does not invest knowing S_H or S_L, G does not invest knowing S_L either.

Both properties follow from

$$EV^G_{S_H} > EV^B_{S_H} = EV^B_{S_L} > EV^G_{S_L}$$

Hence, for given beliefs of the public, investment for G knowing S_H is more attractive than investment for B. The opposite occurs when G knows S_L. The remaining configurations are discussed in the following sections.

3 Our analysis is valid for all values $t_B < t^*_B$.

5.1 Separating Equilibria

We first consider all remaining separating equilibria. Separating equilibria can occur in three ways: (1) As a fully separating equilibrium in which a good agent always invests immediately and a bad agent always waits. (2) As an efficient semi-separating equilibrium in which a good agent invests in period 1 only if he observes S_H, while the bad agent waits in all cases. Clearly this equilibrium is efficient, while the fully separating equilibrium involves a rash decision of the good agent to invest even if the returns are low. (3) Finally, as an inefficient semi-separating equilibrium that occurs if a good agent invests only upon observing S_H, while the bad agent always invests in period 1. We obtain:

Proposition 2

(i) *A fully separating equilibrium never exists.*

(ii) *Suppose* $\delta > \delta^* = \frac{\pi_H V_H + (1-\pi_H) V_L}{\pi_H V_H}$

Then, there exist some weight m_{ES} $(0 < m_{ES} < 1)$ *such that an efficient semi-separating equilibrium exists if and only if* $m > m_{ES}$

(iii) *An inefficient semi-separating equilibrium never exists.*

The proof is given in the appendix.

The result indicates that an efficient equilibrium exists as soon as the weight the agent places on correct decisions is sufficiently high. If agents care only about the public's beliefs concerning his ability, no efficient equilibrium exists.

5.2 Pooling equilibria

In the next section, we consider all remaining pooling equilibria. Pooling equilibria can occur in three different ways. (1) As a rash pooling equilibrium in which a bad and a good agent invest immediately, independently of the information signals they received. (2) As a waiting pooling equilibrium in which both agents wait independently of the signals. (3) As a balanced pooling equilibrium in which agent G invests upon S_H and waits upon S_L and agent B invests with some probability p $(0 \leq p \leq 1)$ and does not invest with probability $1-p$. We obtain:

Proposition 3

(i) *There exists some weight* m_{BP} $(0 < m_{BP} < 1)$ *such that a balanced pooling equilibrium exists if and only if* $m \leq m_{BP}$.

(ii) *In any balanced pooling equilibrium* $p < \pi_H$.

The proof is given in the appendix.

Hence, in any balanced pooling equilibrium the bad agent chooses I with a lower probability than agent G. This implies $\mathrm{pr}(G/I) > \mathrm{pr}(G/NI)$ which compensates lower expected benefits from the project if agent B invests and therefore agent B can be indifferent between I and NI. Note that for $p = \pi_H$ the equilibrium beliefs are

$$pr(G|I) = pr(G|NI) = g_0$$

Since $t_B < t_B^*$, $EV_{S_H}^B$ is smaller than the expected benefits from the project if the bad agent waits. Thus, I cannot be a best response since the beliefs of the public are the same for I and NI.

To examine rash and waiting pooling equilibria, the specification of beliefs out-of-equilibrium becomes crucial. We first establish the nature of pooling equilibria without restricting the nature of out-of equilibrium beliefs. We obtain

Proposition 4

(i) Suppose that

$$g_1^* := \frac{m}{1-m} V_L + g_0 \geq 0$$

Then, a rash pooling equilibrium exists if $pr(G|NI) \leq g_1^*$.

(ii) Suppose that

$$g_1^{**} := \frac{m(\delta - 1)}{1-m} V_H + g_0 \geq 0$$

Then, a waiting pooling equilibrium exists if $pr(G|I) \leq g_1^{**}$.

The proof is given in the appendix. Proposition 4 shows that rash and waiting pooling equilibria exist. Note that both g_1^* and g_1^{**} are smaller than g_0, the a priori expectation of the public about the competence of the candidates. Hence, rash and waiting pooling equilibria only exist if the public attaches sufficiently low competence to deviations. In the following, we examine whether out-of-equilibrium beliefs in proposition 4 are plausible. The Bayesian equilibrium notions do not place restrictions on out-of-equilibrium beliefs. Thus we are looking for refinements. We first test whether the pooling equilibria satisfy the Intuitive Criterion [Cho and Kreps 1987, Kreps and Sobel 1994, Fudenberg and Tirole 1992], the most widely applied refinement concept. We obtain:

Proposition 5

The rash and waiting pooling equilibria satisfy the intuitive criterion.

Proof :

The out-of-equilibrium beliefs satisfy $g_1^* < g_0, g_1^{**} < g_0$. Consider e.g. the rash pooling equilibrium. Equlibrium utilities are given by

$$U_G^*(I/S_H) = mV_H + (1-m)g_0$$

$$U_G^*(I/S_L) = mV_L + (1-m)g_0$$

$$U_B^*(I) = m(\pi_H V_H + (1-\pi_H)V_L) + (1-m)g_0$$

If agent G deviates in state S_L and the public attaches full competence to the deviation, utility is

$$U_G(NI/S_L) = 1 - m > U_G^*(I/S_L)$$

If agent B deviates in the same way we have

$$U_B(NI) = m\delta\pi_H V_H + 1 - m > U_B^*(I)$$

Thus, deviations by both agents are not equilibrium dominated and the pooling equilibrium satisfies the intuitive criterion. The arguments are similar for the waiting pooling equilibrium.

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A different approach to equilibrium refinements has been pursued by Umbhauer (1994) and Mailath, Okuno-Fujiwara and Postlewaite (1993). The Consistent Forward Induction Equilibrium Path concept of Umbhauer and the similar undefeated equilibrium concept of Mailath, Okuno-Fujiwara and Postlewaite consider an out-of-equilibrium message as a signal by a player that the beliefs at that message should be viewed from the perspective of another Perfect Bayesian Equilibrium path. Thus, an equilibrium path can only be removed by another equilibrium path. Both ways to apply forward induction arguments to equilibrium refinements could be tried.

Consider e.g. the Consistent Forward Induction Equilibrium Path (CFIEP) concept. If $m > m_{ES}$ (see proposition 2) the rash pooling equilibrium can be eliminated by the efficient separating equilibrium. The out of equilibrium message is NI. G observing S_L is better off in the efficient separating equilibrium since

$$\frac{(1-m)\cdot g_0(1-\pi_H)}{1-g_0\cdot\pi_H} > mV_L + (1-m)g_0$$

Whether B is better off depends on the value of the parameters. Hence, the set of players playing NI is either $\{GS_L\}$ or $\{GS_L, B\}$.

In the first case, if the public focuses its beliefs on G, this only strengthens the incentive of G to choose NI. The incentives to deviate in the second case are not modified if the public focuses its beliefs on $\{GS_L, B\}$ since G observing S_L chooses NI in the efficient separating equilibrium as does B. Finally, G in S_H is not better off switching to NI.[4]

If, however, $m \leq m_{ES}$ rash and waiting pooling equilibria cannot be eliminated by forward induction criteria. Overall, rash and waiting pooling equilibria illustrate the fragility of equilibrium constellations since one equilibrium represents a set of strategies opposite to the other. Depending on out-of equilibrium beliefs, governments either rush towards a decision or delay it excessively. Thus, we can offer an explanation for why governments often view problems as a crisis that demands immediate action. Similarly, we can illustrate why governments demand patience and delay actions excessively in order to avoid a bad signal about their competence.

4 An alternative refinement concept is universal divinity [see Banks and Sobel 1987]. Universal divinity requires that beliefs are concentrated on the player who has the weakest incentive to deviate from a prescribed equilibrium path. Universal divinity would not destroy pooling equilibria.

6 The Money Burning Refinement

In this section, we examine a refinement of the equilibrium notion that seems to be especially well-suited for political races in which candidates can use money to advertise at any point in time. Suppose players envision that a particular type of pooling equilibria is played. Then, we allow agents to test the beliefs the public would attach to out-of-equilibrium strategies in the pooling equilibrium he is considering by burning money.

The process works as follows. Suppose the agent assumes that a particular type of the pooling equilibria is being played, say a rash pooling equilibrium. Then, we can allow an agent to test his competence with the public by incurring costs. Such costs could simply be burning money through uninformative advertising or could occur when extensive polls to review the public's belief about the competence are conducted. Thus, we allow each agent to choose costs for testing out-of-equilibrium beliefs for a particular pooling equilibrium, denoted by $c \geq 0$, before the final actions have to be taken. This additional possibility obviously modifies the game since players can broaden their strategy space. The modified period 1 looks as follows:

Period 1': The agent decides whether to invest immediately or to postpone the decision.

All players consider a potential equilibrium configuration. If players consider a pooling equilibrium, agents can announce their type and can burn money by incurring some cost $c \geq 0$.

The public observes money burning by an agent and the agent's investment decision and forms a posterior estimate of the probability that the agent is good. The public's beliefs that the agent is good are denoted by g_1; it thinks he is bad with probability $1 - g_1$.

We view the modified game as the natural refinement of the original game form. Hence, the refinement in this paper is based on the possibility that agents broaden their strategy space by burning money. Let us denote the possible types of the players by i, j or k which represent a combination of the types of the agent (good or bad) and of the realization of the noisy signal about the state of the world (high or low). Thus, $i, j, k = GH, GL$ or B. Note that a player characterized by B does not receive any informative signal about the state of the world and hence is characterized by the type of the agent alone. Then, we define:

Definition
A player j has a strictly dominant belief-test strategy for a given pooling equilibrium if a cost $c_j \geq 0$ exists such that

$$U_j^j - c_j > U_j^{pool}$$
$$U_k^i - c_j \leq U_k^{pool} \quad \forall k \neq j, \forall i$$

U_j^j is the expected utility if the public believes that player j is telling the truth: U_k^i is the expected utility of player k if the public believes that he is player i who may be equal or different from k. Finally, U_k^{pool} is the expected utility of player k in the pooling equilibria under consideration.We next define the following single crossing property.

Definition
SCP: (Single Crossing Property)

Payoffs in a pooling equilibrium of the original game satisfy the SCP if a player j exists such that

$$U_j^j - U_j^{pool} > \max_{i,k \neq j} \{U_k^i - U_k^{pool}\}$$

Most standard signaling games satisfy SCP. The next proposition is obvious.

Proposition 6
Suppose that the pooling equilibria satisfy SCP. Then there exists a uniquely determined player who has a strictly dominant belief strategy.

In our game, we observe that agent G, who has observed S_H has a strictly dominant belief-test strategy in the waiting pooling equilibrium. Similarly, agent G, who has observed S_L, has a strictly dominant belief-test strategy for the rash pooling equilibrium. We next define the following signaling requirement:

Belief-test Criterion
Suppose that players consider a pooling equilibrium of the original game. Then, a strictly dominant belief-test strategy will be played in the modified game.

The intuition for this criterion is obvious. Suppose that player j considers a pooling equilibrium for which he has a strictly dominant belief-test strategy. If he tests the out-of equilibrium beliefs by incurring the costs

$$c_j = \max_{i,k \neq j} \left\{ U_k^i - U_k^{pool} \right\}$$

his expected payoffs $U_j^j - c_j$ are larger than U_j^{pool} in the original game.

Since $U_k^i - c_j$ is smaller than U_k^{pool} for all other players, independent of which type they would like to mimic, the public believes that player j tells the truth after having burned the money c_j. In this sense, the belief-test corresponds to a revelation compatibility condition.

For the modified game, the final beliefs of the public depend on the actions taken and on potential costs burned for belief-tests. We denote the beliefs of the public after having observed a belief-test with cost c and an action I or NI by $pr(G|I,c), pr(G|NI,c)$. We obtain

Proposition 7

(i) Suppose that

$$\bar{g}_1^{*} = \frac{m}{1-m}\left\{(1-\delta)\pi_H V_H + (1-\pi_H)V_L\right\} + \frac{\pi_H g_0}{1-g_0+g_0\pi_H} \geq 0$$

$$\bar{c}_{GL} = m\left\{(\delta-1)\pi_H V_H - (1-\pi_H)V_L\right\} + (1-m)(1-g_0) > 0$$

Then, an inefficient semi-separating equilibrium exists in which agent G in state S_L tests the beliefs by incurring cost $\bar{c}_{GL}$

and the public beliefs satisfy $pr(G|NI, c < \bar{c}_{GL}) \leq \bar{g}_1^{*}$

(ii) Suppose that

$$\bar{g}_2^{**} = \frac{m}{1-m}\left\{(\delta-1)\pi_H V_H - (1-\pi_H)V_L\right\} + \frac{(1-\pi_H)g_0}{1-g_0\pi_H} \geq 0$$

$$\bar{c}_{GH} = m\{(1-\delta)\pi_H V_H + (1-\pi_H)V_L\} + (1-m)(1-g_0) > 0$$

Then, an efficient semi-separating equilibrium exists in which agent G in state S_H tests the beliefs by incurring cost $\bar{c}_{GH}$

and the public beliefs that $pr(G|I, c < \bar{c}_{GH}) \leq \bar{g}_2^{**}$.

The proof is given in the appendix. The preceding proposition suggests that the inefficiencies involved in pooling equilibria can, at least partially, be alleviated by allowing the government to test beliefs. However, new inefficiencies occur since the costs incurred during testing are pure waste. Thus, allowing governments to spend large amounts of money in order to test beliefs of the public can increase the tendency towards correct decisions, however only at the cost of significant money burning. Since money burning is financed through taxes today or in the future, the possibility of belief-testing may well decrease overall welfare for the public. This will be discussed in the next section.

7 Rush, Delay or Money Burning?

In this section, we compare the welfare of rash and waiting pooling equilibria with the separating equilibria involving money burning. We assume that $m < m_{ES}$, such that according to proposition 2 no efficient semi-separating equilibrium without money burning exists.[5]

5 We do not consider a potential balanced spooling equilibrium in this section. Either m can be larger than m_{BP} and thus the equilibrium may not exist. Or it exists. Then it would help to increase the case against money burning since welfare in a balanced pooling equilibrium is larger than in a rash or waiting pooling equilibrium.

If the agent uses his own money for costly belief tests, the public is better off than rush or waiting pooling equilibria since efficient decisisons will be taken. In politics, however, governments can use the public's resources through taxation. Therefore, in the following we assume that money burning uses tax payers' money. In particular, we consider the following set–up. Before the game starts, the public gives the agent a certain amount of money. Those resources can be used to undertake a socially valuable project that increases the utility of the agent and that of society in the same way[6] and that enters utility additively. Or it can be used for money burning with no direct benefit for society. We examine in which cases the public is better off by giving money which might be used for money burning if a certain type of agent is present.

We denote by λ the shadow costs of public funds. Thus, taxation uses \$ $(1+\lambda)$ of tax-payers' money in order to levy \$1 for burning money. We denote by W_R, W_W, W_{Be}, W_{Bi} the expected welfare of the public in the four possible equilibria rush, waiting, efficient money burning and inefficient money burning. Straightforward calculations yield

$$W_R = \pi_H V_H + (1-\pi_H) V_L \tag{15}$$
$$W_W = \delta \pi_H \, V_H \tag{16}$$
$$W_{Be} = \pi_H \, V_h [(1-\delta) g_0 + \delta] - (1+\lambda) g_0 \, \pi_H \, \bar{c}_{GH} \tag{17}$$
$$W_{Bi} = \pi_H \, V_H + (1-g_0)(1-\pi_H) V_L - g_0 (1-\pi_H)(1+\lambda) \bar{c}_{GL} \tag{18}$$

where $\bar{c}_{GH}$ and $\bar{c}_{GL}$ are defined in propostion 7 and given by:

$$\bar{c}_{GH} = m\left\{(1-\delta)\,\pi_H V_H + (1-\pi_H) V_L\right\} + (1-m)(1-g_0)$$
$$\bar{c}_{GL} = m\left\{(\delta-1)\,\pi_H V_H - (1-\pi_H) V_L\right\} + (1-m)(1-g_0)$$

Note that we have assumed that no disutilities occur for the public if the agent does not burn money and uses the resources for socially valuable projects which also increase the utility of the agent in the same way.[7] By comparing expected welfare for the four different equilibria, we obtain:

Proposition 8

(i) $W_W > 0 > W_R$

(ii) $W_{Be} > W_{Bi}$

(iii) *If* $\delta \geq g_0$, $W_W > W_{Bi}$

The first two statements are obvious since waiting is better than rush. The third statement shows that everybody waiting is better than investing by a bad agent and by a good agent upon observing S_H while a good agent upon observing S_L burns money and does not invest. The efficient money burning and the waiting equilibrium are therefore the potential candidates for further examinations of welfare maximizing equilibria. The waiting equilibrium is socially preferred over efficient money burning if $W_W - W_{Be} > 0$. We obtain

6 It could also mean that the money will be given back to society at the end of the game.

7 One could assume that the money not used for burning may not increase utility of the agent in the same way as for the public. In such cases, the equilibria are altered since they imply larger amounts of money burning in equilibrium in order that the a competent agent can still separate himself from a bad agent. This would further decrease the attractiveness for the public to allow politicians to burn money.

$$
\begin{aligned}
W_W - W_{Be} &= g_0\left[\delta\pi_H V_H + \pi_H\left((1+\lambda)\bar{c}_{GH} - V_H\right)\right] \\
&= g_0\pi_H\left[(1-\delta)V_H\left((1+\lambda)m\pi_H - 1\right)\right. \\
&\left. + (1+\lambda)\left(m(1-\pi_H)V_L + (1-m)(1-g_0)\right)\right]
\end{aligned} \tag{19}
$$

which implies

Proposition 9

(i) $W_W > W_{Be}$ *if and only if* $(\delta - 1)V_H + \bar{c}_{GH} > 0$ *or* $(1-\delta)V_H\left((1+\lambda)m\pi_H - 1\right) + (1+\lambda)\left(m(1-\pi_H)V_L + (1-m)(1-g_0)\right) > 0$

(ii) *If* $\delta = 1$, $W_W > W_{Be}$

Note that second point follows from the observation that for $\delta = 1$

$$W_W = W_{Be} + (1+\lambda)g_0\pi_H\bar{c}_{GH}$$

and that $\bar{c}_{GH} > 0$ because of the assumptions in proposition 7. Proposition 9 implies that for sufficiently large discount factors, the money burning equilibria are socially dominated by the waiting pooling equilibria. Since money burning is obviously in the interest of the agent who burns money in equilibrium it is socially efficient to limit the budgets of the politicians such that money burning becomes impossible.

8 Extensions and Discussion

We have introduced an equilibrium refinement based on money burning that seems to be especially suited for political signalling games. Money burning can alleviate rash and waiting distortions in policy decisions, but can be an even larger source of distortions than biased decisions.

The considerations in this paper may be useful for other applications. Whenever there is a signalling game and players have the possibility to burn money, the money burning refinement can be used to reduce the set of plausible equilibria. Since money burning appears to be a natural way for agents to broaden their strategy space, the refinement could be a useful tool for other signalling problems.

9 Appendix

Proof of Proposition 2:

In the following, we shall make use of the beliefs of the public along the equilibrium paths. Denote by $pr(G|I)$ and $pr(G|NI)$ the probabilities that the agent is good if the public observes investment (I) or waiting (NI). The probabilities are given by Bayes's Theorem. We shall consider the three cases in turn.

(i) Fully separating equilibrium
In the fully separating equilibrium the posterior beliefs are

$$pr(G|I) = 1 \qquad pr(G|NI) = 0 \tag{A1}$$

We need to show that, given these beliefs, the different types of agents will behave in the described way.

Suppose the agent observed S_H. A good agent's utility when he invests is

$$U_G(I|S_H) = m \cdot V_H + 1 - m \tag{A2}$$

If he does not invest in period 1, his expected utility is $m\delta V_H + (1-m)0 = m\delta V_H$. Therefore, a good agent will invest after observing S_H.

Consider next a bad agent whose decisions do not depend on the signals. If he does not invest, he reveals himself to be a bad agent. With probability $pr_B(V_H|S_H) = pr_B(V_H|S_L) = \pi_H$ he will invest in the next period and thus his expected utility is

$$U_B(NI) = m \cdot \delta \cdot \pi_H V_H \tag{A3}$$

If a bad agent invests his expected utility is

$$U_B(I) = m\,[\pi_H V_H + (1-\pi_H)V_L] + (1-m) \tag{A4}$$

The difference in utilities is:

$$U_B(NI) - U_B(I) = m\pi_H(\delta - 1)V_H - m(1-\pi_H)V_L + m - 1 \tag{A5}$$

Suppose that the good agent observed S_L. The good agent must compare the utilities

$$U_G(I|S_L) = m \cdot V_L + (1-m) \tag{A6}$$

and

$$U_G(NI|S_L) = 0 \tag{A7}$$

Hence, the good agent invests if

$$mV_L + 1 - m > 0 \tag{A8}$$

However, if

$$mV_L + 1 - m > 0 \tag{A9}$$

we have

$$m(1-\pi_H)V_L + 1 - m > 0 \tag{A10}$$

and thus

$$U_B(NI) - U_B(I) = m\pi_H(\delta - 1)V_H - \left\{m(1-\pi_H)V_L + 1 - m\right\} < 0 \tag{A11}$$

Therefore, if it is optimal for the good agent to invest upon observing S_H, the bad agent wants to choose I as well. Hence, a fully separating equilibrium cannot exist.

(ii) Efficient semi-separating equilibrium

In the efficient, semi-separating equilibrium, the posterior beliefs about the agent's type are given by

$$pr(G|I) = 1 \tag{A12}$$

$$pr(G|NI) = \frac{(1-\pi_H)g_0}{1-g_0+g_0(1-\pi_H)} = \frac{(1-\pi_H)g_0}{1-g_0\pi_H} \tag{A13}$$

Suppose the agent observes S_H. We want to show that only a good agent would invest. Clearly, investing is the best response for a good agent, since

$$pr(G|I) > pr(G|NI) \tag{A14}$$

For a bad agent, we obtain:

$$U_B(NI) = m \cdot \delta \cdot \pi_H V_H + (1-m)\frac{(1-\pi_H)g_0}{1-g_0\pi_H} \tag{A15}$$

$$U_B(I) = m\left[\pi_H V_H + (1-\pi_H)V_L\right] + (1-m) \tag{A16}$$

The difference in utilities amounts to

$$\begin{aligned} U_B(NI) - U_B(I) =& m\pi_H(\delta-1)V_H - m(1-\pi_H)V_L \\ &+ (m-1)\frac{1-g_0}{1-g_0\pi_H} \\ =& m\delta\pi_H V_H - mEV_0 + (m-1)\frac{1-g_0}{1-g_0\pi_H}. \end{aligned} \tag{A17}$$

Thus, $U_B(NI) - U_B(I)$ is monotonically increasing in m. $U_B(NI) - U_B(I)$ is negative for $m = 0$. Setting $U_B(NI) - U_B(I) = 0$ for $m = 1$ defines a critical value δ^*:

$$\delta^* = \frac{\pi_H V_H + (1-\pi_H)V_L}{\pi_H V_H}$$

Then, $U_B(NI) - U_B(I)$ is greater than zero for $m = 1$ if $\delta > \delta^*$.
Thus, for $\delta > \delta^*$ there exists some m_{ES}, $0 < m_{ES} < 1$ such that NI is a best response for $m \geq m_{ES}$. Consider next the case S_L. Since $t_G = 1 > t_B = 1/2$, $U_G(NI|S_L) - U_G(I|S_L) \geq U_B(NI) - U_B(I)$. Thus, if NI is a best response for B under S_H, it is even more a best response for G under S_L.

(iii) Inefficient semi–separating equilibrium

In the inefficient, semi–separating, equilibrium, the posterior beliefs are

$$pr(G|I) = \frac{\pi_H g_0}{1 - g_0 + g_0 \pi_H} \tag{A18}$$

$$pr(G|NI) = 1 \tag{A19}$$

We first show that a good agent who observes S_L will not invest, since

$$U_G(NI|S_L) = 1 - m > U_G(I|S_L) \tag{A20}$$

where

$$U_G(I|S_L) = mV_L + (1-m)\frac{\pi_H g_0}{1 - g_0 + g_0 \pi_H} \tag{A21}$$

A bad agent will invest if $U_B(NI) \leq U_B(I)$ where

$$U_B(NI) = m \cdot \delta \pi_H V_H + 1 - m \tag{A22}$$

and

$$U_B(I) = m \cdot (\pi_H V_H + (1-\pi_H)V_L) + (1-m)\frac{\pi_H g_0}{1 - g_0 + g_0 \pi_H} \tag{A23}$$

Clearly we have,

$$U_B(NI) > U_B(I) \quad \text{since } EV_0 < 0, \tag{A24}$$

and thus investment cannot be a best response for a bad agent.

■

Proof of proposition 3:

If B chooses I with probability p, a posteriori beliefs are given by:

$$\text{pr}(G/I) = \frac{p(G)p(I/G)}{p(G)p(I/G) + p(B)p(I/B)} = \frac{g_0\pi_H}{g_0\pi_H + (1-g_0)p}$$
$$\text{pr}(G/NI) = \frac{g_0(1-\pi_H)}{g_0(1-\pi_H) + (1-g_0)(1-p)}$$

Hence, expected utilities of a bad agent are

$$U_B(I) = mEV_0 + (1-m)\text{pr}(G/I)$$
$$U_B(NI) = m\delta\pi_H V_H + (1-m)\text{pr}(G/NI)$$

A balanced pooling equilibrium requires that agent B is indifferent between I and NI. Hence,

$$m(\pi_H V_H(\delta - 1) - (1-\pi_H)V_L)$$
$$= (1-m)\cdot\left\{\frac{g_0\pi_H}{G_0\pi_H + (1-g_0)p} - \frac{g_0(1-\pi_H)}{g_0(1-\pi_H) + (1-g_0)(1-p)}\right\} \quad \text{(A25)}$$

The left side is positiv since

$$-EV_0 = -(\pi_H V_H + (1-\pi_H)V_L) > 0.$$

The right side is monotonically decreasing in p. For $p = \pi_H$ the right side is zero. Hence, a balanced pooling equilibrium exists if and only if the right side is at least equal to the left side for $p = 0$ which implies

$$\frac{m}{1-m}\{\pi_H V_H(\delta - 1) - (1-\pi_H)V_L\} \leq 1 - \frac{g_0(1-\pi_H)}{1-g_0\pi_H} = \frac{1-g_0}{1-g_0\pi_H}$$

The left side is zero for $m = 0$, approaches infinity when m approaches 1 and is monotonicallly increasing in m. Hence, there exists some m, denoted by m_{BP}, such the condition is fulfilled for $m \leq m_{BP}$. Therefore, for $m \leq m_{BP}$ a balanced pooling equilibrium exists.

■

Proof of proposition 4:

We first prove (i). Suppose that S_H has occurred.
The expected utilities of the good agent amount to

$$U_G(I|S_H) = mV_H + (1-m)g_0 \quad \text{(A26)}$$

$$U_G(NI|S_H) = \delta mV_H + (1-m)pr(G|NI) \quad \text{(A27)}$$

and thus

$$U_G(I|S_H) \geq U_G(NI|S_H) \quad \text{(A28)}$$

if

$$pr(G|NI) \leq \frac{m}{1-m}(1-\delta)V_H + g_0 \quad \text{(A29)}$$

The bad agent selects I if

$$\begin{aligned} U_B(I) &= m\{\pi_H V_H + (1-\pi_H)V_L\} + (1-m)g_0 \geq \\ U_B(NI) &= m\{\delta\pi_H V_H\} + (1-m)pr(G|NI) \end{aligned} \quad \text{(A30)}$$

and thus if

$$pr(G|NI) \leq \frac{m}{1-m}\{(1-\delta)\pi_H V_H + (1-\pi_H)V_L\} + g_0 \quad \text{(A31)}$$

Finally, suppose S_L has occurred. The good agent selects I if

$$U_G(I|S_L) = mV_L + (1-m)g_0 > U_G(NI|S_L) = (1-m)pr(G|NI) \quad \text{(A32)}$$

and thus if

$$pr(G|NI) \leq \frac{m}{1-m}V_L + g_0 \quad \text{(A33)}$$

The last upper bound for $pr(G|NI)$ is the smallest one. Thus, the rash pooling equilibrium exists if

$$pr(G|NI) \leq \frac{m}{1-m}V_L + g_0 \quad \text{(A34)}$$

The upper bound is denoted as g_1^*.
The proof of (ii) is similar. The crucial comparison is now

$$\begin{aligned} U_G(NI|S_H) &= m \cdot \delta V_H + (1-m)g_0 \geq \\ U_G(I|S_H) &= mV_H + (1-m)pr(G|I) \end{aligned} \quad \text{(A35)}$$

and hence the equilibrium exists if

$$pr(G|I) \leq \frac{m(\delta-1)}{1-m}V_H + g_0 \quad \text{(A36)}$$

which is denoted by g_1^{**}.

■

Proof of Proposition 7:

(i) It is obvious that agent G in state S_L has a strictly dominant belief-test strategy. We first calculate the costs for the belief test. If agent B could pretend to be a good agent in the belief-test, he would choose NI afterwards. His expected utility would amount to:

$$U_B^G(NI) = m\{\delta\pi_H V_H\} + 1 - m$$

The expected utility in the pooling equilibria is given by

$$U_B^{pool}(I) = mEV_0 + (1-m)g_0$$

It is obvious that the good agent in state S_H has a smaller incentive to test beliefs than a bad agent. Therefore, the money player GL needs to burn for the belief-test are given by

$$\bar{c}_{GL} = m\{(\delta - 1)\pi_H V_H - (1-\pi_H)V_L\} + (1-m)(1-g_0).$$

Note that

$$\begin{aligned} U_{GL}^{GL}(NI) - U_{GL}^{pool}(I) &= (1-m)(1-g_0) - mV_L \\ &> \bar{c}_{GL} \end{aligned}$$

Next we discuss the condition on the beliefs of the public. Obviously, the equilibrium requires

$$pr(G|NI, c \geq \bar{c}_{GL}) = 1$$

$$pr(G|I,c) = \frac{\pi_H g_0}{1 - g_0 + g_0\pi_H} \forall c \geq 0$$

Finally, we have to determine $pr(G|NI, c < \bar{c}_{GL})$.

Clearly, the bad agent does not want to incur costs for a belief-test. He therefore selects I over NI if

$$\begin{aligned} U_B(I) &= mEV_0 + (1-m)\frac{\pi_H g_0}{1 - g_0 + g_0\pi_H} > \\ U_B(NI) &= m\delta\pi_H V_H + (1-m)pr(G|NI, c < \bar{c}_{GL}). \end{aligned}$$

Therefore,

$$\begin{aligned} & pr(G|NI, c < \bar{c}_{GL}) \leq \vec{g}_1^{*} = \\ & \frac{m}{1-m}\{(1-\delta)\pi_H V_H + (1-\pi_H)V_L\} + \frac{\pi_H g_0}{1 - g_0 + g_0\pi_H} \end{aligned}$$

is an upper bound for the beliefs of the public when a player tests the belief by burning money less than $\bar{c}_{GL}$ and chooses NI.

(ii) The proof is similar. Agent G tests the beliefs if players consider a waiting pooling equilibrium. The belief-test costs $\bar{c}_{GH}$ are determined by the comparison of

$$U_B^G(I) = mEV_0 + 1 - m$$

with

$$U_B^{pool}(NI) = m\{\delta\pi_H V_H\} + (1-m)g_0$$

Thus

$$\bar{c}_{GH} = m\{(1-\delta)\pi_H V_H + (1-\pi_H)V_L\} + (1-m)g_0$$

Again, by appropriate choices of the beliefs, the bad agent does not want to choose I.

The comparison involves

$$U_B(NI) = m\delta\pi_H V_H + (1-m)\frac{(1-\pi_H)g_0}{1-g_0\pi_H}$$

$$U_B(I) = mEV_0 + (1-m)pr(G|I, c < \bar{c}_{GH})$$

yielding an upper bound

$$pr(G|I, c < \bar{c}_{GH}) \leq \bar{g}_2^{**} = \frac{m}{1-m}\{(\delta-1)\pi_H V_H - (1-\pi_H)V_L\} + \frac{(1-\pi_H)g_0}{1-g_0\pi_H}.$$

■

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