Strategic disclosure of research results: the cost of proving your honesty *

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Abstract

In situations where a biased sender provides verifiable information to a receiver, in order to influence her, we study how strategic reporting affects the incentives to search for information. Research provides series of signals that can be used selectively in reporting. Based on this fact, we show that in equilibrium the sender conducts more research when his research effort is not observed by the receiver. However, in the reporting phase, he discloses all the information he obtained. The sender is therefore strictly worse off when his research effort is unobservable, as he has to incur an extra research cost in order to prove his honesty. In this setting, government subsidization of research can be welfare reducing. Nevertheless, we also find that if the receiver faces uncertainty about the preferences of the sender, certain types will withhold evidence in equilibrium: surprisingly the sender might even conceal positive evidence arguing in his favour. We describe in more detail the case of pharmaceutical companies reporting results of clinical trials on drugs for which they seek approval, and discuss the impact of introducing mandatory disclosure of results.

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1 Introduction

Recent scandals in the pharmaceutical industry, such as the Vioxx case (an anti-inflammatory drug proven to increase the risk of cardiovascular events) or the Paxil case (an anti-depressant that could increase the suicide rates among children), have attracted the public's interest in the possible withholding of negative results by pharmaceutical companies. An article in the Washington Post (2002) quotes a study that claims that the makers of the antidepressants Prozac, Paxil and Zoloft had to conduct 5 clinical trials to obtain the two positive results required by the FDA for approval. Medical journals and Congress have started to address the issue of selective disclosure of results. In May 2005, editors of 11 of the most prestigious medical journals, announced that they would only publish the results of studies that were entered at their start in a publicly available database (see declaration by ICMJE). Congress is considering a legislation, entitled Fair Access to Clinical Trials Act, that would mandate the early registration of clinical trials. All these scandals and initiatives raise a number of questions. Pharmaceutical companies have to decide how many costly clinical trials to conduct and once the information is obtained, what results to disclose. In these conditions, how does the strategic reporting of results affect research incentives? How does the research effort affect the amount of information disclosed? When the research effort cannot be observed, can any information be transmitted credibly? Is it socially optimal to establish mandatory disclosure, thus making the research effort observable? Will positive information ever be withheld? We will answer all these questions in a general theoretical framework applicable to many other settings.

Situations in which a sender communicates verifiable information to a receiver, who will take a decision affecting both their welfare have long been of interest in the literature (in particular in Milgrom (1981) and Milgrom and Roberts (1986)). Milgrom (1981) shows that, when the decision maker knows the quantity of information held by the sender, in every sequential equilibrium of the game, we will observe full disclosure. The idea is that, if some information is withheld, the decision maker considers the worst case scenario, updates her beliefs accordingly and thus the sender will always prefer to reveal all his information. However, these results rest on the assumptions that the information is exogenously obtained and that the receiver knows the number of signals held by the sender. In many situations, including the case of clinical trials, the information transmitted by the sender is not readily available and needs to be obtained through costly research. In this article, we make the search endogenous as we study the interactions between research incentives and disclosure. We will show that studying them jointly allows us to study important behaviours, previously ignored in the literature.

We view research as having two essential functions: it of course allows better knowledge of the underlying state but also provides sequences of pieces of evidence that can be used selectively to influence the receiver. To illustrate the second function, suppose the FDA expects a pharmaceutical company to run 2 clinical trials testing one property of a drug. It might be optimal for the firm to incur the cost of 5 trials to report only the 2 most favourable results. This second function, not taken into account in the literature, will be the main focus of this paper: we will refer to it as the strategic function of research.

To study this alternative function explicitly, we had to propose a different model of research than the one commonly used. In most of the literature,[1] research is modeled as a binary decision: either the sender does not search or he searches and incurs a cost c to obtain one signal that can be informative or not. However, we want to study situations where sequences of signals are obtained and used selectively in reporting.[2] We therefore propose a model, where the outcome of research is a series of infinitesimal positive or negative signals. These can be thought of as a series of small experiments. A positive signal corresponds to a small experiment that gave positive results: for example it could be that a drug does work on a certain type of patient. The aggregate amount of positive signals gives information on the state and allows the agents to update their priors. In this context, increasing Q, the measurable quantity of research, augments the precision but also produces more positive signals that can be used to mislead the decision maker.

In a model where a biased sender first decides on the quantity of research to conduct, obtains series of signals and then selects those to be reported to a receiver, who decides on the policy, we obtain a series of results. We first show that the sender always conducts more research in situations where the receiver cannot observe the amount of research he performed than when his research effort is observable. The intuition is that, in the unobservable case, if the quantity of research the receiver expects is too low, the sender will have an incentive to search further, obtain more favourable evidence, conceal the unfavourable one and thus mislead the receiver into believing the state is higher. The receiver understands these incentives and knows that extra research will be conducted to mislead her, up to the point where the marginal benefits equal the costs. However, surprisingly, in equilibrium the sender reveals all the information he obtained. Therefore we show that the sender is strictly worse off when his research effort is not observed by the receiver: he has to incur the cost of extra research to convince the receiver that he is not hiding any evidence. Therefore, in certain situations, taxing research expenditures is actually socially optimal and might even be strictly preferred by all parties involved. We also find that when two senders compete to provide information, they conduct less research than if they were alone reporting. Finally we show that, when the receiver is uncertain about the bias of the agent or the cost of research, not all information will be revealed in equilibrium. In this case, surprisingly, the sender might even conceal positive information arguing in his favour, to avoid revealing his type.

There are numerous applications of this setup apart from the motivational example

[1] One exception is a working paper by Celik (2003).

[2] We justify in more details in section 3 this new model of the research process.

of clinical trials. It could apply to interest groups providing evidence to influence a decision maker (informational lobbying) or lawyers searching for evidence of their client's innocence. In both cases, the search for information is often delegated to private firms. The sender needs to decide how much to invest in research and, once the results are obtained, what to reveal. In the literature on media bias, economists have sometimes considered journalists as having a desire to influence opinions of their readers (Baron (2006)) or being subject to influence by politicians (Besley and Prat (2004)) . Under these assumptions, our setup also applies to journalists gathering several pieces of evidence on a particular question.

Several other articles are related to our work. Some examine the search for information in other settings. Persico (2000) studies how different voting rules affect the incentives to gather information. He finds that a voting rule that requires large plurality can only be optimal if the information obtained by each decision maker after a search is sufficiently precise. Indeed, they need a big incentive to search as the probability of being pivotal is low. Shavell (1994) looks at whether buyers or sellers of a good have incentives to search for information about the value of that good. We will discuss the results in more detail in section 3. Celik (2003) studies the case where senders conduct research sequentially and shows that there is no equilibrium where the information obtained by the receiver is fully revealed to the receiver. Other articles concentrate on reporting: Sinclair-Desgagne and Gozlan (2003) for instance examine the interaction between a potential polluter and a stakeholder in a situation where disclosure is not mandatory. We also study in our paper how competition between senders affects research incentives. Dewatripont and Tirole (1999) study competition in a different organizational setting: they examine, in a system where contracts specify payments as a function of information obtained, whether a system with competing advocates dominates one with a single non partisan decision maker. They show that when evidence is not concealable, the advocacy system is strictly optimal: it gives incentives for information gathering without abandoning rents.

Our paper is organized as follows: in section 2 we present the model. In section 3 we study a limit case where research is immediately informative. In this situation, even an infinitesimal amount of research will provide full knowledge of the state. This extreme case provides us with most of the intuitions of the model. In section 4 we consider the general case where the outcome of research is subject to uncertainty. In section 5 we study situations where two senders compete to provide information. Finally in section 6 we study cases where the receiver is uncertain about either the bias of the agent or the cost of research and we show it might lead senders to withhold positive evidence.

2 The Model

We describe in this section the details of the model that will be used throughout this article.

2.1 Preferences

As in the cheap talk literature, the instantaneous utilities are:

For the receiver $u_r(p, \theta) = -(p - \theta)^2$.

For the sender $u_s(p, \theta) = -(p - \theta - \delta)^2 - R$.

where:

θ is the state of interest to both the sender and the receiver.

p is the policy set by the receiver.

R is the amount spent by the sender on research (ie we suppose the utility is quasi separable in money).

The parameter δ describes the extent of the bias. Indeed, if the state is known, the receiver's preferred policy p equals θ, whereas the sender's ideal policy is $p = \theta + \delta$.

The receiver will choose the policy p that maximizes her expected utility given the reports of the sender. The policy will therefore be set at $p = E[\theta|r]$.

2.2 Research Technology

The sender will be useful to the extent he provides information on the state θ through research he conducts. The sender and the receiver share a common prior on the state: $f(\theta)$ with support on $[0, 1]$. The sender decides on the quantity Q of research he will perform. This research is costly, the unit cost is noted C.

The outcome of research is modelled as a series of infinitesimal positive and negative signals. This can be thought of as a series of small experiments, of small pieces of evidence. The positive signals indicate a higher value for the state whereas the negative signals indicate a lower value.

Specifically, if the sender conducts an amount Q of research, he will obtain x positive signals given by the distribution $f(x|\theta, Q)$. This aggregate amount of positive signals x thus provides information on the value of θ: the sender can derive a posterior distribution on the state $g(\theta|x, Q)$.

Note that if the receiver knows the quantity Q of research performed and the amount x of positive signals obtained, the negative signals have no informational value. However, we will compare in the article cases where Q is observable to others where it is not. In a situation where Q is not observed, the quantity of negative signals does provide information.

Note also that we could express everything in terms of quantity of negative signals, this would be equivalent.

As we pointed out in the introduction, in most of the literature, authors have chosen to model the search for information as agents drawing one signal that is informative with a certain probability. This was not adapted to study the questions raised in this article for a number of reason. First, we set out to understand how, when multiple results are obtained, they are selected in reporting. Viewing research as a series of positive or negative signals enables us to study the exact opportunities senders have to mislead receivers: by conducting more research, a sender can accumulate more positive signals and can replace some of the negative signals he would have reported, by this more favourable evidence. Second, the model chosen to represent the research process allows us to measure explicitly the amount of research performed and to conduct comparative statics on this variable. Finally we show in section 3 that some of the results of Proposition 1 could have been derived in a simpler model but the scope would have been much more limited.

2.3 Reporting

Once the research is performed, the sender reports a subset of the evidence to the receiver. We suppose throughout the article that the evidence is verifiable.

We denote r the quantity of positive signals the sender reports. The verifiability of the information imposes the constraint: $r \leq x$ (the sender cannot fabricate information and cannot therefore report more positive signals than he obtained).

All these infinitesimal signals are independent pieces of information. So, the sender can choose to report any selection of those. If he obtained 1 positive, then 2 negative and finally another positive, he can choose to report only the 2 positive.

2.4 Timing of the model

To summarize, the timing of the model is the following:

1) The sender decides on Q, quantity of research to perform
2) The sender conducts Q research and obtains signals
3) The sender reports to the receiver a subset or all of these signals
4) The receiver observes the report and sets the policy p

3 A useful benchmark

3.1 The cost of proving your honesty

Different fields require different amounts of research to reach the same degree of certainty. For instance research on the magnitude of climate change, in spite of the amounts already performed, remains very imprecise. On the other hand testing a new product for specific properties can lead to quick conclusions. In this benchmark, we consider the limit case where research is immediately informative.

We therefore suppose that the distribution of signals takes a particular form $f(x|\theta, Q) = 1_{x=\theta Q}$: if the sender conducts an amount Q of research, he knows for sure he will obtain θQ positive signals and will therefore be able to infer the exact value of the state. An infinitesimal amount of research is therefore sufficient to obtain full information about the state. We described in the introduction two essential functions of research: achieve better knowledge of the state and influence the receiver (the strategic function). This benchmark case abstracts from the first function to concentrate on the second one and provides most of the intuitions useful for the general case studied in section 4.

As in the rest of the article, we will compare the situation where the amount of research performed by the sender is not observed by the receiver, to the observable case and to the social optimum. In this benchmark case, if the receiver observes the amount of research performed by the sender, only an infinitesimal amount will be conducted, enough to reveal the exact state. This is also the social optimum as more research does not bring better information and is therefore a social waste. We describe in the following proposition the case where the research effort of the sender is not observed by the receiver.

There exists a lot of Pure Strategy Bayesian Nash Equilibria depending on the beliefs of the receiver off the equilibrium path (when the sender reveals he has conducted more research than the equilibrium amount Q^* by reporting $r > Q^*$ positive signals). However they all share common properties given by the following proposition.

Proposition 1 ***All Pure Strategy Bayesian Nash Equilibria of the game where the quantity of research is not observed by the receiver are characterized by:***

(a) No information is withheld by the sender on the equilibrium path.

(b) The amount of research performed by the sender is strictly greater than if his research effort was observable ($Q^* = \frac{2\delta E(\theta)}{C} > 0$).

(c) The sender is strictly worse off than if his research effort was observable.

Proof: see appendix.

Table 1: Percentage of publications in NEJM sponsored by a pharmaceutical company

	Jul 04	**Aug 04**	**Sep 04**	**Oct 04**	**Nov 04**	**Dec 04**	**Jan 05**	**Feb 05**	**Mar 05**	**Apr 05**
Before Mand. Disclosure	13%	16%	26%	31%	37%	25%	20%	6%	26%	29%
	Jul 05	**Aug 05**	**Sep 05**	**Oct 05**	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	**Apr 06**
After Mand. Disclosure	23%	14%	16%	7%	26%	11%	14%	20%	24%	25%

Before discussing in detail these results, we present some data that illustrates result (b) in the case of clinical trials. As mentioned in the introduction, editors of 11 of the most prestigious medical journals decided that they would only publish the results of studies that were entered at their start in a publicly available database (see declaration by ICMJE), starting July 2005. In effect, these journals decided to move from a system where the research effort was unobservable to one where it could be at least partially observed. We collected data on the publications of one of the journals that committed to this system, the New England Journal of Medicine and recorded the number of published studies that were sponsored by an industrial group.[3] We see in table 1, that the percentage of published studies that were sponsored by an industrial group decreased every month after the adoption of the disclosure requirements except for the months of July and April. Overall, the percentage of publications sponsored by a biased group decreased from 24% to 18% (significant at the 13% level, tstat=-1.578). This seems to confirm result (b): moving to a system with observable research effort decreases the amount of research performed in equilibrium. Of course, this is only partial evidence for a number of reasons,[4] but it gives some empirical confirmation of our results.

The intuition for result (b) is that, if the quantity of research the receiver expects is too low, the sender will have an incentive to search further and obtain more positive signals. He will then still report the quantity of signals the receiver expects, but replace some negative signals by positive ones and thus mislead her into believing the state is higher. The receiver understands these incentives and knows that extra research will be conducted to mislead her, up to the point where the marginal benefits equal the costs.

[3]The ideal would have been to obtain the percentage of submitted studies sponsored by pharmaceutical companies, but the journal editors did not keep information about sponsors for all of the manuscripts sent to them. However we can note that during that period, the number of submissions to the New England Journal of Medicine was rather stable (3430 submissions in 2004 and 3595 in 2005).

[4](a) it is still early to judge the effect of such requirements as these studies take time (b) this is only data on publications and therefore we are implicitly assuming that the ratio of publication to research is constant.

Result (a) is more surprising: in equilibrium, although he performs more research and his research effort is unobservable, the sender reveals all the information he obtained. The intuition is that the receiver knows all the parameters of the game and thus, in equilibrium, can compute, though she can't observe, the quantity of information obtained by the sender. Therefore, Milgrom's unraveling idea applies. This even suggests that if the infinitesimal signals we are considering, took a more complicated form (not just binary signals), we would still get full revelation; as in Milgrom's article, the only possible equilibrium belief of the receiver would be one of extreme skepticism. Of course, result (a) relies on the assumption that the receiver has perfect knowledge of all the parameters of the game (preferences, cost of research...) and we examine in section 6 how the results change when we include some degree of uncertainty.

Result (c) is a consequence of the two previous results: in equilibrium, when his research effort is unobservable, the sender conducts more costly research but reveals all the signals he obtains and therefore the receiver sets the same policy as he would have in the observable case. **The sender has to incur an extra cost just to prove his honesty, to demonstrate he is not hiding any evidence**. This extra cost has been up till now ignored and we will show in the next sections that the results are robust to variations in the assumptions of the model.

We want to discuss the link between our results and those obtained by Shavell (1994). The focus of the two papers and the mechanisms studied differ greatly. Shavell examines whether it is optimal for sellers to make expenditures to acquire information on the value of a good. The research in his paper is modeled as a binary decision and a maximum of one signal is obtained. He shows that when disclosure is mandatory, the probability of searching increases (as in our result (b)). However, the results he obtains depend crucially on the assumption that there are different types of sellers having different costs to acquire information. In particular, as opposed to our result (a), not all information will be revealed in equilibrium: a type with low cost of research who obtains a bad signal will hide this signal and pretend he is a high type who didn't search. Furthermore, we can show that in his model, the low types will be strictly better off under unobservable research effort whereas the high types strictly prefer mandatory disclosure.[5] This is radically different from our result (c). This is due to the fact that we concentrate on a very different question: research that yields series of signals that can be used selectively in reporting. The sender is then always better off under mandatory disclosure because he can avoid the cost of having to prove his honesty.

We note that the difference between the research efforts in the observable and unob-

[5]We use the notation introduced in Shavell (1994). Consider the lowest type facing cost 0 to obtain information. Under mandatory disclosure, he obtains $E[v]$ whereas when his search is unobservable he can expect $E[v \geq v*] + v*P[v \leq v*] > E[v]$. On the other hand the type facing the highest cost will not search and will obtain $v* < E[v]$, thus strictly preferring mandatory disclosure.

servable cases, $Q^* - 0 = \frac{2\delta E(\theta)}{C}$, is decreasing in the unit cost of research, as we would expect. **It is also increasing in the bias: therefore a sender with extreme views will have to spend more on research activity than one with more moderate positions, for an identical result**. This type of sender will therefore tend to favour other modes of action. This is a phenomenon we often observe with lobby groups such as environmental NGOs: the National Research Defence Council will tend to lobby directly decision makers whereas a group such as Greenpeace, with more extreme views, will favour public actions. The intuition is not that groups with more extreme views tend to bias more their reports (in equilibrium they transmit the same amount of information), but that the decision maker expects more research from them (as a guarantee that they are not concealing any information).

3.2 Correcting the inefficiencies

In the previous section we observed that more research was performed when the research effort was unobservable. As we are studying situations where research is immediately informative, this extra amount of research is socially wasteful. In this section, we want to examine solutions to correct this inefficiency. The first obvious solution is a policy that would render the research effort observable (as the one set in place by some medical journals). We address this in section 3.3.1. However this solution is not practical in all situations and we study an alternative approach: a tax. We want to be very explicit here: we are placing ourselves throughout this article in a very specific context where research is used not only to attain better knowledge of the phenomenon, but also to influence a decision maker. We do not make any statements on research in general.

We examine in this section two types of taxes:
(a) A tax on the quantity of research.
(b) A tax on the reports.

We want to emphasize that the tax in case (a) does not make the research effort observable. The tax declaration submitted to the IRS is not available to the public, and even if it were it would be hard to allocate an aggregate amount to different issues. Furthermore, an alternative solution could be to tax the research providers.

3.2.1 Mandatory disclosure

As previously described, the proposal by medical journals to require mandatory disclosure effectively rendered the research effort observable. Congress is considering a similar measure in its legislation entitled Fair Access to Clinical Trials Act. These proposals were made after a few scandals raised concerns that drug companies concentrate on successful trials and thus withhold information from the public. We will discuss in more details in section 6 the effect of mandatory disclosure on the withholding of information. However, our analysis in the previous section reveals another benefit that the promoters of the proposal did not consider: this measure makes the amount of research performed observable and thus eliminates the extra research conducted to convince the receiver that no evidence is withheld. As we saw from our small empirical illustration, the amount of research performed by biased agents decreased significantly after the adoption of the disclosure requirements by medical journals. We discuss in section 4.3.2 if a move to mandatory disclosure is still beneficial in the general case.

Mandatory disclosure seems an appropriate solution when the relation between the sender and the receiver is well established and formalized. This is the case for pharmaceutical companies and medical journals. It is also the case for lawyers and juries. We could imagine a similar system where lawyers would need to declare, at the start of the case, funds they spend searching for evidence, to be able to use the results during the trial. However it seems harder to implement in other cases where the relation is much more informal (such as interest groups and politicians). This is why we examine in the next sections other potential solutions.

3.2.2 Tax on the quantity of research

Let us consider a tax τ on the quantity of research, in the case where research effort is unobservable. The unit cost of research now becomes $(C + \tau)$.

Proposition 2 *In all Pure Strategy Bayesian Nash Equilibria the following is satisfied:*
(a) The sender performs an amount of research $Q^*(\tau) = \frac{2\delta E(\theta)}{C+\tau}$.
(b) The government can raise revenue with this tax without changing the welfare of any of the parties.

Proof:
(a) The unit cost of research C just becomes $(C + \tau)$ and we can apply Proposition 1.
(b) We have:

- The final policy implemented by the receiver is the same: the sender reports truthfully and research reveals the exact state θ.
- The cost of research for the sender remains the same (equal to $2\delta E(\theta)$), so his utility is unchanged.
- The government raises revenue $\tau Q^*(\tau)$. ■

This tax is the "ideal tax": the government raises revenue leaving all agents utilities unchanged. This is true however in the benchmark case, i.e in a limit case. We will determine in section 4 if the results are still valid in a more general situation. One of the limitations of this tax is that it would have to specify very clearly what type of research it applies to: the idea is to limit excessive research conducted to influence a decision maker, not to hinder research in general. Alternatively, the desirability of this type of tax could be judged on the empirical mix between research used to convince and research purely used to attain a better knowledge of the state.

3.2.3 Tax on the reports

A tax that targets directly research used to convince is a unit tax τ on the reports. Suppose the sender reports r positive signals, he would have to pay a tax $r\tau$. We study here its properties:

Proposition 3 *In all Pure Strategy Bayesian Nash Equilibria:*
a) The sender performs an amount of research $Q^*(\tau) = \frac{2\delta E(\theta)}{C+\tau E(\theta)}$.
b) The government can raise revenue with this tax without changing the welfare of any of the parties.

Proof: see appendix.

We are again in this "ideal fiscal environment". This tax would however be harder to implement than the previous one and probably less politically acceptable as the tax rate τ would need to be bigger to raise the same revenue. On the other hand it has the virtue of targeting specifically the type of research we are concerned about: only the research used to convince is taxed in this situation.

4 Research and disclosure

We wish to determine in this section if the results obtained in the benchmark case are still valid when we make the research technology more realistic. We now suppose that the outcome of research is subject to uncertainty. If the sender conducts an amount of research Q, the quantity of positive signals he obtains is given by the distribution $f(x|\theta, Q)$. We suppose that this density is differentiable with respect to Q.

We use the following notations:
- $g(x, Q)$ is the unconditional distribution of signals.
- $f(\theta|x, Q)$ is the posterior distribution of the state given the signals and the amount of research performed.
- $Var[\theta|x, Q]$ is the conditional variance of the posterior distribution of θ given the signals and the amount of research performed.

We make the following assumption:

$$\int_0^\infty Var[\theta|x,Q]\ g(x,Q)dx \text{ is decreasing and convex in Q} \qquad \text{(A)}$$

Assumption (A) means that the more research is performed, the more precise its outcome becomes on average: on average the variance of the posterior decreases with Q. It also implies that the marginal gains in precision are decreasing with Q (convexity). This is a reasonable property for the results of experiments: the more research we conduct, the better informed we become, but the marginal gains decrease as our understanding improves.

4.1 Observable case

It turns out that assumption (A) guarantees the uniqueness of the solution in the case where the research effort is observable:

Proposition 4 *Under assumption (A), in situations where Q is observed by the receiver, in the unique pure strategy equilibrium the amount of research performed Q_0 is solution to:*

$$C = -\frac{\partial}{\partial Q'}[\int_0^\infty \ Var[\theta|x,Q']\ g(x,Q')dx]\ |_{Q'=Q_0}$$

Proof: see appendix.

If the pharmaceutical companies'research activity (number of clinical trials) was observed by the policy maker, they would search up to the point where the marginal cost equals the marginal benefits from getting better information (benefits from decreasing the variance of the posterior).

4.2 Unobservable case

We now turn to the case where the quantity of research performed by the sender is unobservable. In this case, he has to make 2 strategic decisions:

1) The quantity of research to perform.
2) What to report if x positive signals are obtained.

4.2.1 Reporting phase

Let's examine the second consideration. We consider the reporting strategy in a situation where the receiver's belief is that an amount Q^* of research was conducted and the sender in reality performs an amount of research $Q' > Q^*$ and obtains x positive signals.

The sender's desired policy is then $E[\theta|x,Q'] + \delta$.

Therefore his ideal report would be r such that $E[\theta|r, Q^*] = E[\theta|x, Q'] + \delta$ (where the receiver believes Q^* research was conducted.
The only constraint on the report is that $r \leq x$ (verifiable evidence).

Because of this constraint, the sender cannot always obtain his preferred policy. The intervals on which this ideal policy is not attainable are denoted $A_k = [x_{k1}, x_{k2}]$ $k \in 1, .., K$. In these intervals, the constraint is binding and therefore the sender reports $r = x$ (he would like a higher policy but cannot attain it, he therefore tries to induce the highest policy possible corresponding to $r = x$).

At the boundaries of the interval, x_{k1} and x_{k2}, we have $E[\theta|x, Q^*] = E[\theta|x, Q'] + \delta$ (the ideal policy becomes attainable).

To illustrate this, suppose $E[\theta|x, Q] = \frac{x}{Q}$. The ideal report is therefore characterized by $\frac{r}{Q^*} = \frac{x}{Q'} + \delta$. However, we have the constraint $r = \frac{Q^*}{Q'}x + \delta Q^* \leq x$. Therefore, on $A_k = [0, \frac{\delta Q^*}{1-\frac{Q^*}{Q'}}]$, the ideal policy is not attainable (he reports $r = x$) whereas on $(A_k)^c = [\frac{\delta Q^*}{1-\frac{Q^*}{Q'}}, +\infty]$ it is (he reports $r = \frac{Q^*}{Q'}x + \delta Q^*$).

Note that this is an example where there is only 1 interval of each type, but that there could exist multiple intervals of each type if the research technology was less smooth.

4.2.2 Research phase

Let us now turn to the research phase. The sender can only obtain his preferred policy in $(\bigcup A_k)^c$. The sender therefore chooses *Q'* in order to:

$$max_{Q'} \; -\int_0^1 \int_{\bigcup A_k} (E[\theta|x, Q^*] - \theta - \delta)^2 \; f(x|\theta, Q') f(\theta) \; d\theta \; dx$$
$$-\int_0^1 \int_{(\bigcup A_k)^c} (E[\theta|x, Q'] + \delta - \theta - \delta)^2 \; f(x|\theta, Q') \; f(\theta) \; d\theta \; dx \; - CQ'$$

The solution to this problem is characterized by the properties in Proposition 5:

Proposition 5 *When the amount of research is unobservable, the unique equilibrium is characterized by an amount of research Q^*, solution to:*

$$C = -\frac{\partial}{\partial Q'}[\int_0^\infty Var[\theta|x, Q'] \; g(x, Q')dx] \; |_{Q'=Q^*}$$
$$-2\delta \int_0^1 \int_0^\infty \frac{\partial}{\partial Q'}[E(\theta|x, Q')]|_{Q'=Q^*} \; f(x|\theta, Q^*) \; f(\theta)dx \; d\theta$$

Furthermore:
(a) $Q_O < Q^*$: more research is performed when the research effort is unobservable
(b) No information is withheld by the sender on the equilibrium path
(c) The sender is strictly worse off when his research effort is unobservable

Proof: see appendix.

The first term on the right side of this equation represents the marginal benefits from obtaining a better knowledge of the state (decreasing the variance). This gain did not exist in the benchmark case where research was immediately perfectly informative. The second term corresponds to the strategic function of research: it represents the potential benefits from conducting more research in order to obtain more positive signals and thus mislead the receiver. In equilibrium marginal benefits from more research have to be equal to marginal costs. Note that if you consider the values of the benchmark case ($f(x|\theta, Q) = 1_{x=\theta Q}$ and $E(\theta|x, Q) = \frac{x}{Q}$), proposition 5 confirms the result of proposition 1, i.e the second term equals $\frac{2\delta E(\theta)}{Q}$.

As in the benchmark model, we find that the sender conducts more research when the receiver cannot observe his research effort (result (a)), that he reveals all his information in equilibrium (result (b)) and that he is therefore strictly worse off than if his research effort was observable (result (c)). The intuition for result a) is the same as for proposition 1. Furthermore, given that in equilibrium he reveals all the information he obtained, for the sender it is in practice as if the receiver was observing his research effort. Therefore doing more research decreases his utility as the optimal choice of Q under the observability assumption is the amount Q_0. Once again, he has to incur an extra cost to convince the receiver of his honesty. Nevertheless, as we show in the next section, we do not reach the same conclusions as in section 3 relative to overall social welfare.

4.3 Should we tax or subsidize research?

We reevaluate in this section the question whether research should be subsidized or taxed in situations where the results are used to influence.

Proposition 6 *The optimal tax (or subsidy) in the case of lump sum redistribution (or tax) when research is unobservable is given by:*

$$\tau^* \;=\; -2\delta \int_0^1 \int_0^\infty \frac{\partial}{\partial Q'}[E(\theta|x, Q')]|_{Q'=Q_W}\; f(x|\theta, Q_W)\; f(\theta)dx\; d\theta \;-\; \frac{C}{2}$$

where Q_W is the socially optimal amount of research given by:

$$\frac{C}{2} = -\frac{\partial}{\partial Q'}[\int_0^\infty \; Var[\theta|x, Q']\; g(x, Q')dx]\;|_{Q'=Q_W}$$

Proof: see appendix.

Let us first discuss the second equation characterizing the social optimum. Social welfare is understood as the sum of sender and receiver welfare. Because of assumption (A) on the variance, the amount of research performed when research is observable is such that $Q_0 < Q_W$, it is socially suboptimal. The intuition is that the sender, when he decides on his research effort, ignores the positive effects of the information he gathers on the receiver's welfare. There is therefore an ignored externality. In the unobservable case, the strategic consideration can increase the amount of research conducted in equilibrium and potentially correct this ignored externality.

Specifically, with the subsidy (or tax) described in the first part of Proposition 6, the social optimum becomes attainable. The first term represents the strategic consideration (positive benefits from potentially misleading the receiver). The second term represents the cost of the extra research required to attain the social optimum (we will refer to it as the externality). The two effects work in opposite directions. Whether the strategic consideration corrects partially, perfectly or excessively the externality determines whether τ^* is a tax or a subsidy. Note that in the benchmark case, research always needed to be taxed as there was no externality to correct (in both the observable case and the social optimum, only an infinitesimal amount of research was needed).

4.3.1 Choice between tax and subsidy

In this section we study the consequences of Proposition 6. In particular, we determine how the different parameters of the model affect the choice between tax and subsidy.

Corollary 1: There exits δ^* such that research should be subsidized if and only if $\delta \leq \delta^*$.

This corollary states that for any research technology and for any value of the other parameters, if the bias of the sender is big enough, it is socially optimal to tax research. The intuition is that the ignored externality is independent of the bias of the sender. If the bias is too big, the strategic consideration therefore overcorrects this externality. In such a case the amount of research performed in the unobservable case is socially excessive. Note that the fact the externality is independent of the bias of the sender is true because of quadratic preferences. Other assumptions on preferences might therefore change our results.

Corollary 2: For high values of the bias, τ^* is increasing in the unit cost of research C and for low values it decreases with C.

This corollary states that there is no simple monotonic relationship between the cost of research and the choice between tax and subsidy. The intuition is that both the externality and the strategic consideration are increasing in the cost of research (the strategic consideration is decreasing in Q and Q is decreasing in C). The balance between the two marginal effects is therefore determined by the bias of the sender as described in the corollary.

We have obtained systematic criteria to choose between tax and subsidy. We learned that if research is quickly informative (section 3) or if the sender is strongly biased (corollary 1), a tax is socially optimal. However, ultimately, the choice becomes an empirical question depending on the distribution of biases, costs and research technology.

4.3.2 Mandatory disclosure

The results in this section are also useful to analyze the benefits of introducing mandatory disclosure of research results, for instance in the context of clinical trials. Pharmaceutical companies will tend to spend socially insufficient amounts to test the properties of their drugs. The fact that the research effort is unobservable, forces them to conduct more research as we described in all our previous results and confirmed in our empirical application, thus potentially bringing the amount conducted closer to the social optimum. From the previous section, we can conclude that for instance, if the bias of the sender is small, introducing mandatory disclosure could lead to a socially harmful diminution of research performed. **This suggests that if Congress decides to move to a system of mandatory disclosure of clinical trial results, such a reform should be accompanied by a stricter definition of the test required to obtain approval, or in other words the imposition of a minimum of research to be performed.**

5 Competition between senders

In this section, we study how our results extend to the case of two senders gathering information independently and transmitting it strategically to the decision maker. In most practical applications of the model, the most interesting situation is one where these competing agents have opposing preferences. If we want to study some aspect of lobbying for instance, it is important to consider the competition between two lobbies with opposing views. The natural conjecture is that competition tends to increase the incentives for research. We will show that this is not the case here, as it decreases the marginal returns from attempting to mislead the receiver.

We suppose the utility function of sender 1 is given by $u_1 = -(p - \theta - \delta_1)^2$ and that of sender 2 is $u_2 = -(p - \theta - \delta_2)^2$ (with $\delta_1 > 0$ and δ_2 positive or negative). We suppose that the receiver knows the type of both agents. Furthermore, we present the results in the setup of section 3.

We will see in proposition 7 that, in equilibrium, both parties reveal all their information and therefore report the same state (research is perfectly informative). Nevertheless, a lot of equilibria will exist depending on the beliefs of the receiver off the equilibrium path (when conflicting reports are given by the two senders). However, when we impose a reasonable restriction on these beliefs, all equilibria share a surprising property: less research is conducted by both senders than if they were left alone to communicate.

Note that we choose to describe the reports made by the senders as reports on the state. The actual reports are the aggregate amounts of positive and negative signals, but given a set of beliefs of the receiver (that are correct in equilibrium), they are equivalent to reporting the state. Let $p(\theta_1, \theta_2)$ be the policy set by the decision maker when she receives message θ_1 from sender 1 and θ_2 from the second sender. We have on the equilibrium path $p(\theta, \theta) = \theta$. Furthermore, off the equilibrium path, we will impose restrictions that we argue are very reasonable.

5.1 Senders with opposing biases

We introduce the following restriction on beliefs off the equilibrium path in the case where senders have opposing preferences ($\delta_1 > 0$ and $\delta_2 < 0$):

Restriction A: $p(\theta_1, \theta_2) \in [\theta_2, \theta_1]$

Restriction A is justified by the following: sender 1 observes perfectly the state and has a bias towards a higher policy, so he would not voluntarily hide positive signals; the state cannot be bigger than θ_1. In the same way, sender 2 will never hide negative signals therefore the state cannot be smaller than θ_2. We then obtain the following result:

Proposition 7 *Under restriction A, for all PBNE where the quantity of research conducted by the sender is not observed by the receiver, the equilibrium is such that:*

a) all the information is revealed in equilibrium

b) the equilibrium amounts of research Q_1, Q_2, conducted by each sender are such that: $Q_i < \frac{2\delta_i E(\theta)}{C}$, $i = 1, 2$.

Proof: see appendix.

The natural conjecture would be that the two parties, when forced to compete, would conduct more research. Proposition 7 leads to the opposite conclusion: both senders conduct less research than if they were alone to provide information to the decision maker. The intuition is the following: because the other sender is revealing all his information in equilibrium, the marginal benefit from searching for more signals to mislead the receiver is smaller than if he was alone as the information provided by both parties are perfect substitutes.

Furthermore, this result remains valid in the general setup of section 4. The difference between section 4 and the benchmark case is that the decision on research is determined by two considerations: the strategic reporting and the information gathering. The results on competition obtained in this section generalize on both accounts. First, the intuition for the strategic function is the same as in Proposition 7: because the other sender is revealing all his information in equilibrium, the marginal benefits from obtaining more signals to mislead the receiver are smaller. Second, the fact that the other sender is obtaining information to gain a better knowledge of the state, also reduces the benefits from research as an information tool for the first sender. Combining these two effects, in the general setup, we also obtain that less research will be conducted by each sender than if they were alone reporting.

5.2 Senders biased in the same direction

In this case ($\delta_1 > 0$ and $\delta_2 > 0$), the restriction on beliefs off the equilibrium path can even be made stricter.

Restriction B: $p(\theta_1, \theta_2) \leq min(\theta_1, \theta_2)$

Both senders are biased in the same direction therefore neither sender has an interest in dissimulating positive evidence and therefore the state has to be smaller than the minimum report. Under this restriction we obtain the following result.

Proposition 8 *Under restriction B, for all PBNE where the quantity of research is not observed by the receiver, all the information is revealed in equilibrium and both types conduct the same amount of research as if their research effort was observable.*

Proof: see appendix.

With restriction B on beliefs off the equilibrium path, all the benefits from conducting more research to mislead the receiver disappear in equilibrium. Indeed, the competitor will be reporting truthfully, so if the sender reports a higher ratio of positive to negative signal, he will be ignored. The equilibrium therefore unravels and only an infinitesimal amount of research will be conducted, sufficient to reveal exactly the state. **There are therefore more opportunities for strategic withholding of information when the competitor has radically opposed preferences (previous case) then when preferences are more aligned.** When senders are biased in opposite direction, if sender 1 decides to report more positive signals, the receiver cannot know if it is sender 1 reporting more or sender 2 reporting less: senders can use this indeterminacy to their benefit.

6 Hiding good news

All the previous results have highlighted the fact that in equilibrium all the information obtained by the sender is revealed to the receiver. In equilibrium the receiver can compute the amount of research conducted and the receiver is therefore indifferent between revealing or hiding the bad signals. The consequence was that senders always had to incur an extra cost to convince the receiver they were not hiding any evidence.

How do we interpret these results in the light of the casual evidence provided by the case of clinical trials? The Washington Post reports that the makers of the antidepressants Prozac, Paxil or Zoloft had to run at least five clinical trials, comparing their drug to a placebo, to obtain the two positive required by the FDA. Such an observation can be the expression of two possible theories. The first, consistent with the models in the previous sections, is that the FDA knows that in equilibrium in the order of five clinical trials will be conducted (each trial is extremely costly) and that 2 positive to 3 negative is an acceptable ratio to approve a drug. The second (which is a more elaborate version of the first theory) is that the FDA is not aware of all the incentives of the companies [6] and that it can be actually mislead in equilibrium. We will examine in this section, this second more elaborate interpretation of the casual evidence.

Specifically, we depart in this section from the assumption made in the model of the previous sections that the receiver has full information on all the parameters of the model. We show that with some uncertainty about the type of the agents, some information will be withheld in equilibrium. Surprisingly, in some instances the information withheld will actually be positive (i.e information arguing in the sender's favour). We initially suppose the receiver is uncertain about the bias of the agent. In particular, we assume that the bias can take two values: δ_L with probability p and δ_H with probability 1-p, and that both senders are biased in the same direction ($\delta_H > \delta_L > 0$). We will show that the results also apply when the uncertainty relates to other parameters of the model.

Proposition 9 *In all PBNE:*
(a) the low type will conduct less research than the high type ($Q^*_L < Q^*_H$)
(b) for a certain range of results, ***the high type will withhold positive information*** *(if $x \in [Q^*_L, Q_b]$, the high type reports $x_r < x$.)*

Proof: see appendix.

The intuition for result (a) is the following: at his equilibrium level of research, the low type is indifferent between searching for more information to mislead the receiver or

[6] For instance the FDA could be unaware of the profits the company expects from a particular drug: in terms of our model, higher profits will translate in higher bias.

stopping his research effort. The high type however is more biased, so for the same level of research he will have more incentives to pursue his search effort and replace bad signals by good ones. Therefore, in equilibrium, the receiver expects more research from the high type as described in result (a).

Result (b) surprisingly states that in equilibrium, the high type might withhold positive information that goes in his favour. This occurs if the range of positive results is close to Q_L^* but slightly superior (we describe in more detail the equilibrium behavior in Proposition 10). In such cases the sender prefers hiding some positive information in order to avoid revealing his type and have the information he provides be judged on a stricter basis.

This seems to correspond to behavior observed in practice. The clinical trial called "Vigor study" conducted by Merck, that was the first to suggest that Vioxx might increase the risk of cardiovascular incidents, was initially meant to show that the drug had fewer side effects on the stomach and intestines than the other drugs in its category (and successfully proved this). In general a lot of clinical trials aimed at finding new applications of a drug lead to the discovery of possible side effects. In such circumstances, the results might be withheld. Our model therefore suggests that the cost of having the research effort be unobservable corresponds not only to the withholding of negative signals but also to not revealing positive results. Both of these are socially costly.

In the following proposition we provide some further characterization of the equilibrium behavior for a specific distribution of the state: $\theta \sim U[0,1]$.

Proposition 10 *Under the assumption that $\theta \sim U[0,1]$, when research is unobservable, we find a PBNE characterized by the amounts $Q_0 < Q_L < Q_B < Q_H$ such that:*
a) If the amount of positive results x is such that $x \in [0, Q_0]$, both types report truthfully.
b) If the amount of positive results x such that $x \in [Q_0, Q_L]$, both types pool on one message r and the receiver sets a unique policy q.
c) If the high type obtains an amount of positive results x such that $x \in [Q_L, Q_B]$, he withholds some positive information and the receiver sets policy q.
d) If the high type obtains an an amount of positive results x such that $x \in [Q_B, Q_H]$, he reports truthfully.
e) The low type conducts less research than if his type was known with certainty.

As indicated in **result (c)** (that follows from Proposition 9), mandatory disclosure of research results can avoid a cost generally ignored: the fact that positive information might be withheld in equilibrium. Moreover, **result (b)** suggests an additional cost resulting from a situation where research is unobservable: for a certain range of results (in $[Q_0, Q_L]$), neither type is able to transmit credibly the information he obtained and they pool on a single report. The policy chosen by the receiver will therefore be suboptimal. This is yet another benefit from instituting mandatory disclosure. Finally **result (e)** indicates that less research is conducted by the low type in equilibrium than if his type was known. The intuition is that, in the reporting phase, it is harder to transmit information credibly and therefore the marginal benefits from conducting more research to mislead the receiver are smaller. We show in the following corollary that similar results will be obtained when the uncertainty relates to other parameters of the model.

Corollary: If there are two types C_L and C_H such that C_L faces a lower marginal cost of research ($C_L < C_H$), in all PBNE:
a) the low type will conduct more research than the high type ($Q_L^* > Q_H^*$)
b) for a certain range of results, the low type will withhold positive information (if $x \in [Q_L^*, Q_b]$, the high type reports $x_r < x$.)

These results will extend to other sets of parameters. In any situation where one type has more incentives to mislead than the other or faces a research technology that facilitates the gathering of information, he will conduct more research and, for some range of results, will withhold positive information to avoid revealing his type. This effect is a result of the interaction between research and disclosure. Because different types choose different amounts, the quantity of research performed characterizes the type in equilibrium. Introducing such uncertainty in a simple disclosure model without a research phase would not modify the full disclosure result obtained by Milgrom and Roberts and in the disclosure phase, both types would reveal all their information. It therefore proved essential to study in conjunction the research and disclosure phases to demonstrate these effects.

7 Conclusion

We have studied in this article the interaction between research and the strategic disclosure of its results. We have concentrated on the fact that the search for information often produces sequences of pieces of evidence that can be used selectively in reporting. Let us summarize our findings in the case of clinical trials conducted by pharmaceutical companies to obtain FDA approval. We will also give elements of response to the question: should mandatory registration of trials be implemented?

We highlighted in this article several additional benefits of adopting mandatory disclosure requirements, benefits generally ignored in the debates on these questions. We showed in sections 3 and 4 that, in situations where their research effort is not observed by the FDA, pharmaceutical companies will need to conduct more research to convince the agency that they are not hiding any evidence (propositions 1 and 5). Thus, in such an environment, these companies would be strictly better off under a mandatory disclosure system. Mandatory disclosure could avoid them the cost of proving their honesty. In section 6 we show that in an environment with uncertainty on the incentives of the firms or on their research technology, the absence of mandatory disclosure can not only lead to the withholding of negative results as commonly thought, but also to the hiding of positive ones (Proposition 9). Firms might withhold positive results in order not to reveal that they conducted more research. Mandatory disclosure could also render credible communication of results easier (proposition 10). The fact that the high type can withhold information in equilibrium, makes credible communication by the lower types more difficult.

However, our results also highlighted the fact that adopting mandatory disclosure should be done with caution. We show in section 4 that when their research effort is observable, companies tend to conduct a socially insufficient amount of test on their drugs as they are less concerned than the public about side effects (proposition 6). Therefore, the extra amount of research performed to convince might be socially beneficial. In particular we show that if the bias of the sender is small, mandatory disclosure might become socially costly as it decreases the amount of research performed. This suggests that a system of mandatory disclosure should be accompanied with a stricter specification by the FDA of the minimum tests required to obtain approval of a drug, in order to keep the research effort from decreasing too dramatically. Note also that, although it is not exactly included in our model, mandatory disclosure might decrease the attractiveness of another type of research: the research aimed at finding new applications of a drug. Companies might shy away from this type of experimentation for fear of finding side effects that could decrease the attractiveness of the initial drug. The effect of mandatory disclosure on the incentives to conduct this type of research should be examined more closely. This article therefore argues in favour of mandatory disclosure associated with a stricter set of tests needed to obtain approval.

All these results, obtained in a general framework with lots of potential applications, illustrate the fact that it is essential to study jointly the research and disclosure phases. Empirical validation could be an interesting avenue for research and, in that respect, the new measures taken by the International Committee of Medical Journal Editors and the Fair Access to Clinical Trials Act could provide unique opportunities. The challenge however will be to obtain a measure of research activity before their adoption when the research effort was still unobservable.

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Appendix

Proposition 1

For clarity concerns, we first prove the results in cases where the bias of the sender in favor of a higher policy is large ($\delta > 1$ for instance). Such an agent would never withhold information that could lead the receiver to set a higher policy. His optimal reporting strategy is therefore to always report all the positive signals he obtained. The reports takes the very simple form r=x. We show later on in the proof how the results generalizes for all values of the bias.

Case I: large bias

Let the beliefs off the equilibrium path (when $x > Q^*$ positive signals are reported) be such that the policy set by the receiver is *h(x)*, where h is assumed differentiable and the derivative is bounded.

The strategies of the receiver are therefore:
- If the sender reports $r \leq Q^*$ (on the equilibrium path), the receiver believes the report and therefore sets the policy $E[\theta|r] = \frac{r}{Q*}$.
- If the sender reports $r > Q^*$ (off the equilibrium path), the receiver sets policy *h(r)*.

If the sender performs an amount Q' of research, he obtains $\theta Q'$ positive signals, his reporting strategy is:
- $r = \theta Q'$ if $\theta Q' < Q^*$ (ie $\theta < Q^*/Q'$)
- $r = Q^*$ if $\theta Q' > Q^*$ (ie $\theta > Q^*/Q'$).

The reporting strategy described here is clearly a best response to the receiver's strategy. In particular, off the equilibrium path, it is optimal for the sender to report Q^* and thus obtain the highest possible policy of 1. This won't be true in the small bias case (see case II)

We now have to determine the optimal research strategy: the sender will choose Q' to maximize

$$max_{Q'} - \int_0^{min(Q^*/Q',1)} [\frac{\theta Q'}{Q^*} - \theta - \delta]^2 f(\theta) d\theta$$
$$- \int_{min(Q^*/Q',1)}^1 [1 - \theta - \delta]^2 f(\theta) d\theta - CQ'$$

For $Q' > Q^*$, The FOC is:

$$C = - \int_0^{Q^*/Q'} \frac{2\theta}{Q^*} [\frac{\theta Q'}{Q^*} - \theta - \delta] f(\theta) d\theta$$
$$+ (Q^*/Q'^2)(1 - \theta - \delta)^2 - (Q^*/Q'^2)(1 - \theta - \delta)^2$$

For Q^* to be an equilibrium, we need this first order condition to be satisfied at Q^*, we therefore take the limit as $Q' \to Q^*$.

The first term is continuous in *Q'* and therefore, taking the limit, we find that the equilibrium is characterized by:

$$Q^* = \frac{2\delta E(\theta)}{C} \tag{1}$$

We find that the FOC are sufficient as the second order derivative is negative at the optimum $V''(Q^*) = -\frac{2}{(Q^*)^2}$.

Note that the same type of argument can be made for $Q' < Q^*$, leading to the same result. Furthermore, the arguments presented here are valid for any belief function h, off the equilibrium path. We have therefore proved result (b).

We see that on the equilibrium path, the optimal reporting strategy is to reveal all the information obtained. We have therefore shown result (a).

According to result (a), the sender reveals all the information he obtained. Therefore, the same policy is set by the receiver than if the research effort was observable. However, the sender has to incur the cost of more research. We therefore proved result (c): the sender is strictly worse off when his research effort is unobservable.

Case II: small bias

When the bias is small, another strategic consideration appears: the sender could wish to hide some of his positive signals.

If he does an amount of research *Q'*, he gets $\theta Q'$ positive signals.
His desired policy is $\theta + \delta$.
So ideally he would want to report r to induce the policy $\frac{r}{Q^*} = \theta + \delta$.

We call the policy chosen off the equilibrium path (when $r > Q^*$ is reported), $h(r, Q^*)$. We do not make explicit the shape of these beliefs: we even allow for the improbable scenario where the sender could obtain his preferred policy off the equilibrium path. We will see in this proof that these beliefs do not matter.

The report r would therefore be such that:
$\frac{r}{Q^*} = \theta + \delta$ if $r < Q^*$
and $h(r, Q^*) = \theta + \delta$ if $r > Q^*$ (if the beliefs off the equilibrium path allow it)

There is however one constraint on the value of the report: it needs to satisfy $r < \theta Q'$. The sender needs to show hard evidence of his claims and cannot therefore report more positive signals than he obtained.

If $r < Q^*$, this constraint can be written $\theta > \frac{\delta Q^*}{Q'-Q^*}$.

Case IIa: $Q' < (1+\delta)Q^*$

$Q' < (1+\delta)Q^*$ is equivalent to $\frac{\delta Q^*}{Q'-Q^*} > 1$. Therefore, in this case, the sender will always report all his positive signals, because the report that would lead to his preferred policy is always such that $r > \theta Q'$. Therefore when $Q' < (1+\delta)Q^*$, we are brought back to the calculations of Prop 1 and we know there is no optimal deviation from $Q^* = \frac{2\delta E(\theta)}{C}$.

Case IIb: $Q' \geq (1+\delta)Q^*$

We need to show that there is no *Q'* verifying this constraint that would be an optimal deviation from Q^*.

For these values of *Q'*, there can be strategic reporting:
- if $\theta < \frac{\delta Q^*}{Q'-Q^*}$, the sender reports $\theta Q'$.
- if $\frac{\delta Q^*}{Q'-Q^*} < \theta < 1-\delta$, the sender reports r such that $\frac{r}{Q^*} = \theta + \delta$.
- if $\theta > 1-\delta$, his optimal report r is such that $r > Q^*$. We do not explicitly define the report and the policy set in place for these values of θ as it would require us to assume a specific form to the beliefs off the equilibrium path. We call the policy implemented $h(\theta, Q')$.

The problem of the sender is then

$$max_{Q'} - \int_0^{\frac{\delta Q^*}{Q'-Q^*}} [\frac{\theta Q'}{Q^*} - \theta - \delta]^2 f(\theta) d\theta - \int_{\frac{\delta Q^*}{Q'-Q^*}}^{1-\delta} [\theta + \delta - \theta - \delta]^2 f(\theta) d\theta$$
$$- \int_{1-\delta}^{1} [h(\theta, Q') - \theta - \delta]^2 f(\theta) d\theta - CQ'$$

We consider the best of cases for the beliefs off the equilibrium path that would set the third term to 0 and concentrate on the function corresponding to the other terms.
Let *f(Q)* be:

$$f(Q') = - \int_0^{\frac{\delta Q^*}{Q'-Q^*}} [\frac{\theta Q'}{Q^*} - \theta - \delta]^2 f(\theta) d\theta - CQ'$$

We have

$$f'(Q') = -\int_0^{\frac{\delta Q^*}{Q'-Q^*}} \frac{2\theta}{Q^*}[\frac{\theta Q'}{Q^*} - \theta - \delta]f(\theta)d\theta - C$$

and

$$f''(Q') = -2\int_0^{\frac{\delta Q^*}{Q'-Q^*}} [\frac{\theta}{Q^*}]^2 f(\theta)d\theta < 0$$

So, the function f is concave and single peaked. Furthermore, we know that $f'((1+\delta)Q^*) = \int_0^1 \frac{2\theta}{Q^*}[\delta(1-\theta)]f(\theta)d\theta - C = C\frac{\int_0^1 \theta(1-\theta)f(\theta)d\theta}{E(\theta)} - C < 0$ (because $Q^* = \frac{2\delta E(\theta)}{C}$). Therefore on $[(1+\delta)Q^*, +\infty]$, f is decreasing. So, the best deviation on this interval will is bounded by $f((1+\delta)Q^*)$.

In conclusion we just need to compare $f((1+\delta)Q^*)$ to the value function at Q^*.

The value function at Q^* equals $-\delta^2 - CQ^*$ and $f((1+\delta)Q^*) = -\int_0^1 [\delta(1-\theta)]^2 f(\theta)d\theta - C(1+\delta)Q^*$. The difference between this two terms is $\delta^2 E[\theta^2]$ and therefore this is not an optimal deviation from Q^*. Combining cases 1 and 2, we can conclude there is no optimal deviation from Q^*.

This proof is valid for any belief off the equilibrium path and therefore we have shown that Q^* is still an equilibrium. ■

Proposition 3

The sender, if he performs an amount of research *Q'* and the receiver believes he did a quantity Q^*, will obtain $\theta Q'$ positive signals and will report r to maximize:
$(\frac{r}{Q^*} - \theta - \delta)^2 - \tau r$ with $r \leq \theta Q'$.
In the case of a big bias, the sender will report $\theta Q'$.
Therefore in the first phase, the sender chooses research quantity Q' in order to maximize:

$$max_{Q'} - \int_0^{Q^*/Q'} ([\frac{\theta Q'}{Q^*} - \theta - \delta]^2 + \tau\theta Q')f(\theta)d\theta - \int_{Q^*/Q'}^1 ([1-\theta-\delta]^2 + \tau Q^*)f(\theta)d\theta - CQ'$$

The FOC are:

$$C = -\int_0^{Q^*/Q'} (\frac{2\theta}{Q^*}[\frac{\theta Q'}{Q^*} - \theta - \delta] + \tau\theta)f(\theta)d\theta$$

Therefore the equilibrium amount of research will be:

$$Q^* = \frac{2\delta E(\theta)}{C + \tau E(\theta)} \quad ■$$

Proposition 4

When the research effort is observable, the sender solves:

$$max_{Q'} \ -\int_0^\infty \int_0^\infty (E[\theta|x,Q'] - \theta - \delta)^2 \ f(x|\theta,Q') \ f(\theta) \ dx \ d\theta \ - CQ'$$

We have by Baye's rule $f(x|\theta) \ f(\theta) = f(\theta|x) \ g(x,Q')$, so the problem can be rewritten:

$$\begin{aligned} max_{Q'} \ & -\int_0^\infty \int_0^\infty (E[\theta|x,Q'] - \theta)^2 \ f(\theta|x,Q') \ g(x,Q') \ dx \ d\theta \\ & +2\int_0^\infty \int_0^\infty (E[\theta|x,Q'] - \theta)\delta \ f(\theta|x,Q') \ g(x,Q') \ dxd\theta \\ & -\delta^2 \int_0^\infty \int_0^\infty f(\theta|x,Q') \ g(x,Q') \ dxd\theta \ - CQ' \end{aligned}$$

By definition $\int_0^\infty (E[\theta|x,Q'] - \theta) f(\theta|x,Q') d\theta = 0$ and $\int_0^\infty (E[\theta|x,Q'] - \theta)^2 \ f(\theta|x,Q') d\theta = V[\theta|x,Q']$ so the problem is:

$$max_{Q'} \ -\int_0^\infty Var[\theta|x,Q'] \ g(x,Q') \ dx \ - \delta^2 \ - CQ'$$

The hypothesis we made on the variance therefore guarantees that this problem has a unique solution given by the FOC of proposition 4. ■

Proposition 5

The problem of the sender can be rewritten:

$$\begin{aligned} max_{Q'} \ & -\int_0^1 \int_{\bigcup A_k} [(E[\theta|x,Q^*] - \theta - \delta)^2 - (E[\theta|x,Q'] - \theta)^2] \ f(x|\theta,Q') \ f(\theta) \ dx \ d\theta \\ & -\int_0^1 \int_0^\infty (E[\theta|x,Q'] - \theta)^2 \ f(x|\theta,Q') \ f(\theta) \ dx \ d\theta \ - CQ' \end{aligned}$$

As in the proof of proposition 4, we can rewrite the third term as a function of the variance. The objective becomes

$$\begin{aligned} max_{Q'} \ & -\int_0^\infty Var[\theta|x,Q'] \ g(x,Q') dx \ - CQ' \\ & -\int_0^\infty \int_{\bigcup A_k} [\ (E[\theta|x,Q^*] - \theta - \delta)^2 - (E[\theta|x,Q'] - \theta)^2] \ f(x|\theta,Q') \ f(\theta) \ dx \ d\theta \end{aligned}$$

Let's examine the first order conditions. We use the notation $A_k = [x_{k1}, x_{k2}]$ $k \in 1, .., K$.

$$C = -\frac{\partial}{\partial Q'}[\int_0^\infty Var[\theta|x, Q'] \; g(x, Q')dx]$$
$$+\sum_k \int_0^1 \frac{\partial x_{k1}}{\partial Q'}[\; (E[\theta|x_{k1}, Q^*] - \theta - \delta)^2 - (E[\theta|x_{k1}, Q'] - \theta)^2] \;\; f(\theta) \; d\theta$$
$$-\sum_k \int_0^1 \frac{\partial x_{k2}}{\partial Q'}[\; (E[\theta|x_{k2}, Q^*] - \theta - \delta)^2 - (E[\theta|x_{k2}, Q'] - \theta)^2] \;\; f(\theta)d\theta$$
$$-\int_0^1 \int_{\bigcup A_k} [\; (E[\theta|x, Q^*] - \theta - \delta)^2 - (E[\theta|x, Q'] - \theta)^2] \; \frac{\partial f}{\partial Q'}(x|\theta, Q') \; f(\theta)dx \; d\theta$$
$$+2\int_0^1 \int_{\bigcup A_k} \frac{\partial E}{\partial Q'}(\theta|x, Q') \; (E[\theta|x, Q'] - \theta) \; f(x|\theta, Q') \; f(\theta) \; dx \; d\theta$$

For x_{k1} and x_{k2}, the boundaries of the intervals, we have $E[\theta|x, Q^*] = E[\theta|x, Q'] + \delta$, so

$$C = -\frac{\partial}{\partial Q'}[\int_0^\infty Var[\theta|x, Q'] \; g(x, Q')dx]$$
$$-\int_0^1 \int_{\bigcup A_k} [\; (E[\theta|x, Q^*] - \theta - \delta)^2 - (E[\theta|x, Q'] - \theta)^2] \; \frac{\partial f}{\partial Q'}(x|\theta, Q') \; f(\theta)dx \; d\theta$$
$$+2\int_0^1 \int_{\bigcup A_k} \frac{\partial E}{\partial Q'}(\theta|x, Q') \; (E[\theta|x, Q'] - \theta) \; f(x|\theta, Q') \; f(\theta) \; dx \; d\theta$$

For Q^* to be an equilibrium these FOC need to be verified at Q^*. As we did previously, we therefore take the FOC when Q' converges to Q^*. The first thing to observe is that $\bigcup A_k \rightarrow [0, +\infty]$ (indeed at the limit, when the receiver has the right beliefs about the quantity of research, there is no more opportunities to hide information, therefore the ideal policy from the point of view of the sender is never attainable). All the functions are continuous, so taking the limit results in:

$$C = -\frac{\partial}{\partial Q'}[\int_0^\infty Var[\theta|x, Q'] \; g(x, Q')dx] \; |_{Q'=Q^*}$$
$$+\int_0^1 \int_0^\infty \delta \; (2E[\theta|x, Q^*] - 2\theta - \delta) \; [\frac{\partial f}{\partial Q'}(x|\theta, Q')]|_{Q'=Q^*} \; f(\theta)dx \; d\theta$$
$$+2\int_0^1 \int_0^\infty [\frac{\partial E}{\partial Q'}(\theta|x, Q')]|_{Q'=Q^*} \; (E[\theta|x, Q^*] - \theta) \; f(x|\theta, Q^*) \; f(\theta) \; dx \; d\theta$$

Let's examine the 3rd term:

$$2\int_0^1 \int_0^\infty [\frac{\partial E}{\partial Q'}(\theta|x,Q')]|_{Q'=Q^*} \ (E[\theta|x,Q^*]-\theta) \ f(x|\theta,Q^*) \ f(\theta) \ dx \ d\theta$$

$$= 2\int_0^\infty [\frac{\partial E}{\partial Q'}(\theta|x,Q')]|_{Q'=Q^*} \ g(x,Q') \ [\int_0^1 \ (E[\theta|x,Q^*]-\theta) \ f(\theta|x,Q^*) \ d\theta] \ dx \ = \ 0$$

Let's now look at the second term:

$$\int_0^1 \int_0^\infty \delta \ (2E[\theta|x,Q^*]-2\theta-\delta) \ [\frac{\partial f}{\partial Q'}(x|\theta,Q')]|_{Q'=Q^*} \ f(\theta)dx \ d\theta$$

$$= -\int_0^1 \int_0^\infty \delta^2 \ [\frac{\partial f}{\partial Q'}(x|\theta,Q')]|_{Q'=Q^*} \ f(\theta)dx \ d\theta$$

$$+\int_0^1 \int_0^\infty 2\delta \ (E[\theta|x,Q^*]-\theta) \ [\frac{\partial f}{\partial Q'}(x|\theta,Q')]|_{Q'=Q^*} \ f(\theta)dx \ d\theta$$

We have $\int_0^1 \int_0^\infty \ f(x|\theta,Q') \ f(\theta)dx \ d\theta = 1$.
So, by taking the derivative with respect to Q'
$\int_0^1 \int_0^\infty \delta^2 \ [\frac{\partial f}{\partial Q'}(x|\theta,Q')]|_{Q'=Q^*} \ f(\theta)dx \ d\theta = 0$.

We have also $\int_0^1 \int_0^\infty \ (E[\theta|x,Q^*]-\theta) \ f(x|\theta,Q^*) \ f(\theta)dx \ d\theta = 0$.

So, take the derivative,

$$\int_0^1 \int_0^\infty 2\delta \ (E[\theta|x,Q^*]-\theta) \ [\frac{\partial f}{\partial Q'}(x|\theta,Q')]|_{Q'=Q^*} \ f(\theta)dx \ d\theta \tag{2}$$

$$= -2\delta \int_0^1 \int_0^\infty \ [\frac{\partial E}{\partial Q'}(\theta|x,Q')]|_{Q'=Q^*} \ f(x|\theta,Q^*) \ f(\theta)dx \ d\theta \tag{3}$$

Therefore, the first order conditions can be rewritten:

$$C = -\frac{\partial}{\partial Q'}[\int_0^\infty \ Var[\theta|x,Q'] \ g(x,Q')dx] \ |_{Q'=Q^*}$$

$$-2\delta \int_0^1 \int_0^\infty \ \frac{\partial}{\partial Q'}[E(\theta|x,Q')]|_{Q'=Q^*} \ f(x|\theta,Q^*) \ f(\theta)dx \ d\theta$$

Furthermore:
(a) $\frac{\partial E}{\partial Q'}(\theta|x,Q')$ is negative because the number of positive signals is weakly increasing in the quantity of research performed.
$\int_0^\infty Var[\theta|x,Q']g(x|Q')dx$ is convex in Q' according to the hypothesis made on the variance.
Therefore, using these 2 properties, we find that $Q_0 < Q^*$.

(b) As in proposition 1, in equilibrium, the receiver knows although she does not observe, the amount of research performed in equilibrium. Therefore, Milgrom's unraveling result applies and no information will be withheld.

(c) In equilibrium, all the information is revealed. Therefore it is as if the research effort was observable by the receiver. The choice of research is therefore suboptimal from the point of view of the sender and he is strictly worse off. ■

Proposition 6

The socially optimal tax with redistribution is solution to the problem:

$$max_\tau \ -\int_0^\infty \int_0^1 (E[\theta|x, Q_\tau] - \theta - \delta)^2 \ f(x|\theta, Q_\tau) \ f(\theta) dx d\theta$$
$$-\int_0^\infty \int_0^1 (E[\theta|x, Q_\tau] - \theta)^2 \ f(x|\theta, Q_\tau) \ f(\theta) dx d\theta \ -(C+\tau)Q_\tau + \tau Q_\tau$$

where Q_τ is chosen optimally by the sender given a tax τ.

Q_W, the social optimum is solution to:

$$max_{Q'} \ -\int_0^\infty \int_0^1 (E[\theta|x, Q'] - \theta - \delta)^2 \ f(x|\theta, Q') \ f(\theta) dx d\theta$$
$$-\int_0^\infty \int_0^1 (E[\theta|x, Q'] - \theta)^2 \ f(x|\theta, Q') \ f(\theta) dx d\theta \ -CQ'$$

The FOC corresponding to this problem are:

$$\frac{C}{2} = -\frac{\partial}{\partial Q'}[\int_0^\infty \ Var[\theta|x, Q'] \ g(x, Q') dx] \ |_{Q'=Q_W}$$

If there exists a tax such that $Q_\tau = Q_W$ then this is the socially optimal tax. We see from proposition 5 that if the tax is:

$$\tau \ = \ -2\delta \int_0^1 \int_0^\infty \ \frac{\partial}{\partial Q'}[E(\theta|x, Q')]|_{Q'=Q_W} \ f(x|\theta, Q_W) \ f(\theta) dx \ d\theta - \frac{C}{2}$$

the FOC of the two problems are equivalent and therefore $Q_\tau = Q_W$. ■

Proposition 7

In equilibrium, sender 2 reports truthfully, so the problem of sender 1 is:

$$max_{Q'} - \int_0^{Q^*/Q'} [p(\frac{\theta Q'}{Q^*}, \theta) - \theta - \delta]^2 f(\theta) d\theta - \int_{Q^*/Q'}^1 [p(1, \theta) - \theta - \delta]^2 f(\theta) d\theta - CQ'$$

The FOC are:

$$C = -2 \int_0^{Q^*/Q'} \frac{\theta}{Q^*} \frac{\partial p}{\partial \theta_1} [\frac{\theta Q'}{Q^*}, \theta] \; [p(\frac{\theta Q'}{Q^*}, \theta) - \theta - \delta] f(\theta) d\theta$$

The FOC at the equilibrium become:

$$Q^* = \frac{-2}{C} \int_0^1 \theta \frac{\partial p}{\partial \theta_1} [\theta, \theta] \; [p(\theta, \theta) - \theta - \delta] f(\theta) d\theta = \frac{2\delta}{C} \int_0^1 \theta \frac{\partial p}{\partial \theta_1} (\theta, \theta) \; f(\theta) d\theta$$

We have: $\frac{\partial p}{\partial \theta_1}(\theta, \theta) = lim_{h \to 0} \frac{p(\theta+h,\theta) - p(\theta,\theta)}{h}$

Restriction A implies $\theta < p(\theta + h, \theta) < \theta + h$. Therefore, we have $0 < \frac{\partial p}{\partial \theta_1}(\theta, \theta) < 1$.
So, we find $Q^* < \frac{2\delta}{C} \int_0^1 \theta \; f(\theta) d\theta$ ■

Proposition 8

In this case, the restriction placed on beliefs is restriction B: $p(\theta_1, \theta_2) \leq min(\theta_1, \theta_2)$.

In equilibrium, the other sender is reporting truthfully the real value of the state. Because of the beliefs of the receiver, if one sender selects the evidence in order to manipulate his message and reports $\theta_2 > \theta_1$, his message will be ignored. Therefore, there is no marginal benefit from conducting more research to replace bad messages by good ones, and only an infinitesimal amount of research will be conducted, sufficient to reveal the true state.

Proposition 9

(a) Suppose in equilibrium $Q_L = Q_H$. In such a case both types will employ the same reporting strategy: report all the positive signals they obtain (we place ourselves once again in the case of large bias $\delta_L > 1$, but the proof holds as well for small biases). In that case, the equilibrium condition for the low type is given as in section 3: $Q_L = \frac{2\delta_L E(\theta)}{C}$. So if $Q_L = Q_H$, the consequence is that $Q_H < \frac{2\delta_H E(\theta)}{C}$ and therefore this cannot be an equilibrium condition as the high type would have incentives to search more to deceive the receiver (see proof of proposition 1). Therefore, in equilibrium, $Q_L < Q_H$.

(b) Assume there exists an equilibrium where all the positive information is always reported by both types.
Suppose the high type obtains an amount of positive signals $x = Q_L^* + \epsilon$ (ϵ infinitesimal), if he reports all his positive information, he reveals his type and the policy is therefore set at $p = \frac{Q_L^* + \epsilon}{Q_H^*}$. If he hides part of his results, and reports $x = Q_L^*$ he will obtain a strictly higher policy: $p = \frac{Q_L^*}{pQ_L^* + (1-p)Q_H^*}$ as the receiver will be uncertain of the type. Therefore there cannot be an equilibrium where all positive information is revealed.

Proposition 10

According to proposition 9, in all equilibria, if the high type obtains an amount of positive signals close but greater than Q_L, he will not report all of these signals in order to hide his type. However, there cannot exist an equilibrium where, in such situations, the high type always report Q_L positive signals. Indeed, the low type would then never report Q_L and the equilibrium would break down. Therefore, there exists 2 values Q_0 and Q_B such that:
- If research yields a quantity of positive signals in $[0, Q_0]$, all the signals are reported.
- If research yields a quantity of positive signals in $[Q_0, Q_B]$, both types pool their reports and the decision maker sets a policy q.
- If research yields a quantity of positive signals in $[Q_B, Q_H]$, the high type discloses all his information.

The following properties have to be true in equilibrium:
- Q_B is such that $q = \frac{Q_B}{Q_H}$ (at Q_B, the high type is indifferent between reporting truthfully and revealing his type and obtaining the policy q).
- $q = p\frac{Q_L - Q_0}{Q_L} + (1-p)\frac{Q_B - Q_0}{Q_H}$. The policy is set at the expected value of the state given the reports.

We study in this example a particular equilibrium where at Q_0, the sender is exactly indifferent between obtaining q and reporting Q_0. This means we impose the condition $q = p\frac{Q_0}{Q_L} + (1-p)\frac{Q_0}{Q_H}$. However, other equilibria exist where $q > p\frac{Q_0}{Q_L} + (1-p)\frac{Q_0}{Q_H}$.
Under this condition we obtain $q = \frac{p}{1+p}$.

The problem faced by the senders is:

$$max_{Q'} - \int_0^{\frac{Q_0}{Q'}} [p\frac{\theta Q'}{Q_L} + (1-p)\frac{\theta Q'}{Q_H} - \theta - \delta_i]^2 f(\theta)d\theta - \int_{\frac{Q_0}{Q'}}^{\frac{q}{Q'}} [q - \theta - \delta_i]^2 f(\theta)d\theta$$
$$- \int_{\frac{q}{Q'}}^{\frac{Q_H}{Q'}} [\frac{\theta Q'}{Q_H} - \theta - \delta_i]^2 f(\theta)d\theta - CQ'$$

The FOC for the low type can be written

$$-2\int_0^{\frac{Q_0}{Q_L}} [\theta\frac{q}{Q_0}][\frac{Q_L}{Q_0}\theta q - \theta - \delta_L] f(\theta)d\theta = C$$

We want to show that Q_L is smaller than if his type was known. A consequence of the previous equation is that:

$$2\int_0^{\frac{Q_0}{Q_L}} [\theta\frac{q}{Q_0}]\delta_L f(\theta)d\theta = C + 2\int_0^{\frac{Q_0}{Q_L}} [\theta\frac{q}{Q_0}][\frac{Q_L}{Q_0}\theta q - \theta] f(\theta)d\theta > C$$

Therefore, using the uniform distribution, we have $\delta_L \frac{Q_0}{Q_L^2} q > C$ and because $Q_0 < Q_L$, we have $Q_L < \frac{\delta_L}{C}$. This second term is exactly the amount of research performed if the type was known, when the state is distributed uniformly.