Research and the Approval Process*

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Abstract

An agent sequentially collects information to obtain a principal's approval, such as a pharmaceutical company seeking FDA approval to introduce a new drug. To capture such environments, we study strategic versions of the optimal stopping time problem first proposed by Wald (1945). Our flexible model allows us to consider different types of rules and commitments by the principal as well as strategic withholding of information by the agent. We shed light on current regulation and proposed reforms of the drug approval process. The model also captures situations such as a firm seeking antitrust approval to merge with a competitor, a manager proposing a project to the firm's headquarters or an author submitting a paper to an editor.

Keywords: Research, organization, approval, regulation.

JEL Classification: D83 (Search; Learning; Information and Knowledge; Communication; Belief), M38 (Government Policy and Regulation).

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1 Introduction

Pharmaceutical companies run costly clinical trials on new drugs to demonstrate the safety and effectiveness necessary to obtain regulatory approval. Similarly, a firm intending to take over a competitor searches for evidence of synergies to convince the antitrust authority to approve the transaction. A manager collects information to push the firm headquarters to validate his project. And an author submitting a paper conducts research and robustness checks to convince the editor to accept. In turn, the regulator, the headquarters or the editor can can also conduct additional independent research on these issues.

In all these situations an agent searches sequentially for evidence to convince a principal, with a priori different preferences, of the desirability of an activity with uncertain private and social payoffs; the principal, in turn, also conducts some research. How does the organization of the approval process affect the information that gets produced and the quality of the final decision? How does the possibility for the agent to withhold information affect the process?

Consider our leading application to the drug approval process. After identifying a promising compound, pharmaceutical companies conduct an extensive and well defined series of clinical trials to obtain the approval of the regulator in charge of drug safety.[1] Pharmaceutical research is conducted sequentially, so that at each point in time one of three decisions is made: continue research by acquiring additional information, abandon the project altogether, or ask for approval for introducing the drug to market.[2]

This corresponds to the current organization of the drug approval process, in particular in the US. This process has evolved greatly over time and new issues are currently emerging (as described in detail in section 2). The historical evolution of legislation on drug approval has tended to strengthen the powers of the FDA to mandate research and created opportunities for the agency to commit to standards and to a precise process of approval. In this paper, we will study the benefits from these different types of commitment. Currently the attention has turned to both the issue of withholding of information, following some heavily publicized scandals,[3] and

[1] In the US the Food and Drugs Administration (FDA) regulates the approval of new drugs. In the European Union, pharmaceutical companies can choose between applying to a EU-wide authority, the European Medicines Agency (EMA), or to one of the national authorities, such as the Medicines and Healthcare products Regulatory Agency (MHRA) in the UK or the Agenzia Italiana del Farmaco (AIFA) in Italy.

[2] Obtaining additional evidence can mean conducting additional clinical trials or adding patients to a trial. As reported in Nundy and Gulhati (2005), increasingly Western drug companies conduct trials in India to decrease costs and benefit from easier regulatory approval. Moreover, several scandals involve illegal trials not approved by the Indian authorities.

[3] Scandals include the allegation that for several years Merck withheld evidence on adverse effects of its blockbuster drug Vioxx. There has been a recent push to impose stronger disclosure requirements. For example,

the question of post-approval regulation. Our theoretical analysis will shed light on these new concerns and on the necessary regulatory steps.

Our model captures these types of environments in a simple, tractable and flexible way. A choice needs to be made between rejection and approval. Rejection yields a zero payoff while the benefits from approval depend on a binary state of nature; they are positive if the state is high and negative if it is low. Research can be conducted to obtain additional information about the state. It is costly on two accounts: there is a direct financial cost and, in addition, research delays decision making with an associated opportunity cost. The arrival of new information is conveniently modeled in continuous time as a Wiener process with a drift that depends on the state.

If the same player were in full control of both research and approval, the model would boil down to a version of the classic single-agent optimal stopping problem that has been widely analyzed in the statistical decision theory literature on sequential analysis pioneered by Wald (1945). The well-known solution involves two threshold values (or standards) for the belief, such that it is optimal to abandon the project when the belief that the state is high is sufficiently low (below the rejection standard) and such that it is optimal to adopt the project when the belief is sufficiently high (above the approval standard). When the belief lies within these thresholds, it is optimal to continue researching—this is Wald's celebrated sequential probability ratio test.

The payoffs of agent and principal are typically misaligned. For instance, because the pharmaceutical firm does not internalize all externalities, it typically gets a higher payoff than the regulator in the bad state. In most of the paper we thus focus on situations where, for the stand-alone Wald Problem, the agent searches more than the principal at the lower end, when the state is bad, and less at the upper end, when the state is good. It is the case most people have in mind for drug approval: pharmaceutical companies are eager to stop researching, obtain approval, and adopt the drug earlier than the regulator when information is good and more reluctant to abandon the project when the state is bad.

In practice, the research and approval processes are not single agent problems; intuitively the agent controls the research decision, at least initially, while the principal has the hold on the approval decision. The baseline situation we thus study is one where the agent chooses the lower benchmark of search and the principal simultaneously chooses the upper benchmark (the Nash

medical journals and regulatory authorities have pushed for early registration of trials and for disclosure of the results obtained in the trials.

Equilibrium).[4] In equilibrium, we show that the principal will compromise at a lower standard for approval compared to the principal's non-strategic standard. Intuitively, given that the agent now chooses when to abandon research, the principal's value of information is reduced—thus the principal becomes more eager to approve.

Two properties of this Nash equilibrium solution stand out. First, the principal can obtain a negative payoff in equilibrium. Indeed he controls the upper benchmark, and can force immediate approval but cannot force rejection. If the agent has sufficiently misaligned preferences and searches too much at the lower end, the principal at the upper benchmark gets a negative expected benefit. The goal of research in such situations is that it will provide sufficiently bad news that the lower benchmark will be reached and the agent can be convinced to abandon. Second, more research is conducted in the Nash equilibrium solution than in either stand-alone problems.

The principal thus has an interest to commit to a course of action that discourages research by the agent at the lower end. We first consider commitments ex ante to an approval standard, what we call the Stackelberg outcome. The principal chooses his preferred point on the agent's best response curve. Depending on the value of the initial belief, different types of commitments are optimal. When the belief is low, a high blocking commitment that discourages research by the agent is preferred: this allows the principal to avoid the negative payoff that sometimes characterizes the nash outcome. For intermediate values of the belief, the principal will commit to an interior commitment, allowing for some research by the agent. Finally, when the initial belief is very favorable, the principal will commit to immediate approval.

In practice, this type of commitment is not easy to achieve and furthermore, as suggested by the above discussion, cannot be uniform and independent of the current state of knowledge. In fact, as described in section 2, this is not the approach chosen for drug regulation. Rather, there is a commitment to a well defined sequential procedure for approval. We thus study a model where the interaction occurs in two stages as follows:

1. In the first stage the agent conducts research, and then decides when to transfer the decision-making power to the principal.

2. Once that happen, in the second stage, the principal conducts research and eventually decides whether to approve.

[4] This is in fact the outcome of a game where the principal can mandate research: in each period the agent chooses between three actions, research, submit or wait and if the agent chooses submit, the principal chooses between research, approve and wait.

Clearly, the solution in the second stage corresponds to the non-strategic solution for the principal. Expecting that outcome, in the first stage the agent has less incentive to undertake research at the bottom because of the extra research conducted at the top in comparison to the baseline Nash equilibrium. Our analysis shows that this type of commitment is not necessarily optimal from the point of view of the principal. Whereas in the Nash Equilibrium outcome, the issue was excessive research by the agent at the bottom, the issue is here one of excessive research at the top. This suggests that regulation of drug approval should be reoriented towards a commitment to standards.[5]

Recent regulation of the drug approval process has focused on the issue of withholding of information. As recent scandals suggest, the agent can withhold some of the evidence, but this is nevertheless costly; Merck for instance in the Vioxx case has paid over 4.8 billion dollars for settling complaints. We enrich the model and suppose that the agent can report any belief, but is then subject to an expected penalty when the state turns out to be low. The expected penalty increases in the distance between the actual state of knowledge and the report (the case is harder to defend in court when the lie is big).

Even though the agent will always lie in equilibrium, by exploiting the knowledge of the bounds of the agent's research interval, the principal is able to perfectly invert the information and not be deceived. In fact, we demonstrate that the principal will actually benefit from the agent's ability to costly misreport information. The reason is that the cost of lying decreases the value of information for the agent, leading to a reduction of research at the lower end, something that is beneficial for the principal. We show that it is optimal for the principal to choose a penalty for misrepresentation that is not infinite so that the agent carries out some costly misrepresentation in equilibrium.

As initially suggested, our model is rich enough to cover other cases of research and approval than our main application to the pharmaceutical market. We derive some further results in this case, varying some assumptions to better fit the applications. We first depart from the assumption that the agent cares about the cost of the principal's research (i.e.. has to pay for research) and revisit the two stage commitment game. We show that even though this introduces a free riding incentive, the agent still has incentive to do research to move the principal away from his rejection threshold which is inefficiently high from the agent's point of view.

[5] There is some discussion of relevant standards in the literature. For instance, Ocana and Tannock (2011) argue that, even though the FDA has tended to accept any trial showing statistically significant results, they should become stricter and request "clinically important differences", i.e., statistical differences large enough to make it worth running the risk of introducing a new drug.

Related Literature. The original problem of sequential research, examining the tradeoff between the cost of an extra signal and the benefit of a more informed decision, was introduced by Wald (1945, 1947) and Wald and Wolfowitz (1948).[6] The ensuing applied probability literature of this non-strategic problem has a large impact on the actual design of clinical trials. Closely building on Wald's decision-theoretic foundational framework, we focus on the strategic issues that arise when the decisions to collect information and to make the final decision are made by two different players.

Our paper thus relates to the literature on strategic experimentation (see Bolton and Harris 1999) and especially to Strulovici (2010), who highlights how the loss of control of decision making (determined through voting in his model) reduces the incentives to acquire information and thus induces a status quo bias; see also Fernandez and Rodrik (1991). Our model is closest to Gul and Pesendorfer (2012), Lizzeri and Yariv (2011), and Chan and Suen (2012) who consider strategic settings in which public information arrives over time to voters. In Gul and Pesendorfer's (2012) model information is provided by the party that leads, whereas in Lizzeri and Yariv (2011) and Chan and Suen (2012) voters decide collectively themselves when to stop acquiring public information and reach a decision. In their setting information is revealed publicly to all voters, while we focus on the sequential interaction between an agent who collects private information and then reports (or possibly misreports) it to a principal who makes the approval decision. We also analyze the commitment solution in which the principal moves first by setting the approval standard, and then extend the model to analyze approval in multiple stages.

For our baseline analysis we constrain reporting of the belief (corresponding to the final results) to be truthful at the moment of application, for example because misrepresentation is infinitely costly as in the disclosure models of Grossman (1981) and Milgrom (1981). We also consider the possibility of costly misreporting. While Kartik, Ottaviani and Squintani (2007) and Kartik (2009) characterize the amount of equilibrium costly lying in static models of strategic communication, in our dynamic model we show that ex post lying costs reduce the ex ante incentives for information collection. See also Shavell (1994), Henry (2009), and Dahma, GonzÃ¡lez, and Porteiro (2009) for strategic analysis of partial disclosure of research results. In Henry (2009), pharmaceutical firms are worse off when their research efforts are not observed by the regulator as they are forced to do additional tests to convince him they are not hiding any evidence. Our

[6] Moscarini and Smith (2001) recently advanced this literature on non-strategic sequential analysis by analyzing a continuous-time model in which the decision maker can the vary number of experiments in each period. Our formulation is also in continuous time, but we focus on the simpler case with one experiment per period.

setup is different in the sense that information is not verifiable: in fact the possibility of hiding information here reduces research because of the cost of lying. This turns out to be beneficial for the regulator who wants to limit research at the lower end.

Finally, we do not allow our principal to use monetary transfers, in line with the literature on mechanism design without transferable utility; see HolmstrÃ¶m (1977) and Alonso and Matouschek (2008), Armstrong and Vickers (2010), and Taylor and Yildirim (2011). This approach delivers a number of important insights on the functioning of approval processes that we observe in a number of practical settings where, by and large, transfers are actually not used. A complementary literature analyzes the problem of optimal incentive provision for innovation, search, and experimentation where transfers are allowed; recent papers in this area are Manso (2011), Lewis and Ottaviani (2008), Lewis (2012), Gerardi and Maestri (2012), HÃ¶rner and Samuelson (2012), and Halac, Kartik, and Liu (2012).

2 Drug Approval Process

We present a brief overview of the drug approval process, past and present, in the US. This exercise will guide our theoretical analysis: we will both analyze the possible effects of past regulations and consider potential consequences of current regulatory efforts.

The evolution of the legislation on drug approval was a series of reactions to resounding scandals. Prior to 1938, the role of the US Food and Drug Administration (FDA) was mostly limited to preventing misleading statements on drug labeling. In 1937, a drug company developed a liquid preparation that was not tested prior to marketing and contained a poisonous solvent. The drug killed over a 100 people. In reaction, the 1938 Food, Drug and Cosmetic Act was swiftly passed. *The main feature of this law is that it required that research results be submitted to obtain approval for the drugs, although the FDA had little power to mandate further research if the initial evidence was unsatisfactory.*

It was an important step: it introduced the New Drug Application (NDA) necessary to obtain approval, a procedure that still exists today.[7] However, the power of the FDA still remained limited. For instance it had only 60 days to examine the evidence and there was no specification of the rules for testing.

A new scandal in 1962 highlighted the need for regulation of the process of testing. A hypnotic

[7] The NDA had to include "all clinical investigations, a full list of the drug's components and copies of both the packaging and labelling of the new drug"

known as thalidiomide was discovered in Europe to lead to birth defects. It was not allowed the US, but several thousands of samples had been sent to US doctors who gave them to patients without mentioning it was experimental, leading to a number of cases of affected babies. In reaction, the 1962 Drug Amendments introduced the process of drug testing as we know it. The main features of the amendments can be summarized as follows:

- *It put in place a system of pre-clinical testing notification* so that regulators could judge whether it was safe to start testing on humans
- *It gave more power to the regulator to mandate research.* As explained by Junod (2008), "FDA was given the authority to set standards for every stage of drug testing from laboratory to clinic".
- *However the law did not set very strict legal standards for approval.* The law required that there be "substantial evidence" that the drug be effective. As pointed out in Junod (2008), alternative stronger language such as "preponderance of evidence" or "evidence beyond any reasonable doubt" could have been used.

The current phase of regulation is another example of a reaction to a scandal, this time involving misreporting of evidence by firms, in particular information on side effects of drugs. A case in particular, the allegation that for several years Merck withheld evidence on adverse effects of its blockbuster drug Vioxx, has led to a recent push to impose stronger disclosure requirements. The FDA Modernization Act of 1997 created the clinical trial registry ClinicalTrials.gov. The FDA Amendments Act of 2007 expanded the types of clinical trials needed to be registered and the amount of details that should be included. Some legislators are trying to push for further expansions.[8]

3 Model and Best Responses

3.1 Model

To capture most of the features of the interactions between an agent and a principal, such as a pharma firm and the FDA, we consider the following model. A choice needs to be made between two alternatives, adoption A or rejection R. The benefits derived from these alternatives depend

[8] For example, medical journals and regulatory authorities have pushed for early registration of trials and for disclosure of the results obtained in the trials.

on the state of the world ω that can be either high H or low L. The payoff for player i in state j if the choice is k is given by v_{jk}^{i}. We assume that the payoff from rejection is zero for all players, regardless of the state. Furthermore we assume that, for any player i, accepting a good project provides positive payoffs while accepting a bad one provides a negative one: $v_{HA}^{i} > 0$ and $v_{LA}^{i} < 0$.

For convenience, we use the following log-likelihood parametrization of beliefs

$$\sigma = \log \frac{\Pr(\omega = H)}{\Pr(\omega = L)},$$

so that the probability that the state is high is given by $e^{\sigma} / (1 + e^{\sigma})$. All players share a common prior σ_0. Given the restrictions we imposed on the payoffs, if player i is forced to make a decision at belief σ, there exists a threshold value (or standard) of the belief $\hat{\sigma}$, such that A is chosen if $\sigma > \hat{\sigma}$ and R is chosen if $\sigma < \hat{\sigma}$. That value $\hat{\sigma}$ solves

$$\frac{e^{\hat{\sigma}}}{1+e^{\hat{\sigma}}} v_{HA} + \frac{1}{1+e^{\hat{\sigma}}} v_{LA} = 0$$

Research can be conducted to learn the value of the state. The arrival of new information is modeled as a Wiener process $d\Sigma$. The drift is determined by the state. Specifically, the process has positive drift μ and variance ρ^2 if the state is H or drift $-\mu$ and variance ρ^2 if the state is L. Accumulating information over a period of time dt costs $c_i dt$, where the cost of collecting information can vary across individuals.

Finally, payoffs are discounted, so that if an alternative is chosen at date t it is discounted at rate r_i. There are therefore two costs associated with searching for more information: the direct financial cost and the opportunity cost associated to the delay in the accrual of the decision payoffs.

Suppose player i undertakes research until time t. The accumulated information at date t is given by σ_t. The log-likelihood ratio of observing $\sigma_t = \gamma$ in the two states is given by

$$\log \frac{h\left(\frac{\gamma-\mu}{\rho}\right)}{h\left(\frac{\gamma+\mu}{\rho}\right)} = \frac{2\mu\gamma}{\rho^2}, \tag{1}$$

where h is the density of a standard normal distribution. According to Bayes' rule, the log posterior probability ratio is equal to the sum of the log prior probability ratio and the log-likelihood ratio. Thus, the posterior belief at time t is given by

$$\sigma_t = \sigma_0 + \Sigma_t' \tag{2}$$

where $d\Sigma'$ is a Wiener process with drift $2\mu^2/\rho^2$ if the state is H and $-2\mu^2/\rho^2$ if the state is L and instantaneous variance $4\mu^2/\rho^2$.

When the same player i makes both the search and approval decisions, for a belief that is close to σ_i^*, there may be a benefit of searching for more information to make a more informed decision. This is a standard stopping time problem: there exists two values of σ, s and S ($s \leq S$) such that:

- if $\sigma < s$ the player stops researching and rejects;
- if $s < \sigma < S$ the player conducts research;
- if $\sigma > S$ the player stops researching and approves.

It is immediate to characterize the utility function of the player when $\sigma \in (s, S)$ where

$$u(\sigma) = e^{-rdt} E[u(\sigma + d\Sigma')] - cdt.$$

Following Stokey (2009, Chapter 5), starting in the intermediate region, we let T be the first time the belief hits either s or S. The direct monetary cost of searching is given by $\int_0^T ce^{-rt}dt = \frac{c}{r} - \frac{c}{r}e^{-rT}$. Once we define, as in Stokey (2009):

$$\begin{aligned}
\Psi(\sigma, \omega) &= E[e^{-rT}|\sigma(T) = S, \omega]\ Pr[\sigma(T) = S|\omega] \\
\psi(\sigma, \omega) &= E[e^{-rT}|\sigma(T) = s, \omega]\ Pr[\sigma(T) = s|\omega],
\end{aligned}$$

the utility for $\sigma \in (s, S)$ is given by

$$\begin{aligned}
u(\sigma) &= -\frac{c}{r} + Pr[\omega = H]\left(v_{HA} + \frac{c}{r}\right)\Psi(\sigma, H) \\
&+ Pr[\omega = L]\left(v_{LA} + \frac{c}{r}\right)\Psi(\sigma, L) \\
&+ Pr[\omega = H]\left(\frac{c}{r}\right)\psi(\sigma, H) \\
&+ Pr[\omega = L]\left(\frac{c}{r}\right)\psi(\sigma, L).
\end{aligned}$$

The first line corresponds to the case where the state is high and the upper benchmark S is reached first. The second line is the case where the state is low but the upper benchmark is reached first, and so on.

3.2 Best Response Analysis

We start by characterizing the best responses of the research problem. Specifically, for a given value of the lower standard s (resp. upper standard S) we characterize the optimal choice of the upper standard $S = BR(s)$ (resp. lower benchmark $s = br(S)$). This best response analysis allows for a better understanding of our problem and will serve as a building block for the next sections. We start by characterizing $br(S)$. For the moment we drop the subscript i.

Proposition 1 *For a given upper benchmark S:*

1. *The best response $br(S)$ is independent of the current belief σ and is such that $br(S) = S$ if $S < \hat{\sigma}$.*

2. *The best response $br(S)$ is decreasing in v_{HA}, v_{LA} and increasing in c.*

3. *The length of the research interval $l(S) = S - br(S)$ is increasing in S and converges to a finite value $\bar{l}$ when S converges to $+\infty$, where $\bar{l}$ is solution to $v_{HA} = (e^{g(l)} - 1)\frac{c}{r}$.*

The first result states that there is dynamic consistency in the sense that the best response is independent of the current belief. It also states that $br(S) = S$ for values $S < \hat{\sigma}$. This result is natural, since when $S < \hat{\sigma}$, approval at S gives a negative value and the player can guarantee himself a zero payoff, when $\sigma \leq S$, by choosing $s = S$ and imposing rejection.

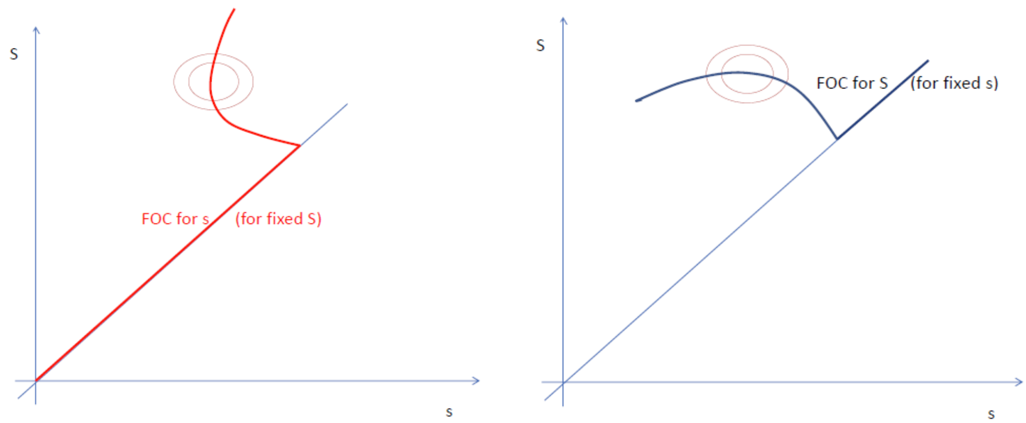
For $S \geq \hat{\sigma}$, the first-order condition characterizing the best response (derived in the appendix) is given by:

$$\underbrace{V_A(S)}_{\text{benefit of gaining more information}} = \underbrace{\beta_1(s, S)\ c/r}_{\text{financial cost of research}} \tag{3}$$

with $\beta_1(s, S) > 0$ and where:

$$V_A(S) = \frac{e^S}{1 + e^S} v_{HA} + \frac{1}{1 + e^S} v_{LA}$$

is the expected benefit from approval when the belief is $\sigma = S$ (with $V_A(S) \geq 0$ if and only if $S \geq \hat{\sigma}$).



At the lower benchmark s, the tradeoff expressed by (3) is clear. There are typically two costs associated with research: first the direct financial cost, proportional to c/r and second the cost of delaying the decision. At the lower benchmark of research rejection yields a zero payoff. Thus there is no cost of delay and the only cost is the financial one. This expected cost has to be equal to the expected value of information which is proportional to $V_A(S)$, i.e., the value if the upper standard is reached. Overall this gives condition 3. The comparative statics then naturally follow. Increasing the cost c naturally decreases research. On the other hand increasing v_{HA} or v_{LA} has the effect of increasing the value of information without affecting the cost and thus decreases the lower benchmark.

Interestingly, result 1.3 indicates that the length of the research interval, measured by $S - br(S)$ (an indirect measure of the quantity of research), is increasing in S. The intuition is the following: for a given length l between s and S, the expected benefit $V_A(S)$ is higher for large values of S and the expected cost of moving from s to S is lower since there is a higher probability that the drift will be positive. Thus, if for a certain value of S, the optimal choice is a length $l(S) = S - br(S)$ of the research interval, for higher values of S, the interval will be larger. This property is visible in Figure 1 where we plot both br(S) and BR(S). As indicated in result 1.3, at the limit, when S goes to infinity, the value of $l(S)$ converges to $\bar{l}$ such that $v_{HA} = (e^{g(\bar{l})} - 1)\frac{c}{r}$. This limit value depends only on c/r and v_{HA}: when S goes to infinity, the player is sure the state is good and at the lower benchmark $br(S)$ he is indifferent between stopping immediately and getting a zero payoff or incurring the cost of research and obtaining v_{HA} when the upper benchmark is reached.

At the upper benchmark, the tradeoff is more intricate since the cost of research now has the two components mentioned above: the direct cost and the cost of delaying the decision. Overall we find:

Proposition 2 *For a given lower benchmark s*

1. *the best response $BR(s)$ is independent of the current belief σ*
2. *the best response $BR(s)$ is decreasing in v_{HA}, v_{LA} and c.*
3. *the length of the research interval $l(s) = BR(s) - s$ is decreasing in s and converges to a finite value $\underline{l}$ when s converges to $-\infty$, where $\underline{l}$ is solution to $-v_{LA} = (e^{-g(l)} + 1)\frac{c}{r}$*

The first order condition characterizing the best response to a given value of s can be expressed in the following way (where $\alpha(s,S) > 0$, $\beta_2(s,S) > 0$ and $\gamma(s,S) > 0$)

$$\underbrace{-\gamma(s,S)\ v_{LA}}_{\text{benefit of information}} = \underbrace{\alpha(s,S)\ V_A(S)}_{\text{cost / benefit of delaying decision}} + \underbrace{\beta_2(s,S)\ c/r}_{\text{financial cost of research}} \tag{4}$$

.

For the interpretation of these conditions we distinguish between the case where $V_A(S) \geq 0$ (i.e $S > \hat{\sigma}$) and the case $V_A(S) < 0$. Consider the first case, that occurs when s is not too low. At the upper benchmark S the cost of research is composed of the direct financial cost and of the cost of delaying the decision, which is proportional to $V_A(S)$. Information has value since it can lead to avoiding the negative payoff v_{LA} if the state is in fact low. Condition (4) reflects this tradeoff between cost and value of information. In the second case, when s is very low, the tradeoff is different: for these values, it will be too costly in terms of expected cost of research, to choose a value of $S > \hat{\sigma}_p$. At the upper benchmark S, the player will thus incur a loss $V_A(S) < 0$. Research then has value to try since it can allow to reach the lower benchmark where a zero payoff can be obtained. Thus, in these cases, at the upper benchmark S the loss $V_A(S)$ has to be equal to the expected cost of research needed to reach the lower benchmark.

Finally, result 2.3 indicates that the length of the research interval decreases with s. As stated above, when s is small, the purpose of research at the upper benchmark S is to avoid incurring the loss $V_A(S)$ by performing research to reach s and get a zero payoff. When s is small, the loss is particularly large and furthermore, the expected time cost to reach s will be smaller, since there are more chances that the drift is negative. This property is represented in Figure 1. At the limit, l converges to a value $\underline{l}$ that depends only on $-v_{LA}$ and c/r. The intuition is similar to that of 2.3. The player is sure that the state is bad and at $BR(s)$, he is indifferent between getting the sure loss $-v_{LA}$ and searching in the hope of reaching the lower benchmark, with a cost proportional to c/r.

These best responses are a natural building block for the rest of our argument. If the same player was making both the research and approval decisions, his optimal choice (s_i^*, S_i^*) would be characterized by the intersection of the best response curves. However in practice these decisions are typically made by different agents and these strategic interactions are the focus of our paper.

To clarify the exposition of the rest of the paper, we add more structure on how the preferences of agent and principal are misaligned. We will focus on the leading case where the agent does not bear the entire social cost of a wrongful adoption, so that the payoffs of adoption in the low state satisfy $v_{LA}^a > v_{LA}^p$. For instance, in the application to drug approval the key concern is that the pharmaceutical company does not fully compensate patients who suffer from taking an unsafe drug because of the difficulty in identifying these individuals and the company's ability to shelter from liability (the judgement proofness problem). According to the previous comparative statics, this implies that the agent prefers to stop earlier at the upper end but to conduct more research at the lower end.

The comparison in the high state is less obvious. It seems reasonable to think that $v_{HA}^a > v_{HA}^p$, i.e.., that the submitter has more at stake than society at large. For instance an author that has a paper accepted gets the full private benefits from that decision, but does not take into account the negative externality he imposes on other authors. In the case of a private firm conducting research, this can be less obvious. Indeed, it is often thought that a firm cannot capture the full social benefit from an innovation; see for instance Bloom, Schankerman, and Van Reenen (2012). Of course the factor mentioned above, that goes in the other direction, is still present: the firm that innovates, in the case of non radical innovations, takes some profits away from the current market leader, an effect typically not internalized. Our results for the leading case hold provided the externality associated to adoption in the high state is either negative or positive but lower than the negative externality associated to adoption in the low state: $v_{HA}^a + v_{LA}^a > v_{HA}^p + v_{LA}^p$.[9]

Given this type of conflict in preference, the bliss point of the principal (s_p^*, S_p^*) and of the agent (s_a^*, S_a^*) are such that the agent conducts more search at the lower end $s_a^* < s_p^*$ and less search at the upper end $S_a^* < S_p^*$ as represented in Figure 2. One property is notable and will

[9] There is an additional factor specific to the pharmaceutical industry that can push v_{HA}^a above v_{HA}^p. Given drug users typically do not pay directly but are reimbursed, pharmaceutical companies might be able to obtain private benefits higher than social benefits.

prove useful in the rest of the paper: the bliss point corresponds to the maximum of the upper best response and the minimum of the lower best response.

4 Approval Regulation

In practice, in all the applications we have in mind, the same player does not control the full research process and at the same time make the approval decision. As described in section 2, in the case of drug regulation, separating these roles was precisely the purpose of the 1938 law, that introduced an approval requirement before marketing.

A natural way of thinking of the effects of such a relatively weak regulation is that the firm conducts research and, at some point submits the evidence to the principal who, based on the evidence, makes a decision to approve or wait. The 1938 law did not give the principal power to mandate further research. Thus, in a subgame perfect equilibrium, the principal approves any drug when the evidence is above σ_p (i.e. any evidence that gives the principal a positive expected benefit). With small conflicts of interest ($v_{LA}^a \cong v_{LA}^p$), the research interval is then the first best of the agent, (s_a^*, S_a^*). With intermediate conflict of interest s.t. $B_a(b_a(\hat{\sigma}_p)) < \hat{\sigma}_p$, the agent searches in $(b_a(\hat{\sigma}_p), \hat{\sigma}_p)$. While with large conflict of interest such that $\hat{\sigma}_p > \bar{S}$ defined as the lowest S above $\hat{\sigma}_p$ such that $S = b_a(S)$, agent does not do any research.

The 1962 Amendments gave the further power to the principal to mandate research. We examine in Section 4.1, how this extra power affects the outcome of the game. We then show in Section 4.2 that committing ex ante to an approval standard can improve the payoff of the designer. This was not the path chosen by the lawmakers, who instead chose to organize the regulation as a sequential process that we examine in Section 4.3. Throughout this section we will maintain the assumption that the regulator cannot misreport the information he obtains, an assumption we relax in Section 5.

4.1 Nash Equilibrium

The effect of granting the principal the power to mandate research (as in the 1962 Amendments) in her interaction with an agent who initiated the research process, is naturally captured by the following baseline model. In each period t, agent and principal move *sequentially*. First, the agent chooses between three actions research $\mathcal{R}^a$, submit $\mathcal{S}^a$ or wait/withdraw $\mathcal{W}^a$. Second, if the agent submits $\mathcal{S}^a$, the principal chooses between research $\mathcal{R}^p$, approve $\mathcal{A}^p$ or wait $\mathcal{W}^p$. Research is the period's outcome if either the agents chooses research $\mathcal{R}^a$ or the agent chooses submit S^a and the principal chooses research $\mathcal{R}^p$ (in that sense the principal can mandate research). Approval A is the period's outcome if the agent chooses $\mathcal{S}^a$ and the principal $\mathcal{A}^p$. Finally withdrawal W is the period's outcome if the agent chooses $\mathcal{W}^a$ or the agent chooses to submit $\mathcal{S}^a$ and the principal chooses $\mathcal{W}$.

We assume that the cost of research enters symmetrically in the agent's and principal's utilities regardless of who conducts the research. In the case of the FDA, the principal can mandate research but integrates this research cost in her welfare function, since these costs reflect the costs to patients. We show in the appendix that the outcome of all Markov Perfect Equilibria of the game above, with σ as the state variable, correspond to what we call the Nash equilibrium solution and denote (s_N, S_N). This equilibrium is at the intersection of the best response curve of the agent to the upper benchmark $br_a(S)$ and the best response curve of the principal to the lower one $BR_p(s)$. In other words, in this setting, the principal controls the upper standard S while the agent controls the lower standard s. We have:

Proposition 3 *There exists a unique Nash equilibrium such that:*

1. *the principal conducts less search at the upper end and the agent less search at the lower end:* $S_a^* < S_N < S_p^*$ *and* $s_p^* > s_N > s_a^*$*;*
2. *the length of the research interval is larger than for the stand-alone problems:* $S_N - s_N > max(S_p^* - s_p^*, S_a^* - s_a^*)$.

The strategic interaction between the agent and the principal of course affects the research decision compared to the non strategic benchmark. These changes can be decomposed in two effects. First, there is an effect on the extensive margin: the range of values of σ for which research is conducted changes. Second, there is an effect on the intensive margin: the length of the research interval is affected.

Result 3.1 above refers to the *extensive margin*. Compared to the principal's first best, in the Nash solution, more research is conducted at the lower end and less at the upper end. The logic of the result is clear. Since both the agent and the principal now control only one benchmark, the value of information is decreased: the principal conducts less research at the upper end and the agent less research at the lower end then in their respective stand-alone problems. These ideas are illustrated in Figure 1. The solid lines correspond to the best response S^* to a given s and the dotted ones to the best response s^* to a given S. The equilibrium (s_N, S_N) is at the

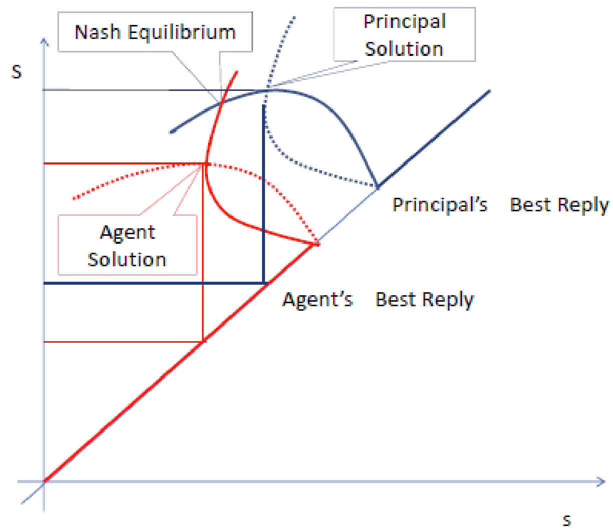


Figure 1: Best replies, the Nash equilibrium, the commitment solution, and comparison with the principal's and the agent's unconstrained solutions.

intersection of the lower best response curve $br_a(S)$ of the agent and the upper best response curve of the principal $BR_p(s)$. The figure illustrates the fact that $S_N < S_p^*$ and $s_N > s_a^*$. Indeed, as the lower benchmark s moves away from s_p^*, the principal's best response decreases (S_p^* being the maximal value), since the value of information is decreasing.

Result 3.2 above refers to the *intensive margin*. Surprisingly, introducing strategic interactions increases the intensity of research (the length of the research interval is increased). This runs contrary to the classical intuition that tends to find the opposite effect (for instance Strulovici 2010). To understand this result, consider the agent's problem. The principal conducts more research at the upper end than the agent would like him to do ($S_N > S_a^*$). Thus, when the agent considers the choice of the lower benchmark, expressed in equation (3), his incentives to search are higher: if he reaches the upper benchmark, he gets a higher value ($V_A(S_N) > V_A(S_a^*)$) and moreover he reaches it faster in expectation since the belief that the state is H is higher for larger values of S. These two effects (underlying the result of Proposition 1.3) imply that the search interval is larger $S_N - s_N > S_a^* - s_a^*$.[10].

We now discuss the payoff of the principal and the agent in the Nash Equilibrium solution. These values are plotted as a function of σ in Figure 1. The key message is that the utility of the principal can be negative at the Nash equilibrium solution. Consider a belief $s_N < \sigma < s_p^*$: if the

[10] A similar logic leads to the result $S_N - s_N > S_p^* - s_p^*$.

principal was picking both benchmarks alone, he would not be able to obtain a positive utility and he would thus choose $s_p > \sigma$, in other words immediate rejection, to guarantee himself a zero payoff. In the Nash equilibrium solution, this is not an option since the agent controls the lower payoff and actually sets it below σ.

Proposition 4 *At the unique Nash equilibrium:*

- *the agent gets a positive payoff for all values of* σ
- *the principal gets a negative payoff for* $\sigma \in [s_N, br_p(S_N)]$,

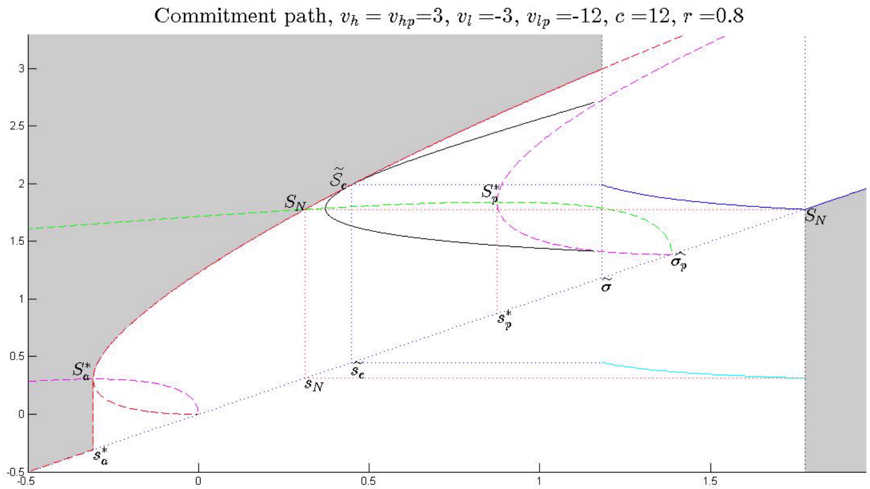
In practice, it seems natural that the principal would try to achieve a higher payoff by committing ex ante to a certain behavior. The most natural form of commitment, that we consider in the next section, would be to commit ex ante to a certain standard of approval. As highlighted in section 2, this was not the approach chosen in the 1962 Amendments, who chose rather weak legal language in terms of standards. The legislator chose rather to commit to perform the evaluation in a predefined number of rounds, something we consider in section 4.3.

4.2 Commitment: Stackelberg Solution

We study in this section the case where the principal has the ability to commit to an approval standard that depends only on the current state of knowledge (and not on the path or time taken to get there). Clearly, if the principal could commit to an approval rule that could be conditioned on the entire path, the principal would be able to obtain the unconstrained optimal solution $\left(s_p^*, S_p^*\right)$. Such commitment, however, might be difficult to achieve in practice so we consider a simpler and more realistic commitment to approval rules that depend only on the current state of knowledge σ with the following cutoff form: approve if and only if $\sigma \geq \mathcal{S}_C$. This is the type of commitment, although weak, that was introduced in the 1962 law with the terms "significant evidence".

We now characterize the path of the commitment solution; see Figure 4.2. Dynamic consistency no longer applies: the optimal choice of commitment by the principal depends on the initial belief σ as described in the following result. We use the notation $\overline{br}_a^{-1}$ for the upper inverse function constructed by inverting br_a for $S > S_a^*$.

Proposition 5 *In the Stackelberg equilibrium with commitment by the principal, there exist beliefs* $\tilde{\sigma} \in (s_p^*, \widehat{\sigma}_p)$ *such that, if the conflict of interest is not too large, i.e* $S_N > \widehat{\sigma}_p$*:*



1. *If the initial belief σ is such that $\sigma < \tilde{\sigma}$, the principal chooses a* ***blocking commitment*** *inducing no research:*

   - *If $\sigma \leq s_a^*$, any commitment above σ is part of an equilibrium: $\mathcal{S}_c(\sigma) \in (\sigma, +\infty)$;*
   - *If $s_a^* < \sigma < \tilde{\sigma}$, any commitment above $\overline{br}_a^{-1}(\sigma)$ is part of an equilibrium: $\mathcal{S}_c(\sigma) \in (\overline{br}_a^{-1}(\sigma), +\infty)$.*

2. *If $\sigma \in (\tilde{\sigma}, S_N)$, the principal chooses an* ***interior commitment*** *$\mathcal{S}_c(\sigma)$ decreasing in σ. There is a discontinuity in commitment at $\tilde{\sigma}$: $\mathcal{S}_c(\tilde{\sigma}) < \overline{br}_a^{-1}(\tilde{\sigma})$.*

3. *If $\sigma > S_N$, the principal chooses an* ***approval commitment*** *$\mathcal{S}_c(\sigma) \leq \sigma$.*

If the conflict of interest is large ($S_N \leq \widehat{\sigma}_p$), then if $\sigma \leq \widehat{\sigma}_p$, the principal chooses a blocking commitment and if $\sigma > \widehat{\sigma}_p$, he chooses immediate approval.

For low values of the initial belief σ, the optimal commitment is what we call a **blocking commitment**: the principal commits to an upper benchmark that induces the agent to do no research. If $\sigma \leq s_a^*$, the initial belief is so low that even the agent would not want to do any research, regardless of the commitment. For σ slightly higher, the commitment to be blocking, i.e induce the agent to do no research, needs to be above $\overline{br}_a^{-1}(\sigma)$ (by definition of $br_a(S)$). Note that this minimum blocking commitment is an increasing function of σ.

When the initial belief σ, starts to be sufficiently favorable, blocking research by the agent by committing to rejection becomes too costly and there is a preferable **interior commitment**.

This happens at belief $\tilde{\sigma}$, which is the belief at which the zero iso-utility curve of the principal is tangent to the lower best response curve of the agent: if the principal chose his preferred point on the best response curve of the agent $\overline{br}_a^{-1}(\tilde{\sigma})$, he would get a zero utility and he is thus indifferent. If the belief is above that value, an interior commitment is strictly preferable. At this point there is a discontinuity in the commitment: there is a discrete downwards jump from a blocking commitment to the optimal interior commitment.

Proposition 5, indicates that the value $\tilde{\sigma}$ is above s_p^*. Intuitively, for beliefs lower than s_p^*, the principal cannot obtain a positive utility even when in full control; a fortiori, $\tilde{\sigma}$, the lowest σ at which the principal can only obtain a zero utility when the agent controls the lower standard must be above s_p^*. [In addition, at $\sigma = br_p(S_N)$, the principal obtains a zero payoff at the Nash equilibrium solution and could do strictly better by committing to a different point on the agent's lower best response curve. The belief for which the principal is indifferent between interior commitment and the blocking commitment (yielding zero payoff) thus has to occur earlier.]

The fact that interior commitment is strictly above S_N for $\sigma \in (\tilde{\sigma}, S_N)$ reflects the tradeoff between two effects:

- *A second-order negative direct effect:* Holding fixed the agent's strategy s, an excessive amount of research is induced at the upper end, which induces a loss for the principal. This loss is clearly second order by the envelope theorem because we start from the principal's optimal choice of S holding fixed the agent's choice of s.

- *A first-order positive strategic effect:* The agent's strategic response of the increase in S is to increase s given that the agent's best reply is upward sloping in the relevant range—strategies are strategic complements in the terminology of Bulow, Geanakoplos, and Klemperer (1985). Intuitively, the increased loss of control at the upper end further reduces the agent's value of information at the lower end. Given that the agent's choice of s at the lower end was originally lower than the principal would have liked, this increase in s benefits the principal. This is first-order effect because the envelope theorem does not apply given that the agent, not the principal, chooses s.

As we show, an increase in σ increases the direct effect and reduces the strategic effect. Thus, as the optimal interior commitment decreases in σ. At $\sigma = S_N$ the strategic effect becomes zero, and commitment has e negative value for $\sigma > S_N$. When the initial belief σ is very high, the optimal choice for the principal is to chose immediate approval, what we call an **approval**

commitment. This occurs for beliefs below S_p^* (the point where the principal would chose immediate approval if in full control), since the principal cannot control the upper benchmark. In fact, as indicated in Proposition 5, for beliefs above S_N immediate approval is optimal.

In terms of welfare, it is clear that the principal can always do weakly better by committing. In fact, the following proposition indicates that she does strictly better whenever the initial belief is in (s_a^*, S_N). This result naturally follows from the previous discussion. First, the blocking commitment is chosen for beliefs where the Nash equilibrium gives negative utility to the principal, so that commitment is strictly preferable. Second, when an interior commitment is chosen, the principal's optimal commitment is strictly above S_N indicating that a better commitment exists.

Proposition 6 *In the Stackelberg equilibrium, the principal's payoff is:*

- *weakly higher than the payoff in the Nash equilibrium for all values of σ;*
- *strictly higher for $\sigma \in (s_a^*, S_N)$.*

The final essential consideration is the effect of commitment on both the extensive and intensive margins of research discussed in the previous sections.

Proposition 7 *In the Stackelberg equilibrium:*

- *The extensive margin of research is decreased compared to the outcome in the stand-alone principal solution: $(\tilde{\sigma}, S_N) \subset (s_p^*, S_p^*)$.*
- *The intensive margin of research is increased compared to both the Nash Equilibrium and the stand-alone principal outcomes: for $\sigma \in (\tilde{\sigma}, S_N)$, $S_c - br_a(S_c) > max(S_N - s_N), S_p^* - s_p^*)$.*

Proposition 7 suggests that, in the Stackelberg solution, there are less instances where some research is conducted, but for the values where this is the case, more research will be performed. There are two instances where no research is performed in the Stackelberg solution: for low values of σ, the principal chooses a blocking commitment and for high values he induces immediate approval. The first result is then due to the fact that the principal, since he does not control the lower benchmark, wants to prevent research for more values of σ. The second result echoes the result on the extensive margin for the Nash outcome: for beliefs such that research is conducted, more research will be performed.

4.3 Commitment: Sequential Research

In practice a commitment is not always easy to achieve. In fact, as stated earlier, the 1962 law explicitly chose not to commit to a strict standard. As suggested in the previous section, one of the main reason could be that the optimal level of commitment is specific to the baseline state of knowledge, which can vary across types of drugs, and thus there is no uniform standard that can be applied. Of course, the close interaction between the firm and the regulator could allow for individualized commitments, but even those are not easy to credibly make. A different way of committing is in the way research is organized. Often the communication between the agent and the principal is organized in a number of rounds. This was the approach chosen by the 1962 law that organized the interaction between the firm and the regulator in a well defined series of clinical trials.

We consider in this section a model where the interaction is organized in two rounds of indefinite length. First the agent conducts research and at some point decides to transfer this information to the principal. The principal then decides how much additional research to perform before making the approval decision.[11] We maintain the assumption that the agent cares about the research cost of the principal. This assumption is sensible in the application to the FDA that can mandate research. It is less so for other applications and we consider those in section 7. We denote (s_{seq}, S_{seq}) the choice of the agent, where *seq* stands for sequential.

When the agent submits the information to the principal, the principal performs research and makes the approval decision as in the stand-alone case since there will be no more interaction with the agent: the principal will then perform research if $\sigma \in (s_p^*, S_p^*)$. Thus the agent will never want submit before S_p^* is reached because the agent bears the full research cost regardless of who performs the research but would lose from submitting to the principal before S_p^* is reached because then principal would carry too little research at the lower end in the eyes of the agent. Furthermore, at the lower end the agent chooses the best response to S_p^*: $s_{seq} = br_a(S_p^*)$. These results are summarized in the following proposition:

Proposition 8 *In the sequential problem:*

1. *In equilibrium the agent conducts research whenever σ is in $(br_a(S_p^*), S_p^*)$, abandons for lower values and submits the evidence for higher ones*

[11] In most applications, there could be additional round but we will focus on the one round case without loss of generality of the message.

2. *If $\sigma \in (s_N, \tilde{\sigma})$, the principal obtains a higher payoff in the sequential than in the Nash equlibrium*

3. *If $\sigma \in (\hat{\sigma}, S_p^*)$, the principal obtains a higher payoff in the Nash equlibrium than in the sequential*

4. *The length of the research interval is larger in the sequential than in the Nash or in the stand-alone problems*

The Nash equilibrium, the Stackelberg commitment solution considered in section 4.2 and the sequential research procedure correspond each to a different point on the best response curve of the agent, $br_a(S)$. Clearly, the Stackelberg point results in highest expected payoff for the principal. Results 8.2 and 8.3, indicate that the comparison between the Nash and sequential outcomes is potentially ambiguous. This suggests that the type of commitment put in place through the 1962 law was not necessarily welfare enhancing, in particular in cases where the initial belief is quite favorable as in 8.3.

Does the principal prefer the Nash equilibrium outcome or the sequential research outcome? Compared to the Nash equilibrium, the sequential procedure results in more research at the top and less research at the bottom. The principal is not necessarily better off, as illustrated in Figure 2. On the one hand, the principal benefits from reduction of s and increase in S along p's $BR_p(s)$; the movement toward North-East along $BR_p(s)$ from (s_N, S_N) to $(br_a(S_p), BR_p(br_a(S_p)))$ increases the principal's expected payoff. On the other hand, the principal loses for additional increase in S; the upward movement from $(br_a(S_p), BR_p(br_a(S_p)))$ to $(br_a(S_p), S_p)$ results in a reduction in the principal's expected payoff. The dashed indifference curve corresponds to a setting in which the principal prefers the sequential solution to the Nash equilibrium; the opposite ranking holds with the continuous indifference curve. As can be seen graphically, a sufficient condition for the principal to prefer the sequential solution to be Nash equilibrium is that $\mathcal{S}_C > S_p^* = S_{seq}$; otherwise the ranking is ambiguous.

In the region where the blocking commitment is the optimal Stackelberg commitment ($\sigma \in (s_N, \tilde{\sigma})$), the principal prefers sequential commitment to the Nash outcome because sequential commitment results in the same outcome as the Stackelberg commitment in some cases and limits the amount of research performed in others. When instead $\sigma \in (\bar{\sigma}, S_p^*)$, the optimal commitment is to approve immediately and this is also the outcome with the Nash solution, whereas additional research is performed under the sequential commitment thus leading to a lower payoff for the

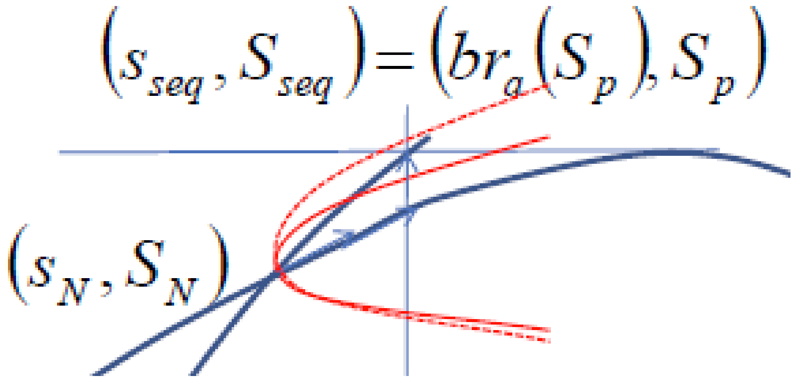


Figure 2: Welfare comparison between the Nash solution and sequential research.

principal.

5 Misrepresentation of Information

The new phase of regulation has started focusing on the regulation of the disclosure of clinical trial results. The alleged withholding of negative results by pharmaceutical companies in the recent cases of Vioxx (an anti-inflammatory drug proven to increase the risk of cardiovascular events) or Paxil (an anti-depressant that could increase the suicide rates among children) generated major uproar and large demands for compensation.

Withholding information has a potential cost for the firm itself: in the case of Vioxx, Merck paid over 4.85 billion dollars for settling individual complaints from patients. In 2011, it agreed to plead guilty and pay 950 million to the federal government to settle the criminal and civil charges filed against it. These costs seem to be an increasing function of the size of the misrepresentation. It is because Merck was shown to have withheld evidence that the penalties were of that magnitude. A larger lie makes it easier for the plaintiffs to win their case in court.

To capture such situations, we enrich the model and assume that the agent who collects the evidence can misreport it at no cost.[12] However, if the state turns out to be low the agent expects a fine F. The probability of obtaining this sentence depends on the size of the misreporting. If the agent has collected evidence showing that the state is σ and conveys information σ' the probability of being convicted is given by $P(\sigma - \sigma')$ and we denote the overall expected sentence $C(\sigma - \sigma') = F * P(\sigma - \sigma')$ where C (i.e.., P) is increasing and $C(0) = C'(0) = 0$.

[12] In our model, evidence comes in infinitesimal amounts so that the agent can for any state, always hide a sufficient quantity of negative results to be able to present verifiable evidence consistent with that state.

We concentrate on the commitment case as in Section 4.2 where the principal can commit to an approval standard, that we denote $\mathcal{S}_M$ (M stands for withholding). The rule is thus: "approve if and only if the reported evidence is above $\mathcal{S}_M$". In this setting, the agent is in full control of both extremities of the search interval, but the agent expects a lower value when deciding to stop at a belief $\sigma < \mathcal{S}_M$ provided that the state turns our to be low.

Two limit cases are of special interest. When $F = +\infty$ we are back to the commitment case of section 4.2 where truthful reporting was assumed, (s_C, S_C). When $F = 0$, the agent's stand-alone solution of Section 3 results, (s_a^*, S_a^*). However nothing refrains the principal from choosing intermediate values of F. He now has two instruments available that are indeed used in practice: the fine F imposed for misreporting and the standard for acceptance $\mathcal{S}_M$.

In the context where F takes intermediate values, the cost of lying has two effects on research:

- The cost of lying weakly decreases the payoff from approval and thus affects research at both ends.
- The cost of lying creates an additional incentive to conduct more research at the upper end, to accumulate further positive evidence in order to decrease the expected fine.

We show in the following results that this modified research problem has a unique solution (s_M, S_M), which are the lower and upper benchmark of the search interval chosen by the agent when the principal sets a standard for acceptance $\mathcal{S}_M$. In other words, there is full information revelation in equilibrium. The agent will lie but the principal will know exactly the state at which search was stopped. Sequential search is key for this result—if, instead, the agent was just observing the state and reporting, different types would pool on the same report given the binary decision made by the principal.

Proposition 9 *With private information and misreporting, there is a unique solution (s_M, S_M) such that the agent conducts research if and only if $\sigma \in (s_M, S_M)$ and such that, if $\mathcal{S}_M > S_a^*$, lying occurs in equilibrium, i.e the agent chooses an upper benchmark of search strictly lower than the standard for acceptance: $S_M < \mathcal{S}_M$.*

Proposition 9 indicates that there will always be lying in equilibrium. The intuition is that the marginal cost of lying when the report is close to the truth is zero while the added value of getting more information is strictly negative since the standard set by the principal is greater than the optimal upper benchmark of the agent ($\mathcal{S}_M > S_a^*$). Thus the agent prefers to stop a bit earlier and incur the expected lying cost.

We now examine the modified best responses in this case. For the lower benchmark, the best reply to S is characterized by a condition identical to condition (3),

$$\underbrace{V_A(S)}_{\text{benefit of gaining more information}} = \underbrace{\beta_1(s,S)\ c/r}_{\text{financial cost of research}},$$

except that the value V_A upon stopping is given by

$$V_A(S) = \frac{e^S}{1+e^S} v_{HA} + \frac{1}{1+e^S}\left(v_{LA} - C(\mathcal{S}_M - S)\right).$$

Clearly, for given values of S less than $\mathcal{S}_M$ the agent will search less at the lower end than he would in the absence of misreporting since his value in case the state turns out to be bad will be lower due to the expected penalty. It thus decreases the value of information which is proportional to V_A.

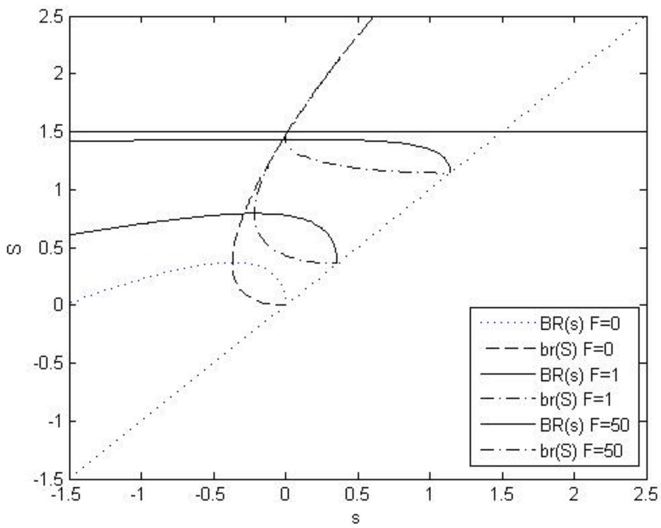
For the best response to s, there is an additional effect: searching more provides evidence that directly decreases the expected cost in case the state is in fact low. The first order condition is

$$\underbrace{-\gamma(s,S)\ \left(v_{LA} - C(\mathcal{S}_M - S)\right)}_{\text{benefit of information}} - \underbrace{\gamma(s,S)\ C'(\mathcal{S}_M - S)}_{\text{value of evidence}} = \underbrace{\alpha(s,S)\ V_A}_{\text{cost of delaying decision}} + \underbrace{\beta_2(s,S)\ c/r}_{\text{financial cost of research}}.$$

At the upper benchmark three factors push the agent to do more research than in the stand-alone problem:

- The value of information (proportional to $-v_{LA} + C(\mathcal{S}_M - S)$) increases since there is a higher cost to avoid in case the state is shown to be low.
- The cost of delaying the decision, proportional to V_A is smaller.
- There is a value of collecting evidence (independent of the value of information), proportional to $-C'(\mathcal{S}_M - S)$, this extra evidence making a court case less likely.

We can now use this best response analysis to compare the welfare of the principal in this case compared to the commitment case studied in Section 4.2. Note that the commitment case with no misreporting is equivalent to this model with an infinite penalty. The question we therefore address is the following: *Should penalties be in fact limited?*



In Section 4.2 we characterized the optimal commitment of the principal S_C in the case of no misreporting, i.e.., the principal's preferred point on the agent's best response $br_a(S)$. In what follows, we focus on the case of interior commitment, i.e according to Proposition 5, the case where the initial belief σ is such that $\sigma \in (\tilde{\sigma}, \overline{\sigma})$.[13] The first thing to note is that in the case of limited penalties, the principal can always choose a large value of $\mathcal{S}_M > S_C$ such that the agent chooses in equilibrium the upper benchmark of search to be S_C. Indeed, for any value of s the best response $BR_a(s)$ is an increasing function of $\mathcal{S}_M$. So $\mathcal{S}_M$ can be chosen so as to induce the agent to do the same amount of research at the upper end as in the commitment case analyzed in Section 4.2. However in this case with misreporting, the agent will also search less at the lower end for the reasons outlined above. If this extra research is not excessive, this will be beneficial for the principal:

Proposition 10 *For $\sigma \in (\tilde{\sigma}, \overline{\sigma})$, the principal can always find a combination of instruments $(F, \mathcal{S}_M)$ with $F < +\infty$ that results in a strictly higher expected payoff than in the commitment case without misreporting.*

Proposition 10 indicates that it is optimal in equilibrium to allow some misreporting. Misreporting induces the agent to conduct less excessive research at the lower end. The intuition is presented in Figure 9.

[13] In the case where without misreporting the optimal commitment is a blocking commitment, this can also be obtained with misreporting.

6 Post-Approval Regulation

After the approval of the drug by the regulator, the drug is prescribed to patients and further information is thus accumulated on a large scale. If very bad information is accumulated, the principal can decide to order a withdrawal of the drug. However, this information accumulation strongly depends on the monitoring effort of the principal.[14] In practice, it appears that the monitoring effort of the FDA in the United States is rather weak: for instance there is no central recording system of all adverse effects. The FDA intervenes only in the case where litigation starts for serious injuries due to the drug.

We thus extend our model to this setting and it further demonstrates the flexibility and applicability of our setup. We assume that while the drug is on the market, the regulator obtains a flow benefit w and the firm a flow profit π. However, if the state is in fact low, at some point in time very serious adverse effects will occur. We assume that the players then gets a negative payoff $-P_i$ (where $i \in a, p$) whose arrival time is distributed according to an exponential distribution of parameter λ. Furthermore we assume that P_i is large enough so that if the regulator is sure the state is bad, he will immediately withdraw (condition formally stated below).

Initially, before the start of the game, the principal chooses how closely he will monitor the drug post approval. Specifically, we assume he chooses a costless monitoring effort e.[15] Given a choice of e, post approval, there is a probability $\phi(e)$ that principal obtains further information. In this case he chooses a benchmark of withdrawal W. With probability $1 - \phi(e)$, no further information is collected.

The timing of the game is therefore:

1. The principal chooses e at no cost
2. The agent and the principal simultaneously choose s and S (Nash equilibrium as in Section 4.1)
3. If the decision is to approve, with probability $\phi(e)$ further information is obtained and the principal chooses the withdrawal benchmark W

Stage 2 is unchanged compared to the Nash Equilibrium resolution of section 4.1. However, the addition of stage 3 puts structure on the payoffs in the different states (v_{LA} and v_{HA}):

[14] It also depends on the amount of sales, something that could also give rise to a different extension of our model.

[15] In the case of the FDA, this corresponds to setting up a central system to collect information on adverse effects.

- If there is no additional information accumulated post approval (probability $1-\phi(e)$), the agent and the principal have no decision to make, they just collect benefits and potentially suffer from penalties. If the state is high, the principal obtains $\frac{w}{r}$ and the agent $\frac{\pi}{r}$. If the state is low, they collect these benefits until the adverse effect arises: the principal obtains $\frac{w}{r}-\frac{\lambda}{\lambda+r}(w+P_p)$ and the agent obtains $\frac{\pi}{r}-\frac{\lambda}{\lambda+r}(\pi+P_a)$

- If additional information is accumulated (probability $\phi(e)$), the principal has to choose W the withdrawal benchmark. In the bad state, benefits will be obtained up to the point where either the belief reaches the withdrawal benchmark W or the adverse shock occurs leading to withdrawal. In the good state, benefits will be continuously obtained unless the belief reaches the withdrawal benchmark W

Given the choice of W we denote $f_L(t|\sigma)$ (resp. $f_H(t|\sigma)$) the distribution of the first time the belief reaches the withdrawal benchmark $W<S$ for a belief σ. The distribution $f_L(t|\sigma)$ is an inverse Gaussian of parameters $(\frac{\sigma-W}{\mu'},\frac{(\sigma-W)^2}{\rho'^2})$.[16]

Conditional on the low state, the expected benefit of the principal for a choice of W at belief σ is

$$\begin{aligned}
&v_{LA}(W)\\
=\;&\int_0^{+\infty}\lambda e^{-\lambda t}\left[\int_0^t \tfrac{1-e^{-rT}}{r} w f_L(T|\sigma,W)dT+\int_t^{+\infty}\left(\tfrac{1-e^{-rt}}{r}w-P_pe^{-rt}\right)f_L(T|\sigma,W)dT\right]dt\\
=\;&\tfrac{w}{r}-(\tfrac{w}{r}+P_p)\int_0^{+\infty}\lambda e^{-(\lambda+r)t}P[T>t|W]-\int_0^{+\infty}\lambda e^{-\lambda t}\left(\int_0^t\tfrac{e^{-rT}}{r}wf_L(T|\sigma,W)dT\right)dt
\end{aligned}\tag{5}$$

When the state is high, this is

$$v_{HA}(W)=\int_0^{+\infty}\frac{1-e^{-rT}}{r}wf_H(T|\sigma,W)dT=\frac{w}{r}-\int_0^{+\infty}\frac{e^{-rT}}{r}wf_H(T|\sigma,W)dTdt. \tag{6}$$

If the state is low, there are two countervailing effects of an increase in W: it decreases the chance of getting the penalty but increases the expected flow of benefits w obtained. If the penalty is large enough, the first effect dominates and v_{LA} increases in W. If the state is high, an increase in W unambiguously decreases the expected payoff v_{HA}. Thus, if the belief becomes sufficiently negative, the regulator has an incentive to withdraw:

Proposition 11 *In the three stage game with post approval, there exists a value $\overline{P}$ such that, if $P_i>\overline{P}$:*

[16] Distribution of the first time a Brownian motion hits a particular value

- *the principal imposes a withdrawal benchmark $W > -\infty$ and achieves a strictly higher payoff than when no information is obtained.*

- *the agent's lower best response and the principal's upper best responses are decreasing in e.*

When the penalty is high, choosing partial monitoring, i.e. picking a low value of e, is a way for the principal to decrease the value obtained when the state is bad v_{LA} and thus to commit to perform more research at the upper end. It also forces the agent to do less at the lower end. This could explain the behavior of the FDA that chooses not to have a systematic review of post approval evidence.

7 Other Applications: Research with Private Costs

Our model can be extended to analyze a wide range of situations involving an agent initiating research and a principal making approval decisions. As discussed in the introduction, most relevant are the cases of an author trying to convince an editor, firms wanting to merge trying to influence the antitrust authority or a manager trying to push his project at the headquarters. This section extends the model to address these applications.

Throughout the previous sections, we maintained the assumption that both the principal and the agent cared about the full cost of the research, even if the other party was performing it. It was natural in the case of drug approval: the firms conduct the research (since the regulator can mandate it) and thus care about the cost and the regulator also cares as a social planner. In the applications discussed above, instead, the agent does not typically bear the cost of the research undertaken by the principal.

Of course, it is always possible for the principal to charge the agent for the cost of his research. For instance the competition authority could charge a fee proportional to the number of staff members it puts on a particular case, or the firm headquarters could ask the manager to pay a fee for examination of the case. However, it does not seem to be the approach taken in most applications. We examine in this section, under what conditions it is optimal for the principal to charge the agent for the additional research.

We place ourselves in the context of the sequential two stage game considered in section 4.3. A different interpretation of the setting considered in that section is that it corresponds to the case where the agent has to pay for the principal's research cost. We are now going to derive the other polar case.

The first thing to note is that, regardless of whether the agent pays or not for his research effort, once he transfers the information, the behavior of the principal will be identical: after the agent's report is received, if the report of the agent is in the interval (s_p^*, S_p^*), the principal will conduct additional research using these stopping times (s_p^* and S_p^*).[17]

Denoting $(\widehat{s}^{seq}, \widehat{S}^{seq})$ the agent's search interval when he does not pay for the principal's research ((s^{seq}, S^{seq}) is the analogous interval in the case where he does pay, derived in section 4.3), we see that from the principal's point of view, the welfare benefits from charging for the principal's research, will only depend on the difference between $\widehat{s}^{seq}$ and s_{seq} since at the upper end the final outcome will be identical (search will be conducted until S_p^*). We obtain the following result that shows that it is not necessarily optimal for the agent to charge for his research:

Proposition 12 *It is optimal for the principal to charge for his research if and only if* $\frac{-v_{LA}}{v_{HA}} < D_1(S_p^*, s_p^*)$.

In the case where the agent pays for the principal's research (case of section 4.3), the agent searches in the interval $(br(S_p^*), S_p^*)$. Indeed, he knows that if he stops searching before S_p^*, the principal will keep searching and he will run the risk that bad information arrives and the principal abandons the search inefficiently early since they do not agree on the lower benchmark of search. Since he pays in any case for the research, he has no incentive to stop before S_p^*.

As a reminder, in this case, the lower best response to S is characterized by:

$$\underbrace{V_A}_{\text{benefit of gaining more information}} = \underbrace{\beta_1(s,S)\ c/r}_{\text{financial cost of search}}$$

with

$$V_A = \frac{e^S}{1+e^S} v_{HA} + \frac{1}{1+e^S} v_{LA}$$

In the case where he does not pay, a tradeoff emerges: the agent might want to stop earlier to save on research costs even though he runs the risk that the principal stops early. When he stops at a belief $S < S_p^*$, the agent knows that the principal will conduct additional search and thus uncertainty remains. If the state is high, rather than expecting a payoff of v_{HA}, he expects $\Psi_p(S,H)v_{HA}$ that we denote v_{HS} and if the state is low, $\Psi_p(S,L)v_{LA}$ replaces v_{LA} that we denote v_{HS}, where $\Psi_p(S,I) < 1$ characterizes the expected time for the principal to reach his upper benchmark when the state is I.

[17] Given the result of Proposition 2, the boundaries of the principal's search interval will be independent of the report of the agent.

The first-order condition characterizing the best reply is then

$$\underbrace{V_H}_{\text{benefit of gaining more information}} = \underbrace{\beta_1(s,S)\ c/r}_{\text{financial cost of search}}$$

with

$$V_H = \frac{e^S}{1+e^S} v_{HS} + \frac{1}{1+e^S} v_{LS}$$

So it is the same condition as in the case with the fee except for the value of information (V_H rather than V_A). The key to result in Proposition 12 is that V_H can be lower (resp. higher than) V_A if $-v_{LA}$ is small (resp. large) compared to v_{HA}. The intuition is clear: the fact that the principal conducts more search has a negative impact if the state is high (delay good decision) and a positive one if the state is low (potentially avoid bad decision). If $-v_{LA}$ is large compared to v_{HA}, the positive impact outweighs the negative one and the agent would in fact search more.[18]

8 Conclusion

For the sake of concreteness, most of the paper focused on illustrating how our model sheds light on current and considered regulation of the drug approval process. Similar considerations are relevant for approval regulation in other areas, from competition and consumer policy to financial regulation. These applications are particularly relevant given the recent trend toward increased consumer protection and the move toward using the ex ante approval approach when regulating systemically important financial institutions.

Given its tractability, the model can be extended to address a number of other applications. In the case of managers proposing projects to the headquarters, it would be natural to consider competing agents. Considering an agent facing a sequence of principals would be a natural extension. For example, in the case of authors submitting papers, upon rejection in one journal, authors can submit to another outlet. In some applications, the cost of research might differ across players. It is worth revisiting the question of delegation of decision rights by the principal to the agent within this model.

[18] Note that reasoning on the lower best response functions is sufficient since, given the smooth pasting condition, the equilibrium in both the case with and without the fee will correspond to the maximum of the best reply.

9 Appendix

Proposition 1

We can rewrite the utility is the research area as

$$u(\sigma) = -\frac{c}{r} + \frac{1}{1+e^{\sigma}}\left\{e^{\sigma}\Psi(\sigma,H)\left[\left(v_{HA}+\frac{c}{r}\right)+e^{-S}\left(v_{LA}+\frac{c}{r}\right)\right]+\psi(\sigma,H)\frac{c}{r}\left(e^{\sigma-s}+e^{\sigma}\right)\right\}.$$

where, for a given process with mean μ and variance σ^2 and optimal stopping times s and S, standard results as in Stokey (2009) give

$$\Psi(\sigma,H) = \frac{e^{-R_1(\sigma-s)}-e^{-R_2(\sigma-s)}}{e^{-R_1(S-s)}-e^{-R_2(S-s)}} \tag{7}$$

$$\Psi(\sigma,L) = \frac{e^{R_2(\sigma-s)}-e^{R_1(\sigma-s)}}{e^{R_2(S-s)}-e^{R_1(S-s)}} \tag{8}$$

$$\psi(\sigma,L) = \frac{e^{-R_1(S-\sigma)}-e^{-R_2(S-\sigma)}}{e^{-R_1(S-s)}-e^{-R_2(S-s)}} \tag{9}$$

$$\psi(\sigma,H) = \frac{e^{R_2(S-\sigma)}-e^{R_1(S-\sigma)}}{e^{R_2(S-s)}-e^{R_1(S-s)}} \tag{10}$$

with $R_1 = \frac{1}{2}\left(1-\sqrt{1+\frac{4r}{\mu'}}\right)$ and $R_2 = \frac{1}{2}\left(1+\sqrt{1+\frac{4r}{\mu'}}\right)$. We can derive useful relations among these values using the fact $R_1+R_2=1$. We have

$$\begin{aligned}
\Psi(\sigma,L) &= \frac{e^{R_2(\sigma-s)}-e^{R_1(\sigma-s)}}{e^{R_2(S-s)}-e^{R_1(S-s)}} \\
&= \frac{1}{e^{(S-s)}}\frac{e^{R_2(\sigma-s)}-e^{R_1(\sigma-s)}}{e^{(R_2-1)(S-s)}-e^{(R_1-1)(S-s)}} \\
&= e^{-(S-s)}\frac{e^{R_2(\sigma-s)}-e^{R_1(\sigma-s)}}{e^{-R_1(S-s)}-e^{-R_2(S-s)}} \\
&= e^{\sigma-S}\frac{e^{-R_1(\sigma-s)}-e^{-R_2(\sigma-s)}}{e^{-R_1(S-s)}-e^{-R_2(S-s)}} \\
&= e^{\sigma-S}\Psi(\sigma,H)
\end{aligned}$$

and

$$\begin{aligned}
\psi(\sigma,L) =& \frac{e^{-(1-R_2)(S-\sigma)}-e^{-(1-R_1)(S-\sigma)}}{e^{-(1-R_2)(S-s)}-e^{-(1-R_1)(S-s)}} \\
=& \frac{e^{-S+\sigma+R_2(S-\sigma)}-e^{-S+\sigma+R_1(S-\sigma)}}{e^{-S+s+R_2(S-s)}-e^{-S+s+R_1(S-s)}} \\
=& \frac{e^{\sigma-S}}{e^{s-S}}\frac{e^{R_2(S-\sigma)}-e^{R_1(S-\sigma)}}{e^{R_2(S-s)}-e^{R_1(S-s)}} \\
=& e^{\sigma-s}\psi(\sigma,H).
\end{aligned}$$

We now determine the **best response to a given upper benchmark S.** The first order condition w.r.t. s is

$$\frac{\partial u}{\partial s} = \frac{e^{\sigma}}{1+e^{\sigma}}\frac{\partial \Psi}{\partial s}\left[\left(v_{HA}+\frac{c}{r}\right)+e^{-S}\left(v_{LA}+\frac{c}{r}\right)\right]+\frac{\partial \psi}{\partial s}\frac{c}{r}\frac{\left(e^{\sigma-s}+e^{\sigma}\right)}{1+e^{\sigma}}-\psi\frac{c}{r}\frac{e^{\sigma-s}}{1+e^{\sigma}}=0.$$

Substituting the expressions for $\partial\Psi/\partial s$

$$\begin{aligned}\frac{\partial \Psi}{\partial s} =&(R_1-R_2)\frac{\left[e^{-R_1(S-s)-R_2(\sigma-s)}-e^{-R_2(S-s)-R_1(\sigma-s)}\right]}{\left[e^{-R_1(S-s)}-e^{-R_2(S-s)}\right]^2}\\ =&(R_1-R_2)e^{s-\sigma}\frac{\left[e^{-R_1(S-\sigma)}-e^{-R_2(S-\sigma)}\right]}{\left[e^{-R_1(S-s)}-e^{-R_2(S-s)}\right]^2}\\ =&(R_1-R_2)e^{s-\sigma+\sigma-s}\frac{\psi}{\left[e^{-R_1(S-s)}-e^{-R_2(S-s)}\right]}\\ =&(R_1-R_2)\frac{\psi}{\left[e^{-R_1(S-s)}-e^{-R_2(S-s)}\right]}\end{aligned}$$

and for $\partial\psi/\partial s$

$$\begin{aligned}\frac{\partial \psi}{\partial s} =&-\frac{\left(-R_2e^{R_2(S-s)}+R_1e^{R_1(S-s)}\right)\left(e^{R_2(S-\sigma)}-e^{R_1(S-\sigma)}\right)}{\left[e^{R_2(S-s)}-e^{R_1(S-s)}\right]^2}\\ =&\frac{\left(R_2e^{R_2(S-s)}-R_1e^{R_1(S-s)}\right)}{e^{R_2(S-s)}-e^{R_1(S-s)}}\psi.\end{aligned}$$

we have

$$\begin{aligned}\frac{\partial u}{\partial s} &= \frac{e^{\sigma}}{1+e^{\sigma}}\frac{(R_1-R_2)\psi}{\left[e^{-R_1(S-s)}-e^{-R_2(S-s)}\right]}\left[\left(v_{HA}+\frac{c}{r}\right)+e^{-S}\left(v_{LA}+\frac{c}{r}\right)\right]\\ &+ \frac{\left(R_2e^{R_2(S-s)}-R_1e^{R_1(S-s)}\right)}{e^{R_2(S-s)}-e^{R_1(S-s)}}\psi\frac{c}{r}\frac{\left(e^{\sigma-s}+e^{\sigma}\right)}{1+e^{\sigma}}-\psi\frac{c}{r}\frac{e^{\sigma-s}}{1+e^{\sigma}}\end{aligned}$$

We can rewrite the first-order condition as

$$\frac{e^{\sigma+s-S}}{1+e^{\sigma}}\frac{(R_1-R_2)\psi}{\left(e^{-R_1(S-s)}-e^{-R_2(S-s)}\right)}$$
$$\left\{e^{S-s}\left(\left(v_{HA}+\frac{c}{r}\right)+e^{-S}\left(v_{LA}+\frac{c}{r}\right)\right)+\frac{\left(R_2e^{R_2(S-s)}-R_1e^{R_1(S-s)}\right)}{(R_1-R_2)}\frac{c}{r}\left(1+e^{-s}\right)-e^{-s}\frac{\left(e^{R_2(S-s)}-e^{R_1(S-s)}\right)}{(R_1-R_2)}\frac{c}{r}\right\}.$$

This establishes the first part of 1.1: the best response is independent of the current belief σ. In fact, $br(S)$ is implicitly defined by

$$e^{S-s}\left(\left(v_{HA}+\frac{c}{r}\right)+e^{-S}\left(v_{LA}+\frac{c}{r}\right)\right)+\frac{\left(R_2e^{R_2(S-s)}-R_1e^{R_1(S-s)}\right)}{(R_1-R_2)}\frac{c}{r}\left(1+e^{-s}\right)-e^{-s}\frac{\left(e^{R_2(S-s)}-e^{R_1(S-s)}\right)}{(R_1-R_2)}\frac{c}{r}=0.$$

It is useful to introduce the following variables,

$$g=\log\frac{\left[R_2e^{-R_1(S-s)}-R_1e^{-R_2(S-s)}\right]}{(R_2-R_1)}, \tag{11}$$

and

$$g' = \log \frac{\left[e^{R_2(S-s)} - e^{R_1(S-s)}\right]}{(R_2 - R_1)}, \tag{12}$$

Dividing the previous expression by e^{S-s} we can rewrite the $br(S)$ as

$$\left(\left(v_{HA} + \frac{c}{r}\right) + e^{-S}\left(v_{LA} + \frac{c}{r}\right)\right) - e^{g}\frac{c}{r}\left(1 + e^{-s}\right) + e^{-S}e^{g'}\frac{c}{r} = 0.$$

Multiplying by $\frac{e^S}{1+e^S}$, we obtain as in the main text

$$V_A = \beta_1(s, S)\frac{c}{r}$$

where

$$\beta_1(s, S) = \frac{1}{1+e^S}\left[e^g e^S(1 + e^{-s}) - (1 + e^S) - e^{g'}\right].$$

We show below that $\beta_1(s, S) > 0$. We have $e^g > 1$ (e^g is increasing in $S - s$ and is equal to 1 for $S - s = 0$), so the sign is that of $e^g e^{S-s} - e^S - e^{g'}$. Furthermore

$$\begin{aligned}
& e^{-S} - e^g e^{-s} + e^{-S}e^{g'} \\
= \; & \frac{1}{R_2 - R_1}\left[e^{-S}(R_2 - R_1) - e^{-s}\left[R_2 e^{-R_1(S-s)} - R_1 e^{-R_2(S-s)}\right] + e^{-S}\left[e^{R_2(S-s)} - e^{R_1(S-s)}\right]\right] \\
= \; & \frac{e^{-S}}{R_2 - R_1}\left[(R_2 - R_1) - \left[R_2 e^{R_2(S-s)} - R_1 e^{R_1(S-s)}\right] + \left[e^{R_2(S-s)} - e^{R_1(S-s)}\right]\right] \\
= \; & \frac{e^{-S}}{R_2 - R_1}\left[(R_2 - R_1) - \left[R_2 e^{R_1(S-s)} - R_1 e^{R_2(S-s)}\right]\right] < 0.
\end{aligned}$$

Thus $\beta_1(s, S) > 0$.

Comparative Statics for br (S)

We use to derive the comparative statics, the following expression for $br(S)$

$$\left(\left(v_{HA} + \frac{c}{r}\right) + e^{-S}\left(v_{LA} + \frac{c}{r}\right)\right) - e^{g}\frac{c}{r}\left(1 + e^{-s}\right) + e^{-S}e^{g'}\frac{c}{r} = 0. \tag{13}$$

Comparative Statics with Respect to v_{HA}

Taking derivatives of this first order condition, we have

$$\begin{aligned}
& -1 - \frac{\partial g}{\partial s}\frac{\partial s}{\partial v_{HA}} e^g \frac{c}{r}(1 + e^{-s}) + \frac{\partial s}{\partial v_{HA}} e^g \frac{c}{r} e^{-s} + \frac{\partial g'}{\partial s}\frac{\partial s}{\partial v_{HA}} e^{-S}e^{g'}\frac{c}{r} \\
& \frac{\partial s}{\partial v_{HA}}\left[\frac{\partial g}{\partial s} e^g \frac{c}{r}(1 + e^{-s}) - e^g \frac{c}{r} e^{-s} - \frac{\partial g'}{\partial s} e^{-S} e^{g'}\frac{c}{r}\right] \\
= \; & 1.
\end{aligned}$$

Given that

$$\frac{\partial g}{\partial s} = \frac{\left[R_2 R_1 e^{-R_1(S-s)} - R_1 R_2 e^{-R_2(S-s)}\right]}{\left[R_2 e^{-R_1(S-s)} - R_1 e^{-R_2(S-s)}\right]} < 0 \tag{14}$$

and

$$\frac{\partial g'}{\partial s} = \frac{\left[R_2 e^{R_2(S-s)} - R_1 e^{R_1(S-s)}\right]}{\left[e^{R_2(S-s)} - e^{R_1(S-s)}\right]} > 0, \tag{15}$$

we have

$$\frac{\partial s}{\partial v_{HA}} < 0.$$

Comparative Statics with Respect to v_{LA}

As above, we have

$$\frac{\partial s}{\partial v_{LA}}\left[\frac{\partial g}{\partial s} e^{g}\frac{c}{r}(1+e^{-s}) - e^{g}\frac{c}{r}e^{-s} - \frac{\partial g'}{\partial s}e^{-S}e^{g'}\frac{c}{r}\right] = e^{-S}.$$

Using the same arguments as above, we have

$$\frac{\partial s}{\partial v_{LA}} < 0.$$

Comparative Statics with Respect to c

Follow immediately from the fact that $\beta_1(s,S) > 0$.

$S - br(S)$ increasing in S

We denote $l = S - br(S)$. Equation (13) can be rewritten as

$$\left(e^{S}\left(v_{HA} + \frac{c}{r}\right) + \left(v_{LA} + \frac{c}{r}\right)\right) - e^{g}\frac{c}{r}\left(e^{S} + e^{l}\right) + e^{g'}\frac{c}{r} = 0.$$

Taking derivatives with respect to S, we have

$$e^{S}\left(v_{HA} + \frac{c}{r}\right) - \frac{\partial g}{\partial l}\frac{\partial l}{\partial S}e^{g}\frac{c}{r}\left(e^{S} + e^{l}\right) - e^{g}\frac{c}{r}\left(e^{S} + \frac{\partial l}{\partial S}e^{l}\right) + \frac{\partial g'}{\partial l}\frac{\partial l}{\partial S}e^{g'}\frac{c}{r} = 0.$$

$$\frac{\partial l}{\partial S} = \frac{e^{S}\left(v_{HA} + \frac{c}{r}(1 - e^{g})\right)}{\frac{\partial g}{\partial l}e^{g}\frac{c}{r}\left(e^{S} + e^{l}\right) + e^{g}\frac{c}{r}e^{l} - \frac{\partial g'}{\partial l}e^{g'}\frac{c}{r}} \tag{16}$$

Following the same arguments as above we can show $\frac{\partial g}{\partial l} > 0$ and $\frac{\partial g'}{\partial l} < 0$.

At $l = 0$ (i.e $s = S$), $e^{g} = 1$ so that $\frac{\partial l}{\partial S} > 0$. Equation 16 then implies that $\frac{\partial g'}{\partial l} < 0$ is always increasing and asymptotically approaches the value $\bar{l}$ solution to $v_{HA} = (e^{g(l)} - 1)\frac{c}{r}$, as indicated in result 3.

Proposition 2

We use the notation Ψ for $\Psi(\sigma, H)$ and ψ for $\psi(\sigma, H)$. Using the expression for the utility derived in the proof above, the first order condition with respect to S is given by:

$$\frac{\partial \Psi}{\partial S}\frac{e^{\sigma}}{1+e^{\sigma}}\left(\left(v_{HA}+\frac{c}{r}\right)+e^{-S}\left(v_{LA}+\frac{c}{r}\right)\right)-\Psi\frac{e^{\sigma-S}}{1+e^{\sigma}}\left(v_{LA}+\frac{c}{r}\right)+\frac{\partial \psi}{\partial S}\left(\frac{c}{r}\right)\frac{(e^{\sigma-s}+e^{\sigma})}{1+e^{\sigma}}=0.$$

We now derive the expressions for the partial derivatives of Ψ and ψ with respect to S. We have

$$\begin{aligned}\frac{\partial \Psi}{\partial S}&=-\frac{\left[-R_1e^{-R_1(S-s)}+R_2e^{-R_2(S-s)}\right]\left(e^{-R_1(\sigma-s)}-e^{-R_2(\sigma-s)}\right)}{\left[e^{-R_1(S-s)}-e^{-R_2(S-s)}\right]^2}\\&=\frac{-\left(R_2e^{-R_2(S-s)}-R_1e^{-R_1(S-s)}\right)}{e^{-R_1(S-s)}-e^{-R_2(S-s)}}\Psi.\end{aligned}$$

From the definition of ψ we have

$$\frac{\partial \psi}{\partial S}=\frac{\left(R_2e^{R_2(S-\sigma)}-R_1e^{R_1(S-\sigma)}\right)\left(e^{R_2(S-s)}-e^{R_1(S-s)}\right)-\left(R_2e^{R_2(S-s)}-R_1e^{R_1(S-s)}\right)\left(e^{R_2(S-\sigma)}-e^{R_1(S-\sigma)}\right)}{\left[e^{R_2(S-s)}-e^{R_1(S-s)}\right]^2}.$$

This is equal to

$$\begin{aligned}\frac{\partial \psi}{\partial S}&=(R_2-R_1)\frac{e^{R_2(S-s)}e^{R_1(S-\sigma)}-e^{R_1(S-s)}e^{R_2(S-\sigma)}}{\left[e^{R_2(S-s)}-e^{R_1(S-s)}\right]^2}\\&=(R_2-R_1)\frac{e^{R_2S-R_2s+R_1S-R_1\sigma}-e^{R_1S-R_1s+R_2S-R_2\sigma}}{\left[e^{R_2(S-s)}-e^{R_1(S-s)}\right]^2}.\end{aligned}$$

Given that $R_1+R_2=1$, collecting e^S we obtain

$$\frac{\partial \psi}{\partial S}=(R_2-R_1)e^S\frac{e^{-R_2s-R_1\sigma}-e^{-R_1s-R_2\sigma}}{\left[e^{R_2(S-s)}-e^{R_1(S-s)}\right]^2}.$$

After adding and subtracting $R_2\sigma$ to the first exponential in the numerator and, similarly, after adding and subtracting $R_1\sigma$ to the second exponential in the numerator, this is equal to

$$\frac{\partial \psi}{\partial S}=(R_2-R_1)e^S\frac{e^{-R_2s-R_1\sigma+R_2\sigma-R_2\sigma}-e^{-R_1s-R_2\sigma+R_1\sigma-R_1\sigma}}{\left[e^{R_2(S-s)}-e^{R_1(S-s)}\right]^2}.$$

Then, using $\sigma R_2+\sigma R_1=\sigma$ and collecting $e^{-\sigma}$ we obtain

$$\frac{\partial \psi}{\partial S}=(R_2-R_1)\,e^{S-\sigma}\frac{e^{R_2(\sigma-s)}-e^{R_1(\sigma-s)}}{\left[e^{R_2(S-s)}-e^{R_1(S-s)}\right]^2}.$$

Substituting the definition of

$$\Psi(\sigma,L)=\frac{e^{R_2(\sigma-s)}-e^{R_1(\sigma-s)}}{e^{R_2(S-s)}-e^{R_1(S-s)}}$$

and using $\Psi(\sigma,L)=e^{\sigma-S}\Psi(\sigma,H)$, we conclude that

$$\frac{\partial \psi}{\partial S}=\frac{(R_2-R_1)\,\Psi}{e^{R_2(S-s)}-e^{R_1(S-s)}}.$$

Thus, we have:

$$
\begin{aligned}
\frac{\partial u_i}{\partial S} &= \frac{-\left(R_2 e^{-R_2(S-s)} - R_1 e^{-R_1(S-s)}\right)}{e^{-R_1(S-s)} - e^{-R_2(S-s)}} \frac{e^{\sigma}}{1+e^{\sigma}} \Psi \left(\left(v_{HA} + \frac{c}{r} \right) + e^{-S} \left(v_{LA} + \frac{c}{r} \right) \right) \\
&+ \frac{(R_2 - R_1)}{e^{R_2(S-s)} - e^{R_1(S-s)}} \frac{c}{r} \frac{\Psi}{1+e^{\sigma}} \left(e^{\sigma - s} + e^{\sigma} \right) - \Psi \frac{e^{\sigma - S}}{1+e^{\sigma}} \left(v_{LA} + \frac{c}{r} \right).
\end{aligned}
$$

Exploiting the following relation

$$
\begin{aligned}
e^{R_2(S-s)} - e^{R_1(S-s)} &= e^{(1-R_1)(S-s)} e^{(1-R_2)(S-s)} \\
&= e^{(S-s)} \left(e^{-R_1(S-s)} - e^{-R_2(S-s)} \right),
\end{aligned}
$$

rewrite the condition above in a more compact way as

$$
\begin{aligned}
\frac{\partial u_i}{\partial S} = \Psi \frac{e^{\sigma - S}}{1+e^{\sigma}} & \frac{(R_2 - R_1)}{\left(e^{-R_1(S-s)} - e^{-R_2(S-s)}\right)} \\
& \left\{ - \frac{R_2 e^{-R_2(S-s)} - R_1 e^{-R_1(S-s)}}{R_2 - R_1} e^{S} \left(\left(v_{HA} + \frac{c}{r} \right) + e^{-S} \left(v_{LA} + \frac{c}{r} \right) \right) \right. \\
& \left. + \frac{c}{r} e^{s-\sigma} \left(e^{\sigma - s} + e^{\sigma} \right) - \frac{\left(e^{-R_1(S-s)} - e^{-R_2(S-s)}\right)}{(R_2 - R_1)} \left(v_{LA} + \frac{c}{r} \right) \right\},
\end{aligned}
$$

so that

$$
\begin{aligned}
\frac{\partial u_i}{\partial S} = \Psi \frac{e^{\sigma - S}}{1+e^{\sigma}} & \frac{(R_2 - R_1)}{\left(e^{-R_1(S-s)} - e^{-R_2(S-s)}\right)} \\
& \left\{ - \frac{R_2 e^{-R_2(S-s)} - R_1 e^{-R_1(S-s)}}{R_2 - R_1} e^{S} \left(\left(v_{HA} + \frac{c}{r} \right) + e^{-S} \left(v_{LA} + \frac{c}{r} \right) \right) \right. \\
& \left. + \frac{c}{r} \left(1 + e^{s} \right) - \frac{\left(e^{-R_1(S-s)} - e^{-R_2(S-s)}\right)}{(R_2 - R_1)} \left(v_{LA} + \frac{c}{r} \right) \right\}.
\end{aligned}
$$

We can now express the best reply as

$$
\begin{aligned}
& - \frac{R_2 e^{-R_2(S-s)} - R_1 e^{-R_1(S-s)}}{R_2 - R_1} e^{S} \left(\left(v_{HA} + \frac{c}{r} \right) + e^{-S} \left(v_{LA} + \frac{c}{r} \right) \right) + \frac{c}{r} \left(1 + e^{s} \right) \\
& - \frac{\left(e^{-R_1(S-s)} - e^{-R_2(S-s)}\right)}{(R_2 - R_1)} \left(v_{LA} + \frac{c}{r} \right) \\
= \; & 0.
\end{aligned}
$$

where

$$
f = \log \frac{\left[R_2 e^{R_1(S-s)} - R_1 e^{R_2(S-s)} \right]}{(R_2 - R_1)}, \tag{17}
$$

and

$$
f' = \log \frac{\left[e^{-R_1(S-s)} - e^{-R_2(S-s)} \right]}{(R_2 - R_1)}. \tag{18}
$$

We can rewrite the implicit equation defining $BR(s)$ as

$$-e^f e^s \left(\left(v_{HA} + \frac{c}{r}\right) + e^{-S}\left(v_{LA} + \frac{c}{r}\right)\right) + \frac{c}{r}\left(1 + e^s\right) - e^{f'}\left(v_{LA} + \frac{c}{r}\right) = 0,$$

or $\alpha(s,S)V_A + \beta(s,S)\frac{c}{r} = -\gamma(s,S)v_{LA}$ where

$$\begin{aligned}
\alpha(s,S) &= e^f e^{s-S}(1+e^S) > 0 \\
\beta(s,S) &= e^f e^s(1+e^{-S}) - (1+e^s) + e^{f'} \\
\gamma(s,S) &= e^{f'} > 0.
\end{aligned}$$

To show that $\beta(s,S)$, we use the fact that

$$e^f(1+e^{-S}) - (1+e^{-s}) + e^{f'}e^{-s} = (e^f - 1) + e^f e^{-S} - e^{-s} + e^{f'}e^{-s}.$$

Note that $e^f > 1$ and we can show that $e^f e^{-S} - e^{-s} + e^{f'}e^{-s}$ is of the same sign as

$$\left[R_2 e^{R_2(S-s)} - R_1 e^{R_1(S-s)}\right] - \left[R_2 e^{(S-s)} - R_1 e^{(S-s)}\right] > 0.$$

Comparative Statics

To derive the comparative statics on $BR(s)$, we use the following characterization of the best reply

$$-e^f e^s \left(\left(v_{HA} + \frac{c}{r}\right) + e^{-S}\left(v_{LA} + \frac{c}{r}\right)\right) + \frac{c}{r}\left(1 + e^s\right) - e^{f'}\left(v_{LA} + \frac{c}{r}\right) = 0. \tag{19}$$

Comparative Statics with Respect to v_{HA}

Taking derivatives of (19)

$$-\frac{\partial S}{\partial v_{HA}}\frac{\partial f}{\partial S}e^f e^s \left(\left(v_{HA} + \frac{c}{r}\right) + e^{-S}\left(v_{LA} + \frac{c}{r}\right)\right) + \frac{\partial S}{\partial v_{HA}}e^f e^s e^{-S}v_{LA} - \frac{\partial S}{\partial v_{HA}}\frac{\partial f'}{\partial S}e^{f'}\left(v_{LA} + \frac{c}{r}\right) = e^f e^s,$$

so that

$$\frac{\partial S}{\partial v_{HA}}\left[\frac{\partial f}{\partial S}e^f e^s \left(\left(v_{HA} + \frac{c}{r}\right) + e^{-S}\left(v_{LA} + \frac{c}{r}\right)\right) - e^f e^s e^{-S}v_{LA} + \frac{\partial f'}{\partial S}e^{f'}\left(v_{LA} + \frac{c}{r}\right)\right] = -e^f e^s.$$

Given that

$$\frac{\partial f}{\partial S} = \frac{\left[R_2 R_1 e^{R_1(S-s)} - R_1 R_2 e^{R_2(S-s)}\right]}{\left[R_2 e^{R_1(S-s)} - R_1 e^{R_2(S-s)}\right]} > 0 \tag{20}$$

and

$$\frac{\partial f'}{\partial S} = \frac{\left[-R_1 e^{-R_1(S-s)} + R_2 e^{-R_2(S-s)}\right]}{\left[e^{-R_1(S-s)} - e^{-R_2(S-s)}\right]} > 0, \tag{21}$$

if $V_A(S) > 0$, we clearly have

$$\frac{\partial S}{\partial v_{HA}} < 0.$$

If $V_A(S) < 0$, we can rewrite the expression

$$\frac{\partial S}{\partial v_{HA}}\left[\frac{\partial f}{\partial S}e^f e^s\left(\left(v_{HA}+\frac{c}{r}\right)+e^{-S}\frac{c}{r}\right)-e^f e^s e^{-S}\left[1-\frac{\partial f}{\partial S}\right]v_{LA}+\frac{\partial f'}{\partial S}e^{f'}\left(v_{LA}+\frac{c}{r}\right)\right]=-e^f e^s.$$

Given that $\frac{\partial f}{\partial S} < 1$, we also obtain the result.

Comparative Statics with Respect to v_{LA}

We obtain

$$\frac{\partial S}{\partial v_{LA}}\left[\frac{\partial f}{\partial S}e^f e^s\left(\left(v_{HA}+\frac{c}{r}\right)+e^{-S}\left(v_{LA}+\frac{c}{r}\right)\right)-e^f e^s e^{-S}v_{LA}+\frac{\partial f'}{\partial S}e^{f'}\left(v_{LA}+\frac{c}{r}\right)\right]=-(e^f e^s e^{-S}+e^{f'}).$$

Thus the same arguments allow us to establish that

$$\frac{\partial S}{\partial v_{LA}} < 0.$$

Comparative Statics with Respect to c

Follow immediately from the fact $\beta(s,S) > 0$.

$BR(s) - s$ **decreasing in s**

We denote $l = BR(s) - s$. Equation (19) can be rewritten as

$$-e^f\left(e^s\left(v_{HA}+\frac{c}{r}\right)+e^{-l}\left(v_{LA}+\frac{c}{r}\right)\right)+\frac{c}{r}\left(1+e^s\right)-e^{f'}\left(v_{LA}+\frac{c}{r}\right)=0.$$

Taking derivatives with respect to s, we have

$$\begin{aligned}
&-\frac{\partial f}{\partial l}\frac{\partial l}{\partial s}e^f\left(e^s\left(v_{HA}+\frac{c}{r}\right)+e^{-l}\left(v_{LA}+\frac{c}{r}\right)\right)-e^f e^s\left(v_{HA}+\frac{c}{r}\right)\\
&+\frac{\partial l}{\partial s}e^f e^{-l}\left(v_{LA}+\frac{c}{r}\right)+\frac{c}{r}e^s-\frac{\partial f'}{\partial l}\frac{\partial l}{\partial s}e^{f'}\left(v_{LA}+\frac{c}{r}\right)\\
=\;&0.
\end{aligned}$$

This can be written as

$$\frac{\partial l}{\partial s}=\frac{-e^f e^s\left(v_{HA}+\frac{c}{r}\right)+\frac{c}{r}e^s}{\frac{\partial f}{\partial l}e^f\left(e^s\left(v_{HA}+\frac{c}{r}\right)+e^{-l}\left(v_{LA}+\frac{c}{r}\right)\right)-e^f e^{-l}\left(v_{LA}+\frac{c}{r}\right)+\frac{\partial f'}{\partial l}\,e^{f'}\left(v_{LA}+\frac{c}{r}\right)}.$$

Following the same arguments as for the proof of the comparative statics with respect to v_{HA}, we have that the denominator is positive. Since $e^f > 1$, the numerator is negative and we obtain $\frac{\partial l}{\partial s} < 0$.

We now establish the result by taking the limit of the above first order condition. We obtain at the limit

$$-(e^f e^{s-S}+e^{f'})\left(v_{LA}+\frac{c}{r}\right)+\frac{c}{r}=0.$$

We can show that $e^f e^{s-S} + e^{f'} = e^g$, so that indeed, $\underline{l}$ is solution to $-v_{LA} = (e^{-g(l)} + 1)\frac{c}{r}$

Foundation for the Nash Equilibrium Solution

At each instant t, agent and principal move *sequentially*:

- First, the agent chooses research $\mathcal{R}^a$, submit $\mathcal{S}^a$ or wait/withdraw $\mathcal{W}^a$
- Second, if the agent submits $\mathcal{S}^a$, the principal chooses research $\mathcal{R}^p$, approve $\mathcal{A}^p$ or wait $\mathcal{W}^p$
- R results if $\mathcal{R}^a$ or $(S^a, \mathcal{R}^p)$; A results if $(\mathcal{S}^a, \mathcal{A}^p)$, W results if $\mathcal{W}^a$ or $(\mathcal{S}^a, \mathcal{W}^p)$

We solve for the Markov Perfect Equilibria where the state variable is given by the current information σ. We show that the unique MPE outcome is: R for $\sigma \in \left[s^N = b^a\left(S^N\right), S^N = B^p\left(s^N\right)\right]$, W for $\sigma < s^N$ and A for $\sigma > S^N$.

This unique outcome can supported by multiple equilibrium strategies.

Proposition 3

We prove the result in a number of steps:

Step 1: $br_i(S)$ reaches its minimum at S_i^* and $BR_i(s)$ reaches its maximum at s_i^*.

According to the smooth pasting condition, given that rejection always yields a zero value, we have:

$$\frac{\partial u_i}{\partial s}(s^*, S^*) = 0.$$

Taking derivatives with respect to S, taking into account that $s = br(S)$ yields

$$\frac{\partial^2 u_i}{\partial s \partial S}(s^*, S^*) + br_1(S^*)\frac{\partial^2 u_i}{\partial s^2}(s^*, S^*) = 0.$$

Furthermore, given that $\frac{\partial u_i}{\partial s}(S^*) = 0$, we have

$$br_1(S^*) = 0.$$

The best response function br(S) reaches a minimum for $S = S^*$.

Similarly

$$\frac{\partial u_i}{\partial S}(s^*, S^*) = \frac{\partial(\frac{e^S}{1+e^S}v_{HA} + \frac{1}{1+e^S}v_{LA})}{\partial S}.$$

Taking derivatives with respect to s yields

$$BR_1(s^*, S^*)\left[\frac{\partial^2 u_i}{\partial S^2}(S^*) - \frac{\partial^2(\frac{e^S}{1+e^S}v_{HA} + \frac{1}{1+e^S}v_{LA})}{\partial S^2}\right] = 0$$

The best response function BR(s) reaches a maximum for $s = s^*$.

Step 2: If br_a and BR_p cross it is for values such that $BR_p(s)$ is increasing in s and $br_a(S)$ is decreasing in S.

In Proposition 1 and 2, we showed that $br_a(S) \leq br_p(S)$ and $BR_p(s) \geq BR_a(s)$. According to step 1 and 2, BR_p crosses br_p at (s_p^*, S_p^*) where BR_p is maximum. Given that $br_a(S) \leq br_p(S)$, and that br_p is single peaked, it has to be the case that br_a and BR_p cross for values such that $BR_p(s)$ is increasing in s. The same logic applies to show that $br_a(S)$ is increasing in S when br_a and BR_p cross.

Step 3: $\frac{\partial BR(s)}{\partial s} < 1$.

We derived in the proof of Proposition 2, that $BR(s)$ is defined by

$$-e^f e^s\left(\left(v_{HA} + \frac{c}{r}\right) + e^{-S}\left(v_{LA} + \frac{c}{r}\right)\right) + \frac{c}{r}(1 + e^s) - e^{f'}\left(v_{LA} + \frac{c}{r}\right) = 0.$$

defining $y = S - s$, and taking derivatives of the implicit equation above, we have

$$\begin{aligned}
&-\frac{\partial f}{\partial y}\left(\frac{\partial S}{\partial s} - 1\right)e^f e^s\left(\left(v_{HA} + \frac{c}{r}\right) + e^{-S}\left(v_{LA} + \frac{c}{r}\right)\right) - e^f e^s\left(\left(v_{HA} + \frac{c}{r}\right) + e^{-S}\left(v_{LA} + \frac{c}{r}\right)\right)\\
&+\frac{\partial S}{\partial s}e^f e^s e^{-S}\left(v_{LA} + \frac{c}{r}\right) + \frac{c}{r}e^s - \frac{\partial f'}{\partial y}e^{f'}\left(\frac{\partial S}{\partial s} - 1\right)\left(v_{LA} + \frac{c}{r}\right)\\
= \;& 0.
\end{aligned}$$

This can be rewritten as

$$\begin{aligned}
&\left(\frac{\partial S}{\partial s} - 1\right)\left[-\frac{\partial f}{\partial y}e^f e^s\left(\left(v_{HA} + \frac{c}{r}\right) + e^{-S}\left(v_{LA} + \frac{c}{r}\right)\right) + e^f e^s e^{-S}\left(v_{LA} + \frac{c}{r}\right) - \frac{\partial f'}{\partial y}e^{f'}\left(v_{LA} + \frac{c}{r}\right)\right]\\
= \;& e^f e^s\left(v_{HA} + \frac{c}{r}\right) - \frac{c}{r}e^s.
\end{aligned}$$

Furthermore we have

$$e^f e^s e^{-S} = \frac{\partial f'}{\partial y}e^{f'}.$$

So that

$$\left(\frac{\partial S}{\partial s} - 1\right)\left[-\frac{\partial f}{\partial y}e^f e^s\left(\left(v_{HA} + \frac{c}{r}\right) + e^{-S}\left(v_{LA} + \frac{c}{r}\right)\right)\right] = e^f e^s\left(v_{HA} + \frac{c}{r}\right) - \frac{c}{r}e^s.$$

Given that $e^f > 1$ the right hand side is positive. Furthermore, we have that along $BR(s)$ that $v_{HA} + \frac{c}{r} + e^{-S}\left(v_{LA} + \frac{c}{r}\right) > 0$. Therefore, since we established that $\frac{\partial f}{\partial y} > 0$, we conclude that $\frac{\partial S}{\partial s} < 1$.

Step 4: $\frac{\partial br^{-1}(s)}{\partial s} > 1$ for values such that $br(S)$ is decreasing in S.

$br(S)$ is defined by the following implicit function

$$\left(\left(v_{HA} + \frac{c}{r}\right) + e^{-S}\left(v_{LA} + \frac{c}{r}\right)\right) - e^{g}\frac{c}{r}\left(1 + e^{-s}\right) + e^{-S}e^{g'}\frac{c}{r} = 0.$$

We have shown that for $s > s^*$, $br(S)$ is an increasing function. On this interval, $br^{-1}(s)$ is a well defined function. Taking derivatives of the implicit equation above, we have

$$-\frac{\partial S}{\partial s}e^{-S}\left(v_{LA} + \frac{c}{r}\right) - \frac{\partial g}{\partial y}\left(\frac{\partial S}{\partial s} - 1\right)e^{g}\frac{c}{r}\left(1 + e^{-s}\right) + e^{g}\frac{c}{r}e^{-s} - \frac{\partial S}{\partial s}e^{-S}e^{g'}\frac{c}{r} + \frac{\partial g'}{\partial y}\left(\frac{\partial S}{\partial s} - 1\right)e^{-S}e^{g'}\frac{c}{r} = 0.$$

Grouping terms we have

$$-\left(\frac{\partial S}{\partial s} - 1\right)\left[\frac{\partial g}{\partial y}e^{g}\frac{c}{r}\left(1 + e^{-s}\right) - \frac{\partial g'}{\partial y}e^{-S}e^{g'}\frac{c}{r} + e^{g}\frac{c}{r}e^{-s}\right] - \frac{\partial S}{\partial s}e^{-S}v_{LA} - \frac{\partial S}{\partial s}\left[e^{-S}e^{g'} + e^{-S} - e^{g}e^{-s}\right] = 0$$

We showed in the proof of Proposition 1 that: $e^{-S}e^{g'} + e^{-S} - e^{g}e^{-s} < 0$. Given that $v_{LA} < 0$, to have the equation above satisfied, since we are deriving a property of the curve over which $\frac{\partial S}{\partial s} > 0$, it has to be that

$$-\left(\frac{\partial S}{\partial s} - 1\right)\left[\frac{\partial g}{\partial y}e^{g}\frac{c}{r}\left(1 + e^{-s}\right) - \frac{\partial g'}{\partial y}e^{-S}e^{g'}\frac{c}{r} + e^{g}\frac{c}{r}e^{-s}\right] < 0.$$

We also showed in the proof of Proposition 1 that $\frac{\partial g'}{\partial y} < 0$ and $\frac{\partial g}{\partial y} > 0$. So the above inequality implies that $\frac{\partial S}{\partial s} > 1$.

Step 5: Deriving the results.

Step 3 implies that if a crossing between $br_a(S)$ and $BR_p(s)$ occurs, it will be for values of (s, S) such that the properties of step 4 and 5 apply. Furthermore these properties imply both that the curves do cross and that the crossing is unique: when the curves cross, $\frac{\partial br^{-1}(s)}{\partial s} < 1$ and $\frac{\partial BR(s)}{\partial s} < 1$, so the curves cannot cross again.

Result 1. then follows from step 1.

Finally from Proposition 1.3, we know $S - br(S)$ is increasing in S, so since $S_N < S_a^*$ and $s_N = br_a(S_N)$, we have $S_N - s_N > S_a^* - s_a^*$. Similarly, using Proposition 2.3, we have $S_N - s_N > S_p^* - s_p^*$. This establishes result 3.

Proposition 4

Result 1: We have $S_N > S_a^* > \hat{\sigma}_a$. So, if $\sigma \geq S_N$, the agent gets a strictly positive payoff and if $\sigma < S_N$ he can guarantee himself a zero payoff by choosing $s = \sigma$. Thus the agent's payoff is positive for all values of σ

Result 2: Given a value of the upper benchmark S_N, the principal gets a zero payoff when he chooses the lower benchmark $\sigma = br_p(S_N)$ since it implies rejection. In the Nash equilibrium solution, since $s_N = br_a(S_N) < br_p(S_N)$, he gets a strictly negative payoff. The result is true for any value of $\sigma \in [s_N, br_p(S_N)]$ since even if the principal was choosing alone, he could only guarantee a zero payoff. However, when $s_N > \sigma$, the principal, by definition of s, gets a zero payoff.

Proposition 5

We first examine the case of small conflict of interest:

Result 1. If $\sigma \leq s_a^*$, the agent never experiments, since even when he controls both benchmarks, he gets a negative payoff when experimenting. Thus, in this case, as indicated in Proposition 5.1, any commitment $\mathcal{S}_c(\sigma) > \sigma$ will be equivalent for the principal and will give the zero rejection payoff. Furthermore, choosing a commitment below σ leads to immediate approval and a negative payoff. We conclude on the first result: if $\sigma \leq s_a^*$ then $\mathcal{S}_c(\sigma) \in (\sigma, +\infty)$.

For $\sigma > s_a^*$, the principal has the choice between an interior commitment that leads the agent to perform research and a blocking commitment, such that the agent performs no research: even though the principal cannot force rejection because the lower threshold s is controlled by the agent, the principal can induce the agent to reject immediately by committing to a sufficiently high adoption threshold S such that $br_a(S) = s \geq \sigma$. The **lowest** possible such **blocking commitment** $S_c = \overline{br}_a^{-1}(\sigma)$, where $\overline{br}_a^{-1}$ is the upper inverse function constructed by inverting br_a for $S > S_a^*$. Clearly, any S strictly above $\overline{br}_a^{-1}(\sigma)$ is equally blocking and results in exactly the same outcome and gives the principal a zero payoff.

Consider the other option of an interior commitment. We first show that if, for a starting belief σ, an interior commitment gives a strictly positive value (i.e is strictly preferred to a blocking commitment), then it will also be the case for $\sigma' > \sigma$. Consider any point $(\overline{br}_a^{-1}(S), S)$ (point on the agent's best response curve). The utility is given by

$$u(s, S, \sigma) = -\frac{c}{r} + \frac{1}{1+e^{\sigma}} \left\{ e^{\sigma} \Psi(\sigma, H) \left[\left(v_{HA} + \frac{c}{r} \right) + e^{-S} \left(v_{LA} + \frac{c}{r} \right) \right] + \psi(\sigma, H) \frac{c}{r} \left(e^{\sigma - s} + e^{\sigma} \right) \right\}$$

so that

$$\frac{\partial u(s,S,\sigma)}{\partial\sigma}=\frac{\partial\left(\frac{e^{\sigma}}{1+e^{\sigma}}\Psi(\sigma,H)\right)}{\partial\sigma}\left[\left(v_{HA}+\frac{c}{r}\right)+e^{-S}\left(v_{LA}+\frac{c}{r}\right)\right]+\frac{\partial\left(\frac{e^{\sigma}}{1+e^{\sigma}}\psi(\sigma,H)\right)}{\partial\sigma}\frac{c}{r}\left(e^{-s}+1\right).$$

We have

$$\frac{\partial\left(\frac{e^{\sigma}}{1+e^{\sigma}}\psi(\sigma,H)\right)}{\partial\sigma}=\frac{e^{\sigma}\psi(\sigma,H)+(1+e^{\sigma})e^{\sigma}\psi_{\sigma}(\sigma,H)}{(1+e^{\sigma})^{2}}$$

where

$$\psi_{\sigma}(\sigma,H)=\frac{-R_2e^{R_2(S-\sigma)}+R_1e^{R_1(S-\sigma)}}{e^{R_2(S-s)}-e^{R_1(S-s)}}<0.$$

So overall

$$\frac{\partial\left(\frac{e^{\sigma}}{1+e^{\sigma}}\psi(\sigma,H)\right)}{\partial\sigma}<0.$$

On the contrary, we have

$$\frac{\partial\left(\frac{e^{\sigma}}{1+e^{\sigma}}\Psi(\sigma,H)\right)}{\partial\sigma}>0.$$

We need to show that the second effect dominates to prove that

$$\frac{\partial u(s,S,\sigma)}{\partial\sigma}>0$$

and thus if $u(s,S,\sigma)>0$, then for $\sigma'>\sigma$, $u(s,S,\sigma')>0$. Therefore, there exists a value of the initial belief $\tilde{\sigma}$ such that the interior commitment is preferred to the blocking commitment if and only if $\sigma\geq\tilde{\sigma}$.

We conclude the proof of result 1 by showing that $\tilde{\sigma}\in(s_p^*,\hat{\sigma}_p)$. For $\sigma\leq s_p^*$, any choice (s,S) gives the principal a negative or zero payoff, so naturally $\tilde{\sigma}>s_p^*$. For $\sigma=\hat{\sigma}_p$, the Nash equilibrium outcome (s_N,S_N) gives the principal a positive payoff since he could always choose $S=\hat{\sigma}_p$ and guarantee a zero payoff. So we have $\tilde{\sigma}\leq\hat{\sigma}_p$.

Result 2. According to result 1, if σ is above and close to $\tilde{\sigma}$, an interior commitment is optimal. We first show that the interior commitment is decreasing in σ.

We have

$$\frac{du_p}{dS}=\frac{\partial u_p}{\partial S}+\frac{\partial u_p}{\partial s}\frac{ds}{dS},$$

where $\frac{\partial u_p}{\partial S}$ and $\frac{\partial u_p}{\partial S}$ are derived in the proof of Propositions 1 and 2 and $\frac{ds}{dS}$ corresponds to the lower best response of the agent to a choice of S. The first term is the **non strategic direct effect** of S on the principal's utility. The second is the **strategic effect** of S working through the indirect impact of S on the agent's choice.

We first examine how the direct non strategic effect reacts to an increase in σ.

Using the formulas derived in Proposition 2, we have that $\frac{\partial^2 u_p}{\partial S \partial \sigma}$ is proportional to

$$\frac{\partial \left(\frac{e^\sigma}{1+e^\sigma} \Psi(\sigma, H) \right)}{\partial \sigma} \frac{\partial u_p}{\partial S}.$$

Both terms are positive so that

$$\frac{\partial u_p}{\partial S \partial \sigma} > 0.$$

For the strategic effect, we use the fact that the agent's best response to S is independent of σ, so that $\frac{ds}{dS}$ is independent of σ. Using the formulas derived in Proposition 1, we have that $\frac{\partial^2 u_p}{\partial s \partial \sigma}$ is proportional to

$$\frac{\partial \left(\frac{e^\sigma}{1+e^\sigma} \psi(\sigma, H) \right)}{\partial \sigma} \frac{\partial u_p}{\partial s}.$$

The first term is positive while the second is negative. Thus we have

$$\frac{\partial u_p}{\partial S \partial \sigma} > 0.$$

Overall we need to show that the strategic effect dominates and we have

$$\frac{d^2 u_p}{dS d\sigma} < 0.$$

In a second step we show that

$$\frac{d^2 u_p}{dS^2} < 0$$

We have

$$\frac{d^2 u_p}{dS^2} = \frac{\partial^2 u_p}{\partial S^2} + \frac{\partial^2 u_p}{\partial s \partial S} \frac{ds}{dS} + \frac{\partial u_p}{\partial s} \frac{d^2 s}{dS^2}.$$

We showed in the proof of result 2 that $\frac{\partial^2 u_p}{\partial s \partial S} < 0$ and $\frac{ds}{dS} > 0$.

We now show

$$\frac{\partial^2 u_p}{\partial S^2} < 0$$

We have established in the proof of Proposition 2

$$\frac{\partial u_p}{\partial S} = \Psi \frac{e^{\sigma - S}}{1+e^\sigma} \frac{(R_2 - R_1)}{\left(e^{-R_1(S-s)} - e^{-R_2(S-s)}\right)} \left\{ -e^f e^s \left(\left(v_{HA} + \frac{c}{r} \right) + e^{-S} \left(v_{LA} + \frac{c}{r} \right) \right) + \frac{c}{r}(1+e^s) - e^{f'} \left(v_{LA} + \frac{c}{r} \right) \right\}.$$

We have

$$\frac{\partial}{\partial S} \left(\Psi \frac{e^{\sigma - S}}{1+e^\sigma} \frac{(R_2 - R_1)}{\left(e^{-R_1(S-s)} - e^{-R_2(S-s)}\right)} \right) < 0.$$

In the proof of Proposition 2 when we examine the comparative statics with respect to v_{HA}, we established that the second term is also decreasing in S. Thus we have

$$\frac{\partial^2 u_p}{\partial S^2} < 0.$$

We also have $\frac{d^2 s}{dS^2}$, so that overall, the utility the principal is a concave function of the level of commitment S.

$$\frac{d^2 u_p}{dSd\sigma} < 0$$

This establishes that u_p has a unique interior maximum defined by $\frac{du_p}{dS} = 0$. Furthermore, we established that $\frac{d^2 u_p}{dSd\sigma} < 0$, so that u_p will reach a maximum for lower values of S as σ increases, i.e the optimal commitment $\mathcal{S}_C(\sigma)$ is decreasing in σ

Result 3. We now identify the belief where the principal will switch from an interior commitment to an approval commitment where the principal chooses immediate approval. Denote $\overline{\sigma}$, the first belief such that the principal is indifferent between commitment and immediate approval. Such a belief exists: indeed, the payoff from approval and from interior commitments are continuous and, for $\sigma \geq S_p^*$, the optimal commitment is $S_c = \sigma$ since even when the principal has full control, he would adopt immediately. For belief $\overline{\sigma}$, we must have $\mathcal{S}_C(\overline{\sigma}) = \overline{\sigma}$. Furthermore, since we showed above that the interior commitment $\mathcal{S}_C(\overline{\sigma})$ is decreasing in σ, we will also have that for $\sigma \geq \overline{\sigma}$ the interior commitment is below σ and the principal therefore chooses immediate approval.

We conclude the proof by showing that $\overline{\sigma} = S_N$. Note that we necessarily have $\overline{\sigma} \geq S_N$ since for $\sigma < S_N$, at the Nash equilibrium, the principal could choose immediate approval but does not do so, in other words, for those values of σ, a commitment $\mathcal{S}_C = S_N$ does better than immediate approval.

For $\sigma = S_N$, an interior commitment at $S = S_N$ gives the payoff of immediate approval. We conclude the proof by showing that at $\sigma = S_N$, the optimal interior commitment is indeed $\mathcal{S}_C = S_N$. We have

$$\frac{du_p}{dS} = \frac{\partial u_p}{\partial S} + \frac{\partial u_p}{\partial s}\frac{ds}{dS}.$$

At $(s, S) = (s_N, S_N)$, we have $\frac{\partial u_p}{\partial S}(s_N, S_N) = 0$. Furthermore, for $\sigma = S_N$, we have $\psi = 0$, so that $\frac{\partial u_p}{\partial s}(s_N, S_N, \sigma)$ (multiple of ψ) is equal to zero. Thus, we have for

$$\frac{du_p}{dS}(s_N, S_N, \sigma = S_N) = 0.$$

As we established before, the unique interior commitment is characterized by $\frac{du_p}{dS} = 0$ so that the optimal commitment is $\mathcal{S}_C = S_N$. This concludes the proof.

Proposition 6

This follows immediately from the results in Proposition 5. For $\sigma \in (s_a^*, \overline{\sigma})$, the optimal commitment is either a blocking commitment or an interior commitment that gives a strictly higher payoff than the Nash. For $\sigma < s_a^*$, both yield a zero payoff. For $\sigma > \overline{\sigma}$, both give the approval payoff.

Proposition 7

In Proposition 5 we showed that $\tilde{\sigma} > s_p^*$ and $\overline{\sigma} < S_p^*$. This establishes the first result: $(\tilde{\sigma}, \overline{\sigma}) \subset (s_p^*, S_p^*)$.

We have for $\sigma \in (\tilde{\sigma}, \overline{\sigma})$, $S_c(\sigma) \geq S_N$. We showed in Proposition 1 that $S - br_a(S)$ is increasing in S, so that $S_c - br_a(S_c) > S_N - br_a(S_N)$. The fact that $S_c - br_a(S_c) > S_p^* - s_p^*$ then follows immediately from Proposition 3.

Proposition 8

Result 1: As explained in the main text, in the second phase, the principal will search in the interval (s_p^*, S_p^*). By backwards induction, the agent will thus search in the interval $(br_a^*(S_p^*), S_p^*)$. Indeed, since the agent pays the cost of research even if the principal searches, stopping for $\sigma < S_p^*$ decreases the utility of the agent since $s_p^* > br_a^*(S_p^*)$ and thus with some probability, the principal would stop too early.

Result 3: For $\sigma \in (\hat{\sigma}, S_p^*)$, the Nash equilibrium outcome coincides with the optimal commitment and is strictly different from the outcome of sequential search. The principal will thus achieve a strictly higher level of utility

Result 4: The length of the research interval is larger in the sequential case than in the Nash since $(br_a^*(S_p^*), S_p^*)$ is a point on the agent's best response curve for a higher value of S. The result in Proposition 2.3 yields the result. It is also clearly larger than for the standalone problem since the value of $S = S_p^*$ is the same but the lower benchmark $s = br_a^*(S_p^*) < br_p^*(S_p^*)$.

Proposition 9

Given an acceptance standard $\mathcal{S}_M$, when the agent chooses a search interval (s, S) with $S \leq \mathcal{S}_M$, the utility is

$$
\begin{aligned}
u(\sigma) &= -\frac{c}{r} \\
&+ \frac{1}{1+e^{\sigma}}\left\{e^{\sigma}\Psi(\sigma,H)\left[\left(v_{HA}+\frac{c}{r}\right)+e^{-S}\left(v_{LA}-C(\mathcal{S}_M-S)+\frac{c}{r}\right)\right]+\psi(\sigma,H)\frac{c}{r}\left(e^{\sigma-s}+e^{\sigma}\right)\right\}.
\end{aligned}
$$

The change compared to the benchmark case is that an additional cost is incurred if the state is low. The best response to the upper benchmark is given by

$$
V_A = \beta_1(s, S)\frac{c}{r}
$$

but with

$$
V_A = \frac{e^S}{1+e^S}\left[e^S v_{HA} + v_{LA} - C(\mathcal{S}_M - S)\right].
$$

Thus the best response is above the best response in the benchmark case.

We now examine the best response to the lower benchmark. The first order condition with respect to S is slightly modified

$$
\begin{aligned}
& \frac{\partial \Psi}{\partial S}\frac{e^{\sigma}}{1+e^{\sigma}}\left(\left(v_{HA}+\frac{c}{r}\right)+e^{-S}\left(v_{LA}-C(\mathcal{S}_M-S)+\frac{c}{r}\right)\right) \\
& -\Psi\frac{e^{\sigma-S}}{1+e^{\sigma}}\left(v_{LA}-C(\mathcal{S}_M-S)+\frac{c}{r}\right)+\Psi\frac{e^{\sigma-S}}{1+e^{\sigma}}C'(\mathcal{S}_M-S)+\frac{\partial\psi}{\partial S}\left(\frac{c}{r}\right)\frac{\left(e^{\sigma-s}+e^{\sigma}\right)}{1+e^{\sigma}} \\
= \; & 0.
\end{aligned}
$$

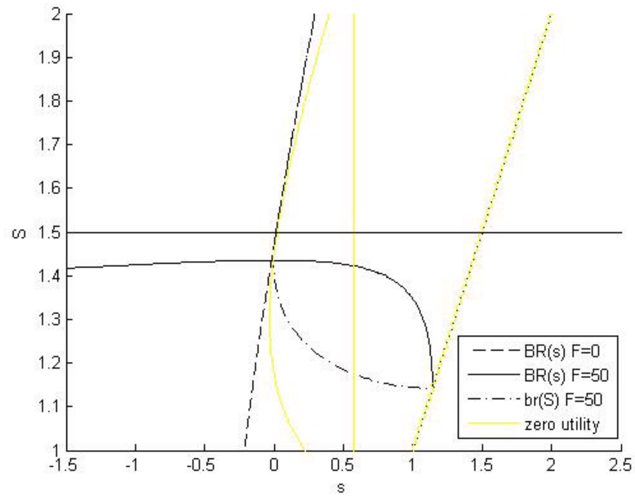
We have

$$
\begin{aligned}
\frac{\partial u_i}{\partial S} &= \Psi\frac{e^{\sigma-S}}{1+e^{\sigma}}\frac{(R_2-R_1)}{\left(e^{-R_1(S-s)}-e^{-R_2(S-s)}\right)} \\
& \left\{-\frac{R_2e^{-R_2(S-s)}-R_1e^{-R_1(S-s)}}{R_2-R_1}e^{S}\left(\left(v_{HA}+\frac{c}{r}\right)+e^{-S}\left(v_{LA}-C(\mathcal{S}_M-S)+\frac{c}{r}\right)\right)\right. \\
& \left.+\frac{c}{r}e^{s-\sigma}\left(e^{\sigma-s}+e^{\sigma}\right)-\frac{\left(e^{-R_1(S-s)}-e^{-R_2(S-s)}\right)}{(R_2-R_1)}\left(v_{LA}-C(\mathcal{S}_M-S)+C'(\mathcal{S}_M-S)+\frac{c}{r}\right)\right\}.
\end{aligned}
$$

We can then rewrite the first order condition in a more compact way as

$$
\alpha(s,S)V_A + \beta(s,S)\frac{c}{r} = -\gamma(s,S)\left[\left(v_{LA} - C(\mathcal{S}_M - S)\right) + C'(\mathcal{S}_M - S)\right].
$$

We conclude the proof by showing that the upper benchmark chosen S_M by the agent is such that $S_M < \mathcal{S}_M$. Suppose this was not the case and the agent chose $S_M = \mathcal{S}_M$. Then the best response above would be the same as the best response for the agent's stand-alone problem. However,



given that $S_M = \mathcal{S}_M > S_a^*$ and that the agent's stand-alone upper best response reaches its maximum at a value $S = S_a^*$, S_M cannot be on the agent's best response curve. We therefore reach a contradiction. As can be verified grapically in Figure 5, the agent's upper best response with misreporting is strictly below the horizontal line $S = \mathcal{S}_M$.

Proposition 10

We are in the case $\sigma \in (\tilde{\sigma}, \overline{\sigma})$, i.e the case of an interior commitment. At $S = \mathcal{S}_c(\sigma)$, by definition of the interior commitment, the iso-utility curve of the principal is tangent to the lower best response curve of the agent for a fine $F = O$ ($br_a(S)$, i.e. the best response of the agent used in all the previous sections).

For a fine $F > 0$ and an approval standard $\mathcal{S}_M = \mathcal{S}_c$, the best response curve of the agent $br_a(S, F)$ is modified. It is also tangent to $br_a(S)$ at $S = \mathcal{S}_c(\sigma)$ since $C'(0) = 0$. However, locally, for F large enough it is to the right of the iso-utility curve of the agent: for a given S, s is strictly increasing in F. As a consequence, the intersection with the agent's upper best response $BR_a(S, F)$, (s_M, S_M) belongs to a higher iso-utility curve. All these properties are represented in Figure 9.

Proposition 11

If the state is low, the expected benefit of the principal for a choice of W at belief σ, given by (5), is decreasing in W for sufficiently large values of P_p. If the state is high, (6) is increasing in W. Thus, there will be a benchmark belief W^* where these two effects cancel each other and such that withdrawal should be chosen, whenever $\sigma \leq W^*$.

Given that the expected payoff upon approval are

$$\begin{aligned} v_{HA} &= p(e)v_{HA}(W^*) + (1 - p(e))\overline{v}_{HA} \\ v_{LA} &= p(e)v_{LA}(W^*) + (1 - p(e))\overline{v}_{LA} \end{aligned}$$

with $\overline{v}_{LA} = \frac{w}{r} - \frac{\lambda}{\lambda+r}(w + P_p)$ and $\overline{v}_{HA} = \frac{w}{r}$, we have that v_{LA} is increasing in e and v_{HA} is increasing in e. For P_p sufficiently large, the effect on v_{LA} dominates and according to Proposition 2, the best response of the agent is decreasing in e. A similar argument can be made for the lower best response of the agent.

Proposition 12

The utility of the agent is given by

$$\begin{aligned} u(\sigma, s, S) = &-\frac{c}{r} \\ &+ \frac{1}{1+e^{\sigma}}\left\{e^{\sigma}\Psi(\sigma, H)\left[\left(v_{HS} + \frac{c}{r}\right) + e^{-S}\left(v_{LS} + \frac{c}{r}\right)\right] + \psi(\sigma, H)\frac{c}{r}\left(e^{\sigma-s} + e^{\sigma}\right)\right\}, \end{aligned}$$

where the expected value upon stopping research depends on the uncertainty due to the principal's research process,

$$\begin{aligned} v_{HS} &= \Psi_p(S, H)v_{HA} \\ v_{LS} &= \Psi_p(S, L)v_{LA}. \end{aligned}$$

We have

$$\Psi_p(S, H) = \frac{e^{-R_1(S-s_p^*)} - e^{-R_2(S-s_p^*)}}{e^{-R_1(S_p^*-s_p^*)} - e^{-R_2(S_p^*-s_p^*)}}.$$

We first examine the first order condition characterizing the lower benchmark of search s. Since neither $\Psi_p(S, H)$ nor $\Psi_p(S, H)$ depends on s, the first order condition is identical to the base case except for the value of V_A. We have

$$V_H(S) = \beta_1(s, S)\ c/r$$

with

$$V_H(S) = \frac{e^S}{1+e^S}v_{HS} + \frac{1}{1+e^S}v_{LS}.$$

using the fact that $\Psi_p(S, L) = e^{S-S_p^*}\Psi_p(S, H)$, we have

$$V_H(S) = \frac{e^S}{1+e^S}\Psi_p(S, H)\left[v_{HA} + e^{-S_p^*}v_{LA}\right].$$

We examine how V_H compares to V_A. We have that for $S = S_p^*$, $V_H(S) = V_A(S)$. Thus, we look at the comparative statics of $V_H(S)$ with respect to S_p^*, for $S \leq S_p^*$

$$
\begin{aligned}
\frac{\partial V_H}{\partial S_p^*} &= \frac{e^S}{1+e^S}\left[\frac{\partial \Psi_p(S,H)}{\partial S_p^*}(v_{HA} + e^{-S_p^*}v_{LA}) - e^{-S_p^*}v_{LA}\Psi_p(S,H)\right] \\
&= \tfrac{e^S}{1+e^S}\tfrac{\Psi_p(S,H)}{e^{-R_1(S_p^*-s_p^*)}-e^{-R_2(S_p^*-s_p^*)}} \\
&\quad \left[\left(R_1 e^{-R_1(S_p^*-s_p^*)} - R_2 e^{-R_2(S_p^*-s_p^*)}\right)(v_{HA} + e^{-S_p^*}v_{LA}) - e^{-S_p^*}(e^{-R_1(S_p^*-s_p^*)} - e^{-R_2(S_p^*-s_p^*)})v_{LA}\right] \\
&= \tfrac{e^S}{1+e^S}\tfrac{\Psi_p(S,H)}{e^{-R_1(S_p^*-s_p^*)}-e^{-R_2(S_p^*-s_p^*)}} \\
&\quad \left[\left(R_1 e^{-R_1(S_p^*-s_p^*)} - R_2 e^{-R_2(S_p^*-s_p^*)}\right)v_{HA} + e^{-S_p^*}\left[-R_2 e^{-R_1(S_p^*-s_p^*)} + R_1 e^{-R_2(S_p^*-s_p^*)})\right]v_{LA}\right].
\end{aligned}
$$

Therefore we have $\frac{\partial V_H}{\partial S_p^*} \geq 0$ iff

$$
\frac{-v_{LA}}{v_{HA}} > \frac{\left(-R_1 e^{-R_1(S_p^*-s_p^*)} + R_2 e^{-R_2(S_p^*-s_p^*)}\right)}{e^{-S_p^*}\left[R_2 e^{-R_1(S_p^*-s_p^*)} - R_1 e^{-R_2(S_p^*-s_p^*)}\right]}.
$$

Note that $\frac{\left(-R_1 e^{-R_1(S_p^*-s_p^*)} + R_2 e^{-R_2(S_p^*-s_p^*)}\right)}{\left[R_2 e^{-R_1(S_p^*-s_p^*)} - R_1 e^{-R_2(S_p^*-s_p^*)}\right]} < 1$. We use the notation

$$
D_1(S_p^*, s_p^*) \equiv \frac{\left(-R_1 e^{-R_1(S_p^*-s_p^*)} + R_2 e^{-R_2(S_p^*-s_p^*)}\right)}{e^{-S_p^*}\left[R_2 e^{-R_1(S_p^*-s_p^*)} - R_1 e^{-R_2(S_p^*-s_p^*)}\right]}.
$$

Note that this condition is independent of S.

Thus we have that if $\frac{-v_{LA}}{v_{HA}} > D_1(S_p^*, s_p^*)$, $V_H(S) > V_A(S)$ for all $S \leq S_p^*$. Thus in this case, the lower best response is lower in the case where the agent does not pay (he searches more). For the same reasons as in the proof of Proposition 3, the equilibrium is reached at the point where the best response is maximized. Thus in equilibrium, we will have $\widehat{s}^{seq} < s_{seq}$. The reverse holds if $\frac{-v_{LA}}{v_{HA}} < D_1(S_p^*, s_p^*)$.

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