Manufacturing Doubt

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September 2015

Abstract: In their persistent fight against regulation, firms have developed specific strategies to take advantage of scientific uncertainty. They have spent large amounts of money to manufacture doubt and artificially keep controversies alive. We develop a new model to study the interplay between scientific uncertainty, firms' communication and public policies. The government is benevolent but populist and maximizes social welfare as perceived by citizens. The industry can provide costly evidence that its activity is not harmful. Citizens incorrectly treat the industry's information on par with scientific knowledge. We characterize the industry's optimal communication policy. We find that communication effort is non-monotonous and discontinuous in scientific belief. As scientists become increasingly convinced that the industrial activity is harmful, firms first fight harder and harder to reassure people. When scientists' beliefs reach a critical threshold, however, overcoming the scientific consensus becomes too costly and the industry stops its efforts abruptly. We then study the impacts of firms' communication on scientific funding. Perversely, a populist government may want to support research to better allow firms to miscommunicate. Populist policies can entail significant welfare losses. Establishing an independent funding agency always reduces these losses and may lead to under- or over- investment in research with respect to the first-best.

Keywords: Scientific Uncertainty, Populist Policies, Indirect Lobbying, Research Funding.

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I Introduction

In their persistent fight against regulation, firms have developed specific strategies to take advantage of scientific uncertainty. For instance, tobacco producers have consistently denied adverse effects of active smoking in the 1950s and 1960s and of second-hand smoke exposure during the 1970s through the 1990s, see Bero (2013). They have spent large amounts of money to generate and publicize favorable scientific findings, to discredit and downplay unfavorable ones and to shape the public's perceptions through large scale communication campaigns, see Proctor (2011).[1] More recently, insecticide manufacturers appear to have adopted similar strategies in their resistance against bans on neonicotinoid insecticides, thought to negatively affect bees and other pollinators, see Maxim and van der Sluijs (2013). On climate change, special interest groups have long exploited scientific uncertainties to promote inaction.[2] This deliberate manufacturing of doubt appears to be a main reason behind the many documented cases of unheeded early warnings, see EEA (2013).[3] It has likely had a first-order detrimental impact on welfare in our innovations-filled societies. While firms' practices are being increasingly scrutinized by social scientists,[4] their economic analysis is still underdeveloped. Our study aims to fill this gap.

In this paper, we develop a new model to study the interplay between scientific uncertainty, firms' communication and public policies. We consider a government which is benevolent but populist: It maximizes social welfare as perceived by citizens. The industry tries to affect public opinion to obtain a more lenient regulation. Citizens' beliefs evolve through incorrect Bayesian updating. We assume that the industry can, at a cost, provide evidence that its activity is not harmful and that citizens incorrectly treat the industry's

[1] For instance, a 1978 report prepared for the Tobacco Institute states that "The strategic and long-run antidote to the passive smoking issue is, as we see it, developing and widely publicizing clear-cut, credible medical evidence that passive smoking is not harmful to the non-smoker's health" Ropert Organization (1978), cited in Bero (2013).

[2] Oreskes & Conway (2010) document how a handful of scientists in the US were coopted by industrial lobbies to advance the lobbies' agenda. Interestingly, the same individuals have played a key role in science denying communication campaigns across widely different issues.

[3] Cases with long delays in regulatory and legislative actions despite sufficient early evidence include, among others, lead in petrol, Beryllium exposure, Vinyl Chloride, the pesticide DBCP, and Bisphenol A.

[4] See, e.g., Proctor & Schiebinger (2008). Robert Proctor introduced the term "agnotology" to denote the study of the determinants of ignorance.

information on par with scientific knowledge. We develop our analysis in two stages. We first consider a given level of scientific uncertainty. We analyze the lobby's optimal communication policy and its impact on beliefs, regulation and welfare. In a second stage, we endogenize the level of research. We ask how firms' communication affects scientific funding under different types of institutions.

Our analysis yields two main insights. We show, first, that the industry's communication effort is a non-monotonous and discontinous function of scientific belief. As scientists become increasingly convinced that the activity is harmful, the industry first fights harder and harder to reassure people. When scientists' beliefs reach a critical threshold, however, overcoming the scientific consensus becomes too costly and the industry stops its efforts abruptly. This result can help explain some documented tendencies. It is consistent with the large lags typically observed between the times where scientists reach a consensus on regulation necessity and where a serious public policy is implemented.[5] It predicts abrupt reversals in the official positions of special interest groups as was observed in the past on tobacco and as recently seen on climate change. It also predicts large swings in public opinion and episodes of abrupt awakening to the dangers posed by some activity, induced by potentially unremarkable events or informations.

We then show that the wedge driven by the industry between scientists' and citizens' beliefs has key consequences for scientific funding. We analyze the incentives of different types of institutions to support research. We uncover some rich effects. Since a populist government cares about perceived welfare, its utility increases when citizens are unduly reassured. This may lead to a partial alignement of interests between the government and the industry. In some cases, a populist government does not wish to support research. In other cases, a populist government supports research *because* this support allows the industry to better influence public opinion.[6] In any case, populist policies lead to significant welfare losses, representing the cost of denial. We show that a partial answer to this problem

[5]See EEA (2013), which notably shows that situations of 'false positives', when preventive actions undertaken due to early scientific warnings turn out to be unnecessary, are much less frequent than those of 'false negatives', where no action is undertaken despite early warnings that are confirmed ex-post.

[6]Such perverse incentives arise in situations where scientists' are initially not too uncertain. There is then a chance that some research may lead to more uncertainty which is then exploited by the industry, see Section 4.

is to establish an independent funding agency, not unlike the current National Science Foundation and European Research Council. Interestingly, the independent agency may decide to provide more or less scientific support than under the first-best. Either strategy may provide the best way to limit the damaging effects of firms' communication.

Our analysis contributes to four literatures. First, a few studies have started to analyze the incentives of special interest groups to affect public opinion.[7,8] In an early study, Yu (2005) looks at the interaction between direct and indirect competition for political influence. In his setup, an industrial and an environmental lobby both try to affect regulation in two ways: through classical lobbying and through communication campaigns. Yu (2005) does not model scientific progress, however. By contrast, scientific uncertainty is central to our analysis. We study how the industry's communication strategies are affected by the extent of scientific progress and how indirect lobbying, in turn, affects scientific funding.[9] In a recent analysis, Shapiro (2014) models competition between special interests to seek political influence through the news media. He notably shows how the journalistic norm of balanced reporting may arise endogenously due to reputational concerns and how, in turn, this norm may be exploited by special interests and may ultimately yield less informative journalistic reports. Balanced reporting may help justify our assumption of incorrect Bayesian updating.[10] We take the process of opinion formation as given here and study how it affects firms' and governments' incentives and actions.

Second, our paper contributes to a literature studying the implications of the fact that citizens often hold incorrect beliefs. In particular, researchers have long debated the normative consequences of citizens' misperceptions. In short, should a benevolent government assuage fears or save lives?[11] Salanié & Treich (2009) analyze optimal regulations for the two types of governments, and we adopt some of their terminology. In this litera-

[7] A large literature analyzes lobbying, where industries compete to affect regulations through monetary transfers to the government, see e.g. Grossman & Helpman (1994). In studies of informational lobbying, lobbies compete in the provision of information to policy-makers, see Grossman & Helpman (2002).

[8] In Laussel & van Ypersele (2012), the actions of lobby groups or unions may provide informative signals to voters about the quality of the government.

[9] Introducing direct lobbying and other interest groups in our setup provide natural directions for future research, see Conclusion.

[10] We discuss this assumption in more detail in Section 2.

[11] See, e.g., Portney (1992), Pollak (1998), Viscusi & Hamilton (1999).

ture, however, citizens' and experts' perceptions are typically taken as given. By contrast, these perceptions are formed endogenously in our framework, and are affected by scientific progress and by industry's communication. This raises new questions such as how the extent of misperception depends on the economy's fundamentals and the determination of scientific policies.

Third, a large and growing literature explores the effect of uncertainty on environmental outcomes. Most studies in this literature consider a benevolent social planner with no misperception.[12] Recently, researchers have started to study uncertainty in strategic contexts, such as free-riding between countries.[13] Here, we focus on a new channel through which uncertainty may affect the environment: citizens' misperceptions induced by firms' communication in the presence of scientific uncertainty. We provide one of the first systematic analysis of this channel and show that it may have a first-order impact on environmental and scientific outcomes.

Finally, our paper contributes to the economic analysis of science. Most studies in this field consider science independently of the political process.[14] By contrast, we focus on the interaction between scientists, firms and the government. We show how an industry can exploit scientific uncertainty to advance its agenda and how these considerations may, in turn, affect scientific funding.

The remainder of the paper is organized as follows. We introduce our model in Section 2. We develop a model of formation of scientific and popular beliefs and characterize the industry's optimal communication policy in Section 3. We endogenize the level of research in Section 4 and conclude in Section 5.

[12] See, e.g., Gollier, Jullien & Treich (2000), Heal & Kriström (2002), Weitzman (2009) and studies based on integrated assessment models as in Nordhaus (1994) and Stern (2007).

[13] As in Baker (2005), Boucher & Bramoullé (2010), Bramoullé & Treich (2009), Finus & Pintassilgo (2013) and Ulph (2004).

[14] See, e.g., Aghion, Dewatripoint & Stein (2008), Bramoullé & Saint-Paul (2009) and Brock & Durlauf (1999).

II Model

We consider a society composed of four groups of agents: firms, scientists, citizens and the government. Firms' economic activity generates pollution, which may be harmful to people's health and to the environment. The government has to decide about the right level of regulation of this pollution. Scientists are uncertain about the impacts of pollution and the extent of harm it might cause. They may do research to reduce this uncertainty. Both firms and scientists communicate about the effects of the economic activity. Citizens then form beliefs about these effects, and the government takes public opinion into account when adopting the regulation.

Formally, firms' benefits from emitting emissions e are equal to $B(e) = be_0e - \frac{1}{2}be^2$ with $b, e_0 > 0$. In the absence of regulation, benefits are maximized by emitting $e = e_0$, the business as usual level of pollution. The government regulates by imposing a maximal level of emissions $e \leq e_0$. The environmental regulation costs $B(e_0) - B(e)$ to firms, and this cost is increasing and convex in the level of abatement $e_0 - e$. Thus, firms have an incentive to be as little regulated as possible.

Emissions may generate damages. For simplicity, we assume that scientific uncertainty takes a binary form. Either pollution is indeed harmful, and overall damages are equal to $D(e) = d_0e + \frac{1}{2}de^2$ with $d_0, d \geq 0$ and $d_0 \leq be_0$. Or pollution is not harmful. Scientists believe that pollution is harmful with probability p. The expected social welfare is thus equal to:

$$W(p, e) = B(e) - pD(e)$$

Say that a government is *technocratic* when it tries to maximize social welfare computed with up-to-date scientific knowledge. A technocratic government sets the emissions level to optimally balance social benefits and social costs. This means that $B'(e) = pD'(e)$, which yields:

$$e(p) = \frac{be_0 - pd_0}{b + pd} \tag{1}$$

This corresponds to the first-best outcome in our context. Note that e is decreasing and convex in scientific belief p.[15]

Citizens' beliefs may differ from scientists' beliefs, however. Firms are organized in a communication lobby, which tries to affect public opinion on the effects of pollution.[16] Citizens' belief, q, then depends on both scientific beliefs and the industry's communication effort. Say that a government is *populist* when it tries to maximize social welfare as perceived by citizens: $W(q, e) = B(e) - qD(e)$. The level of regulation chosen by a populist government is then equal to $e(q)$. When citizens are less worried about the impacts of pollution than scientists, $q < p$ and $e(q) > e(p)$. A populist government then underregulates with respect to the first-best. This provides incentives for the industry to try and orient public opinion in a direction supportive to its views.

We assume that the government is populist in Section 3. We consider an exogenous level of research and study the industry's optimal communication policy. In Section 4, we endogenize the level of research under various institutional arrangements.

III Exogenous Science

In this section, we consider an exogenous level of research. We first develop a simple Bayesian model of scientific progress. We then build on it to model industry communication and opinion formation. We assume that the industry can, at a cost, provide evidence that pollution is not harmful and that citizens incorrectly treat industry's information on par with scientific knowledge. Finally, we characterize the industry's optimal communication policy and its resulting outcomes.

[15] Indeed, we have $e'(p) = \frac{-b(d_0+de_0)}{(b+dp)^2} < 0$ and $e''(p) = \frac{2bd(d_0+de_0)}{(b+dp)^3} \geq 0$.

[16] For instance, US tobacco companies formed in 1954 the Tobacco Industry Research Committee, which later became the Council for Tobacco Research. "The industry stated publicly that it was forming the TIRC to fund independent scientific research to determine whether there was a link between smoking and lung cancer. However, internal documents from Brown & Williamson Tobacco Company have shown that the TIRC was actually formed for public relations purposes, to convince the public that the hazards of smoking had not been proven.", see Bero (2103, p.156).

A Scientific and popular beliefs

Consider the following model of scientific progress. Scientists can do research to reduce their uncertainty on the effects of pollution. They have prior beliefs p_0 that pollution is harmful. They may run n experiments to learn about the truth. Each experiment provides a noisy signal on the true state of the world, and is correct with probability $\frac{1}{2} < P < 1$. Denote by k the number of experiments indicating that pollution is harmful. Applying Bayes' rule, we see that scientists' ex-post belief is equal to

$$p = \frac{p_0 C_n^k P^k (1-P)^{n-k}}{p_0 C_n^k P^k (1-P)^{n-k} + (1-p_0) C_n^k P^{n-k} (1-P)^k}$$

Let $\alpha = P/(1-P) > 1$ denote the relative precision of an experiment. This yields:

$$p(p_0, k, n) = \frac{p_0 \alpha^k}{p_0 \alpha^k + (1-p_0)\alpha^{n-k}} \tag{2}$$

Note that $p \geq p_0 \Leftrightarrow k \geq n/2$. More generally, this formula embodies key features of Bayesian updating. For instance, if experiments are run in several stages the final belief does not depend on their ordering. Formally, $p(p(p_0, k_1, n_1), k_2, n_2) = p(p_0, k_1 + k_2, n_1 + n_2)$ for any $k_1 \leq n_1$ and $k_2 \leq n_2$.

Thus, scientists' belief is a discrete stochastic variable $\tilde{p}$, such that $\tilde{p} = p(p_0, k, n)$ with probability $p_0 C_n^k P^k (1-P)^{n-k} + (1-p_0) C_n^k P^{n-k} (1-P)^k$ for any integer k between 0 and n. We can check that the expectation of scientists' beliefs is equal to the prior: for any n, $E(\tilde{p}) = p_0$. As n increases, $\tilde{p}$ puts more and more weight on beliefs further and further away from p_0. As $n \to \infty$, we show in Appendix that $\tilde{p}$ converges in probability towards the distribution $p_\infty = 0$ with probability $1 - p_0$ and 1 with probability p_0. As the number of experiments becomes arbitrarily large, scientific knowledge converges to the truth.

Citizens' beliefs may differ from scientists' beliefs, however. At cost c, the industry can produce one unit of evidence documenting that pollution is not harmful. Our key assumption is that *citizens fail to account for the biases underlying the information provided by the industry.* The industry's information is incorrectly treated as independent scientific evidence. Thus, citizens' belief is equal to

$$q = \frac{p_0 \alpha^k}{p_0 \alpha^k + (1 - p_0)\alpha^{n-k+m}}$$

where m denotes the industry's communication effort. In fact, q can be expressed as a function of scientists' beliefs p and of communication effort m:

$$q(p, m) = \frac{p}{p + (1 - p)\alpha^m} \tag{3}$$

In reality, the industry's efforts may take various shapes and may affect citizens' perceptions through different channels. The industry may develop its own research program, only publicizing favorable results; it may hire and fund dissenting scientists; or it may launch classical advertising campaigns.[17] Citizens may be exposed to the industry's view directly or through the media. As studied in Shapiro (2014), the journalistic norm of balanced reporting could then help explain citizens' misperceptions. Journalists generally strive to express fairly all sides of controversial public issues. This equity of course often plays a useful social role. However when one side is composed of objective scientists and the other side represents special interests, the resulting reporting is necessarily biased. Citizens who do not account for these biases end up with incorrect beliefs lying inbetween scientists' view and the industry's official position, as in (3).[18]

We next clarify how citizens' belief varies with p and m. We compute q's various derivatives in Appendix. We see, first, that $q_p > 0$ and $q_{pp} < 0$. The marginal impact of scientists' belief on citizens' beliefs is positive and decreasing. Then, observe that $q_m < 0$: q is decreasing in m from $q(p, 0) = p$ to $q(p, \infty) = 0$. Interestingly, its curvature may not be constant: $q_{mm} < 0$ if $q > \frac{1}{2}$ and $q_{mm} > 0$ if $q < \frac{1}{2}$. Two cases emerge. Suppose first that $p \leq \frac{1}{2}$. Then, q is convex in m. In that case, the marginal impact of the lobby's communication on citizens' belief is decreasing in absolute value. In contrast if

[17] Proctor (2011) and Bero (2013) show how tobacco companies adopted variants of these strategies throughout the years. Oreskes & Conway (2010) document how a handful of scientists in the US were coopted by industrial lobbies to advance their agenda.

[18] The effectiveness of firms' communication is further sustained by resolute attempts at hiding industry involvement in research, see Bero (2103, p.157-158).

$p \geq \frac{1}{2}$, q is first concave in m until $q = \frac{1}{2}$, which happens for $m = \ln(p/(1-p))/\ln(\alpha)$, above which q is convex. Therefore, when scientists think that pollution is likely to be harmful, communication efforts first have an increasing marginal impact, in absolute value, on citizens' beliefs. In other words, *incorrect Bayesian updating may give rise to increasing returns in the impact of industry communication.* We will see below that this feature plays an important role in determining the optimal communication policy.

B Lobby's optimal communication

We now derive our first main result. We characterize the industry's optimal communication policy. We uncover the existence of three domains. When p is low and scientists believe that pollution is unlikely to be harmful, the benefits from communication are too low and the industry does not try to change citizens' beliefs. When p takes intermediate values, and scientists are more uncertain about the effects of the pollution, the industry engages in communication and targets a specific level of citizens' belief. As p increases, the target is unchanged and communication efforts first increase continuously. When p reaches a critical threshold, however, the costs of communication become too high and the industry abruptly stops its communication efforts. Optimal communication is therefore non-monotonous and discontinuous in scientists' beliefs.

Formally, the industry's objective is to maximize its payoff $\pi(m) = B(e(q(m))) - cm$. We provide an in-depth study of the variations of this function in the Appendix. Introduce the cost value $\bar{c}$ such that:

$$\bar{c} = \frac{4}{27}\ln(\alpha)\frac{b(d_0 + de_0)^2}{(b+d)^2}$$

and let m^* be a solution to the problem of maximizing π over $[0, +\infty[$.

Theorem 1 *Suppose that $c < \bar{c}$. Then there is a target popular belief $q^* < 2b/(3b+d)$ and a threshold scientific belief $p^* > 2b/(3b+d)$ such that: (1) If $p \leq q^*$, then $m^* = 0$; (2) If $q^* \leq p < p^*$, then $q(m^*, p) = q^*$ and*

$$m^* = \frac{1}{\ln(\alpha)}\left[\ln(\frac{p}{1-p}) - \ln(\frac{q^*}{1-q^*})\right]$$

(3) If $p > p^*$, then $m^* = 0$. If $c \geq \bar{c}$, then $m^* = 0$.

We provide a sketch of the proof here, see the Appendix for details and for characterizations of q^* and p^*. We start by examining the second derivative of the payoff function. We see two cases emerging. On the one hand if $p < 2b/(3b+d)$, π is everywhere concave. Since $\pi(m) < 0$ if m is large enough, the solution is then obtained by analyzing the sign of $\pi'(0)$. We show that $\pi'(0) < 0$ if $p < q^*$, which implies that $m^* = 0$ in that case. In contrast, $\pi'(0) > 0$ if $p > q^*$ and m^* then solves $\pi'(m) = 0$. We can express $\pi'(m)$ as a function of q, and this equation then defines the target belief q^*. On the other hand if $p > 2b/(3b+d)$, π is first convex and then concave. When p is high, the industry's payoff first displays increasing returns in communication efforts. We show that in this case, the solution is either to reach the target q^* or to set $m^* = 0$.[19] We compare the payoffs obtained from these two actions and show that there exists a critical threshold p^* above which q^* brings less payoff than no communication. This discontinuity in the solution is induced by the presence of convexities in payoffs.

We illustrate Theorem 1 in Figure 1. Parameters' values are set as follows: $d_0 = 10$, $d = 1$, $e_0 = 10$, $b = 2$, $c = 5$, and $P = 0.647$. From these values and our characterizations in Appendix, we compute the critical values q^* and p^* and obtain $q^* = 0.3$ and $p^* = 0.97$. Here, the costs of communication to the industry are quite low compared to the benefits and effort is positive over a relatively large range of scientific beliefs. We depict in Figure 1 how m^*, in the Left panel, and $q(m^*, p)$, in the Right panel, vary with p. Note that citizens' belief also varies discontinuously with p. It stays at the target level q^* as long as the industry is engaged in communication and then jumps back to p when the industry stops its efforts.

From our characterization, we can also derive some potentially interesting comparative statics. Consider, for instance, the impact of the precision of scientific experiments. An increase in α has two countervailing effects. On one hand, scientists converge more quickly towards the truth when α is higher. The distribution of scientific beliefs tends to be more dispersed and, in the absence of industry communication, this applies to citizens' beliefs as

[19] At $p = p^*$, the industry is indifferent between playing $m^* = 0$ or reaching q^*. The problem of maximizing π has two solutions.

well. On the other hand, we see that $\bar{c}$ is increasing in α and we show in the Appendix that q^* is decreasing while p^* is increasing in α. Because citizens do not differentiate between information provided by the industry and by scientists, *a higher α makes the industry's communication more effective.*[20] Industry communication thus emerges for higher values of communication costs and over a larger range of scientific beliefs. This runs counter to the first effect and tends to slow down the convergence of citizens' beliefs towards the truth.

IV Endogenous Science

In this section, we endogenize the level of research. We study and compare the levels of research chosen in three different setups: when the government is technocratic; when the government is populist and decides on both the environmental regulation and scientific funding; and when the governement is populist but scientific funding is decided by an independent agency.

A Welfare

We first determine the welfare ranking of these three institutional arrangements. Recall, $W(p, e) = B(e) - pD(e)$ denotes the interim welfare, computed once research is done but before the state of the world is revealed. We now consider social welfare computed *ex-ante*, before research is done. If there are n scientific experiments, the expected interim welfare is equal to $E[W(\tilde{p}, e(\tilde{p}))|n]$ for a technocratic government and to $E[W(\tilde{p}, e(\tilde{q}))|n]$ when the environmental regulation is set by a populist government. Assume that each scientific experiment costs C. A technocratic government chooses the level of scientific funding by maximizing

$$W_{tech}(n) = E[W(\tilde{p}, e(\tilde{p}))|n] - Cn$$

[20] Relatedly, the amount of communication needed to reach a fixed target of popular belief is lower when α is higher.

By contrast, a populist government maximizes

$$\Pi_{pop}(n) = E[W(\tilde{q}, e(\tilde{q}))|n] - Cn$$

where the first part represents the expected *perceived* welfare. Finally, consider an independent research agency deciding on the level of scientific funding before a populist government regulates pollution. Assume that this agency is benevolent and computes welfare based on up-to-date scientific knowledge rather than on public opinion. It seeks to maximize

$$W_{indep}(n) = E[W(\tilde{p}, e(\tilde{q}))|n] - Cn$$

Denote by W_I^* the ex-ante social welfare computed at the level of research chosen by institution I. We show next that welfare can be ranked unambiguously across the three types of institutions.

Proposition 1 $W_{pop}^* \leq W_{indep}^* \leq W_{tech}^*$

To see why Proposition 1 holds, note first that W_{tech}^* corresponds to the first-best - and hence highest - level of welfare attainable in the economy. Therefore, W_{pop}^*, $W_{indep}^* \leq W_{tech}^*$. Then, observe that the independent agency maximizes welfare under a populist environmental regulation. Therefore, W_{indep}^* is the highest level of welfare attainable when $e = e(q)$, which implies that $W_{indep}^* \geq W_{pop}^*$. (We provide a formal proof in the Appendix).

This result captures two main features of our framework. First, populist policies entail welfare losses. Observe that at the interim stage, $W(p, e(q)) - W(p, e(p)) = -\frac{1}{2}(b + pd)[e(p) - e(q)]^2$ and this welfare loss increases in absolute value as q decreases and gets further away from p. This loss may be further amplified by decisions on scientific funding. Second, social losses caused by populist policies may be partly offset when scientific funding is decided by an agency which is independent from the government.

We illustrate Proposition 1 in Figure 2, for the same parameter values as in Figure 1. Figure 2 depicts how W_{pop}^*/W_{tech}^* and W_{indep}^*/W_{tech}^* vary as function of initial belief p_0. As predicted by our result, we see that these ratios are always lower than or equal to 1 and that the welfare loss under an independent agency is always lower than under a populist government. These losses are also strongly affected by the initial belief. In our example, W^*_{pop}/W^*_{tech} is decreasing and concave in p_0. Recall, here firms affect public opinion over a relatively large range of scientific beliefs $[q^*, p^*] = [0.3, 0.97]$. When p_0 increases, firms effectively communicate more often and this reduces welfare under a populist government. An independent agency is able to limit the worst impacts of firms' communication. While W^*_{indep}/W^*_{tech} is also decreasing and concave in p_0, it decreases at a much slower rate. For instance when $p_0 = 0.9$, $W^*_{pop}/W^*_{tech} \approx 0.10$ while $W^*_{indep}/W^*_{tech} \approx 0.53$.

B Scientific policies

We now study the scientific policies adopted under the different institutions. Consider a technocratic government first. Observe that $W(p, e(p)) = B(e(p)) - pD(e(p))$ is convex in p.[21] Therefore, the government wants to obtain a scientific belief which is as dispersed as possible. For instance when D is linear, we have: $E[W(\tilde{p}, e(\tilde{p}))|n] = W(p_0, e(p_0)) + \frac{1}{2}\frac{d_0^2}{b}V(\tilde{p})$ where $V(\tilde{p})$ is the belief's variance. In general, $E[W(\tilde{p}, e(\tilde{p}))|n]$ is maximum when scientists have converged to the truth and $\tilde{p} = p_\infty$. As n increases, expected interim welfare tends to increase at decreasing rate. However, these tendencies are not absolute. Due, in part, to the discrete nature of Bayesian updating in our setup, expected welfare can be locally decreasing or convex in n, giving rise to rich features in the behavior of the first-best scientific policy.[22] To sum up, *a technocratic government trades-off the welfare benefits from uncertainty reduction against the research costs.*

Next, consider a populist government. A key new motive appears in the government's objective. Since $W(q, e(q))$ increases when q decreases, *the utility of a populist government is higher when citizens are reassured* and q is lower, even when this reassurance is scientifically unfounded. This means that the interests of a populist government may be partly aligned with those of the industry. For instance, we show in Appendix

[21] By the enveloppe theorem, the first derivative is equal to $-D(e(p))$. The second derivative is then equal to $-e'(p)D'(e(p)) \geq 0$.

[22] For instance, numerical simulations indicate that $E[W(\tilde{p}, e(\tilde{p}))|n]$ may be initially convex in n when p_0 is close to 0 or 1 and α is not too large. Optimal funding then jumps discontinuously from 0 to a positive, and potentially high, level as the cost of scientific experiments C decreases.

that when $d_0 \ll be_0$ and $d \ll b$, $W(q, e(q))$ is approximately linear in q. In that case, $E[W(\tilde{q}, e(\tilde{q}))|n] \approx W(E\tilde{q}, e(E\tilde{q}))$ and, if C is low, a populist government simply wishes to minimize the expected popular belief.[23]

How does $E\tilde{q}$ vary with n? Broadly speaking, $E\tilde{q}$ is lower when $\tilde{p}$ puts more weight on values from which the industry can better miscommunicate. When n is large, $\tilde{p}$ is close to p_∞ and puts little weight on beliefs lying between $[q^*, p^*]$. Indeed, $\tilde{q}$ converges to p_∞ and $E\tilde{q}$ converges to p_0 as n tends to ∞. Variations of $E\tilde{q}$ are then partly determined by the position of initial scientific belief p_0 with respect to the domain of effective industry communication $[q^*, p^*]$. If $p_0 \in [q^*, p^*]$, the industry affects public opinion even when there is very little research. In that case, $E\tilde{q}$ is often increasing in n and a populist government would want to give no support to scientific activities. In contrast, if $p_0 < q^*$ or $p_0 > p^*$, $E\tilde{q} = p_0$ when $n = 0$. In that case, $E\tilde{q}$ is often non-monotonic in n and reaches a minimum for some positive value n. This is the level of research that allows the industry to most effectively communicate, in expectation. We illustrate these effects in Figure 3. Parameters are such that $q^* = 0.4$ and $p^* = 0.87$.[24] On the left panel, $p_0 = 0.8 \in [q^*, p^*]$ and $E\tilde{q}$ is increasing in n.[25] On the right panel, $p_0 = 0.9 > p^*$ and $E\tilde{q}$ is initially decreasing in n, reaching a minimum at $n = 4$. To sum up, *a populist government may want to support science in order to better allow the industry to unduly reassure citizens.* As shown in Proposition 1, these populist policies are clearly detrimental in terms of welfare. In contrast to the populist government, *an independent research agency will try to lessen the ability of the industry to affect citizens' beliefs.* Depending on the parameters' values, this may lead the independent agency to provide more or less scientific funding than under the first-best.

We illustrate these effects in Figure 5. We depict how the optimal scientific policies under the three institutions vary with initial belief p_0, for the same parameters as in Figure 1. The left bars correspond to the first-best levels of funding, in the absence of citizens'

[23] In general since $W(q, e(q))$ is decreasing and convex in q, the utility of a populist government is higher when both the expectation of popular belief is lower and its dispersion is higher. For instance, when D is linear, $W(q, e(q)) = W(Eq, e(Eq)) + \frac{1}{2}\frac{d_0^2}{b}V(q)$.

[24] We adopt the same parameter values as for Figure 1, except for $P = 0.611$. Note that since P is lower, α is lower and we see that this yields an increase in q^* and a decrease in p^* as predicted in our comparative statics analysis.

[25] We consider even values of n in simulations and Figures.

misperceptions. Support for research first increases and then decreases as p_0 increases. A technocratic government only cares about the direct benefits and costs of reducing scientific uncertainty. Funding reaches a maximum when uncertainty is maximal ($p_0 = 0.5$) while research is not funded when uncertainty is low ($p_0 = 0.1$ or $p_0 \geq 0.8$).

The middle bars depict the scientific policies chosen by a populist government. When scientists have initial suspicions that harm is likely ($0.5 \leq p_0 \leq 0.7$), the government provides less funding for research than under the first-best. Too much research would decrease perceived welfare by reducing the ability of firms to reassure citizens. By contrast when initial belief is low ($p_0 \leq 0.3$), the populist government over-provides support for research. In the unlikely case where the activity is harmful, the government want citizens to be reassured. Providing more research increases the opportunities for, and impacts of, firms' communication.

Finally, the right bars depict the scientific policies of an independent funding agency. We see that the agency essentially has two opposite ways to try and limit the welfare losses induced by populist policies. When initial beliefs are high ($p_0 \geq 0.6$), the agency provides much more funding than under the first-best. This is a strategy of *scientific overkill*: By doing lots of research, scientists necessarily get close to the truth and firms have very little leeway to influence public opinion.[26] The benefits from shutting down firms' communication outweigh the added research costs when the likelihood that the activity is harmful is high. By contrast, when initial beliefs are low ($p_0 \leq 0.5$), the agency provides almost no funding. This is a strategy of *deliberate ignorance*, since some research would lead to a lower welfare than no research. Figure 2 shows that these strategies are quite effective at reducing the welfare losses from populist policies. Overall, we see that firms ' miscommunication has a first-order impact on scientific policies.

[26] That is, there is a low probability that scientists' belief $\tilde{p}$ ends up in the range $[q^*, p^*]$ where firms affect public opinion.

V Conclusion

We provide one of the first analysis of the interactions between scientific uncertainty, firms' communication and public policies. We characterize firms' optimal communication and uncover the existence of three domains. When scientists' belief that firms' activity is harmful is low, engaging in communication is not profitable. When scientists' belief takes intermediate values, firms target a low level of citizens' belief and exert as much effort as needed for public opinion to reach this level. Above a critical level of scientific belief, however, firms give up on their attempts at reassuring citizens. We show that indirect lobbying has a first-order impact on scientific funding. We compare scientific policies under three types of institutions and unearth rich effects. Both a populist government and an independent agency may provide more or less support to research than a technocratic government, although they do so for opposite reasons and in different circumstances.

Our analysis relies on a number of simplifying assumptions. Relaxing them provide natural, and potentially, fruitful directions for future research. Since a populist government maximizes perceived welfare, firms do not have an incentive to engage in classical lobbying here. As in Grossman & Helpman (1994), the government could alternatively maximize a combination of welfare and transfers. Firms would then try to affect regulation both directly through transfers and indirectly via public opinion, and studying the interaction between direct and indirect lobbying could be interesting. We suspect that Theorem 1 would extend and that the sharp drop in communication efforts would be associated with a sharp increase in classical lobbying. As in Yu (2005), it would also be natural to consider interactions between an industrial and an environmental lobby. Competition to affect public opinion would likely raise firms' communication effort and could also lead them to give up communication for lower levels of scientific beliefs. Finally, we have focused our representation of science on the key question of understanding the level of harm induced by the economic activity. In reality, science of course covers a wide variety of issues and questions. A documented strategy of industrial lobbies has been to fund "distraction research", i.e., legitimate research that does not advance knowledge on this key question and distracts scientists and citizens' attention away from it.[27] Developing a richer model of science would allow to analyze these elaborate strategies.

[27] See, in particular, chapter 16 in Proctor (2011).

APPENDIX

Proofs of statements in Section 3.1.

We prove, first, that p converges in probability to p_∞ as n tends to ∞. Suppose that n is even. Introduce $l = k - n/2$ and $\sigma = P(1-P)$. We have: $p(p_0, k, n) = \frac{p_0 \alpha^l}{p_0\alpha^l + (1-p_0)\alpha^{-l}} = \hat{p}(p_0, l)$ with probability $\alpha^l C_n^{l+n/2}\sigma^{n/2}$. Fix l. As n increases, we can see that the probability put on $\hat{p}(p_0, l)$ tends to zero. More precisely, elementary computations show that $C_n^{l+n/2}\sigma^{n/2}/[C_{n+1}^{l+(n+1)/2}\sigma^{(n+1)/2}] \leq K < 1$ if n is high enough. Since $\hat{p}(p_0, l) \to 1$ when $l \to +\infty$ and $\hat{p}(p_0, l) \to 0$ when $l \to -\infty$, this means that $\forall \varepsilon, \eta > 0, \exists \bar{n} : n \geq \bar{n} \Rightarrow pr(p(p_0, k, n) \in [\varepsilon, 1-\varepsilon]) \leq \eta$. Thus, the probability that p belongs to some interior interval becomes arbitrarily small as n becomes large. Since $E(p) = p_0$, p must converge in probability to p_∞. The proof for n odd runs along similar lines. QED.

Next, compute the derivatives of $q(p, m)$:

$$\begin{aligned}
q_p &= \frac{\alpha^m}{[p + (1-p)\alpha^m]^2} \\
q_{pp} &= \frac{-2\alpha^m(1-\alpha^m)}{[p + (1-p)\alpha^m]^3} \\
q_m &= -p(1-p)\ln(\alpha)\frac{\alpha^m}{[p + (1-p)\alpha^m]^2} \\
q_{mm} &= -p(1-p)[\ln(\alpha)]^2\alpha^m \frac{p - (1-p)\alpha^m}{[p + (1-p)\alpha^m]^3}
\end{aligned}$$

QED.

Proof of Theorem 1.

(0). We first derive some useful formulas. By taking the derivative of (1), we get:

$$e'(q) = \frac{-b(d_0 + de_0)^2}{(b + qd)^2}$$

Then, observe that

$$\frac{q}{1-q} = \frac{p}{1-p}\alpha^{-m}$$

Taking logs and deriving with respect to m yields

$$q' = -\ln(\alpha)q(1-q)$$

Deriving again and substituting yields

$$q'' = -\ln^2(\alpha)q(1-q)(2q-1)$$

We now compute the first derivative of π with respect to m:

$$\begin{aligned}\pi'(m) &= b(e_0 - e(q))e'(q)q' - c \\ \pi'(m) &= \ln(\alpha)b^2(d_0 + de_0)^2\frac{q^2(1-q)}{(b+qd)^3} - c\end{aligned}$$

Deriving again and simplifying yields

$$\pi''(m) = -\ln^2(\alpha)b^2(d_0 + de_0)^2\frac{q^2(1-q)}{(b+qd)^4}[2b - (3b+d)q]$$

(1). Suppose first that $p < \frac{2b}{3b+d}$. Since $q \leq p$, $\pi'' < 0$ and π is concave. Since $\pi'(\infty) = -c$, either $\pi'(0) \leq 0$ and the optimal effort is 0 or $\pi'(0) > 0$ and the optimal effort is is the unique $m^* > 0$ satisfying $\pi'(m) = 0$. We have:

$$\pi'(0) = \ln(\alpha)b^2(d_0 + de_0)^2\frac{p^2(1-p)}{(b+pd)^3} - c$$

To understand how $\pi'(0)$ varies with p, study the function $f(p) = \frac{p^2(1-p)}{(b+pd)^3}$. We have:

$$f'(p) = \frac{p[2b - (3b+d)p]}{(b+pd)^4}$$

This implies that $f' > 0$ if $p \in]0, \frac{2b}{3b+d}[$ and < 0 if $p \in]\frac{2b}{3b+d}, 1[$. Therefore, $f(0) = f(1) = 0$ and f is increasing over $[0, \frac{2b}{3b+d}]$, decreasing over $[\frac{2b}{3b+d}, 1]$ and reaches its maximum at $\frac{2b}{3b+d}$. Moreover, $f(\frac{2b}{3b+d}) = \frac{4}{27}\frac{1}{b(b+d)^2}$. Two subcases appear:

(1.1) If $c \geq \frac{4}{27}\ln(\alpha)\frac{b(d_0+de_0)^2}{(b+d)^2}$, then $\pi'(0) \leq 0$ and $m = 0$.

(1.2) If $c < \frac{4}{27}\ln(\alpha)\frac{b(d_0+de_0)^2}{(b+d)^2}$, then there is a unique $q^* \in [0, \frac{2b}{3b+d}]$ such that $\pi'(m) = 0$. It satisfies:

$$\frac{q^2(1-q)}{(b+qd)^3} = \frac{c}{\ln(\alpha)b^2(d_0 + de_0)^2}$$

Optimal communication is then such that $q = q^*$ which implies that

$$m^* = \frac{1}{\ln(\alpha)}[\ln(\frac{p}{1-p}) - \ln(\frac{q^*}{1-q^*})]$$

(2) Suppose, next, that $p > \frac{2b}{3b+d}$. Then π is convex until q reaches $\frac{2b}{3b+d}$, and then concave. The marginal impact of an incremental unit of effort is increasing for $q > \frac{2b}{3b+d}$ and then decreasing when $q < \frac{2b}{3b+d}$. In particular, the optimal effort is such that $q \leq \frac{2b}{3b+d}$. We can see that the optimal effort is either 0 or $\hat{m}$ the unique m such that $\pi'(m) = 0$ and $q \leq \frac{2b}{3b+d}$. Compare the payoffs of these two effort levels:

$$\varphi(p) = \pi(0) - \pi(\hat{m}) = B(e(p)) - B(e(q^*)) + \frac{c}{\ln(\alpha)}[\ln(\frac{p}{1-p}) - \ln(\frac{q^*}{1-q^*})]$$

Study how φ varies with p. We have:

$$\begin{aligned}\varphi'(p) &= -\frac{b^2(d_0+de_0)^2}{(b+pd)^3}p+\frac{c}{\ln(\alpha)}(\frac{1}{p}+\frac{1}{1-p}) \\ \varphi'(p) &= \frac{b^2(d_0+de_0)^2}{p(1-p)}(f(q^*)-f(p))\end{aligned}$$

Note that there is a unique $\bar{q} > \frac{2b}{3b+d}$ such that $f(\bar{q}) = f(q^*)$. From the variations of function f, we know that φ' is > 0 over $]0, q^*[$, < 0 over $]q^*, \bar{q}[$ and > 0 over $]\bar{q}, 1[$. Therefore, φ is increasing over $[0, q^*]$, decreasing over $[q^*, \bar{q}]$ and increasing over $[\bar{q}, 1]$. Since $\varphi(q^*) = 0$ and $\varphi(1) = +\infty$, there is a unique level $p^* > \bar{q} > \frac{2b}{3b+d}$ such that $\varphi(p^*) = 0$ and $p < p^* \Rightarrow \pi(0) < \pi(\hat{m})$ and $p > p^* \Rightarrow \pi(0) > \pi(\hat{m})$. QED.

Comparative statics.
From the characterization of q^*, we can write:

$$q^* = f^{-1}(\frac{c}{\ln(\alpha)b^2(d_0+de_0)^2})$$

where f^{-1} is the inverse of f over the range $[0, \frac{2b}{3b+d}]$. Since f is increasing in that range, f^{-1} is also increasing. Since f only depends on d and b, this shows that q^* is increasing in c and decreasing in α, d_0 and e_0.

To study the comparative statics of p^*, introduce $\psi(p) = B(e(p)) + \frac{c}{\ln(\alpha)}\ln(\frac{p}{1-p})$ such that $\varphi(p) = \psi(p) - \psi(q^*)$. Note that ψ has the same variations as φ. Consider $c_1 < c_2$. Then

$$\psi(p, c_2) - \psi(p, c_1) = \frac{c_2 - c_1}{\ln(\alpha)}\ln(\frac{p}{1-p})$$

and this function is increasing in p. Since q^* is increasing in c, we have: $q_2^* > q_1^*$. Moreover, $q_2^* < \frac{2b}{3b+d}$ hence lies in the range where $\psi(., c_1)$ is decreasing. Since $p_2^* > q_2^*$, $\psi(p_2^*, c_2) - \psi(p_2^*, c_1) > \psi(q_2^*, c_2) - \psi(q_2^*, c)$. This means that $\psi(p_2^*, c_2) - \psi(q_2^*, c_2) > \psi(p_2^*, c_1) - \psi(q_2^*, c_2)$. Since $\psi(p_2^*, c_2) - \psi(q_2^*, c_2) = \varphi(p_2^*, c_2) = 0$ and $\psi(q_1^*, c_1) > \psi(q_2^*, c_1)$, we have

$$\psi(p_2^*, c_1) - \psi(q_1^*, c_1) = \varphi(p_2^*, c_1) < 0$$

and hence $p_2^* < p_1^*$. Finally, note that an increase in α has the same impact as a decrease in c. QED.

Proof of Proposition 1.
Since $e(p)$ maximizes $W(p, e)$, we have: $W(p, e(p)) \geq W(p, e(q(p)))$ for any p. Therefore, $E[W(p, e(p))|n] - Cn \geq E[W(p, e(q(p)))|n] - Cn$ for any n. This means that the maximum of the first function is greater than or equal to the maximum of the second function and $W_{tech}^* \geq W_{indep}^*$. Next, note that for any n, $W_{indep}^* \geq E[W(p, e(q(p)))|n] - Cn$ and this implies that $W_{indep}^* \geq W_{pop}^*$. QED.

Proof of statements in Section 4.2.

If D is linear, $d = 0$ and $e(p) = e_0 - \frac{d_0}{b}p$ and $W(p, e(p)) = \frac{1}{2}be_0^2 - d_0e_0p + \frac{1}{2}\frac{d_0^2}{b}p^2$. This means that $E[W(p, e(p))|n] = \frac{1}{2}be_0^2 - d_0e_0Ep + \frac{1}{2}\frac{d_0^2}{b}Ep^2$. Since $Ep = p_0$ and $Ep^2 = p_0^2 + Vp$, we have: $E[W(p, e(p))|n] = W(p_0, e(p_0)) + \frac{1}{2}\frac{d_0^2}{b}Vp$.

When is $W(q, e(q))$ approximately linear? We have: $W(q, e(q)) = \frac{1}{2}\frac{(be_0 - qd_0)^2}{b+qd} = \frac{1}{2}be_0^2\frac{(1-\frac{d_0}{be_0}q)^2}{1+\frac{d}{b}q}$. If $d_0 \ll be_0$, then $(1 - q\frac{d_0}{be_0})^2 \approx 1 - 2q\frac{d_0}{be_0}$. If $d \ll b$, then $\frac{1}{1+q\frac{d}{b}} \approx 1 - q\frac{d}{b}$. If both conditions are satisfied, then $W(q, e(q)) \approx \frac{1}{2}be_0^2(1 - q\frac{2d_0+de_0}{be_0})$. QED.

Figure 1: Communication and People Belief with $d_0 = 10$, $d = 1$, $b = 2$, $e_0 = 10$, $c = 5$, $C = 0.5$, $q^* = 0.3$, $p^* = 0.97$, $\alpha = 1.829$ and $P = 0.647$.

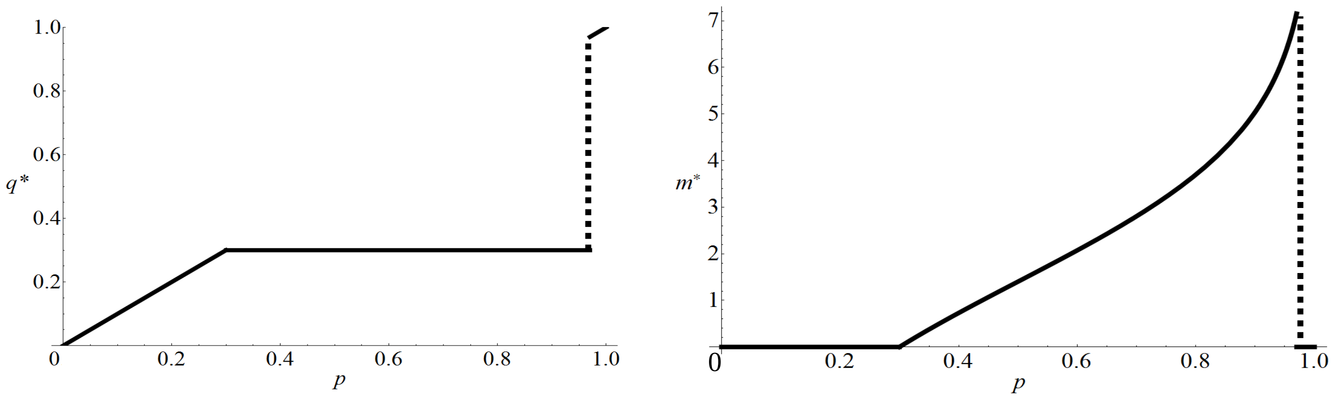
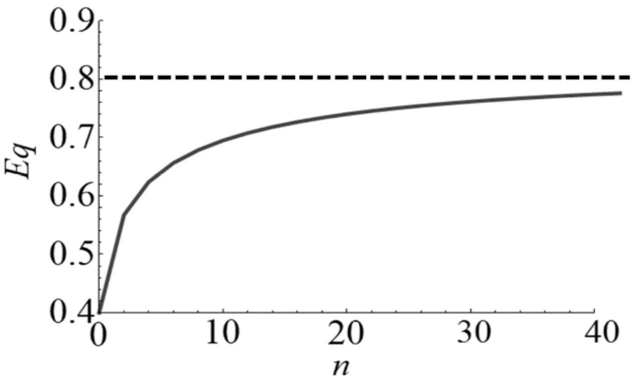


Figure 2: Expected People Belief with respect to the prior belief with $d_0 = 10$, $d = 1$, $b = 2$, $e_0 = 10$, $c = 5$, $C = 0.5$, $q^* = 0.4$, $p^* = 0.87$, $\alpha = 1.568$ and $P = 0.611$. On the right hand side $p_0 = 0.8$ and on the left hand side $p_0 = 0.9$.



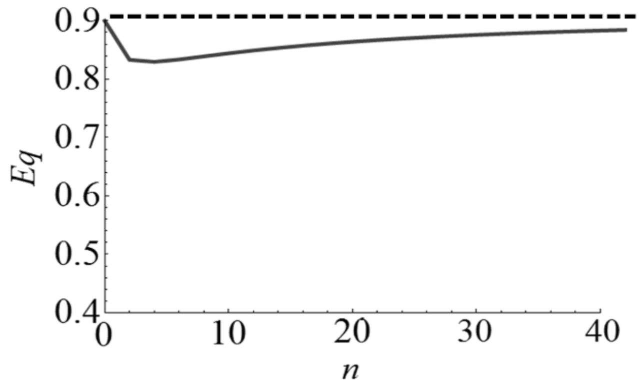


Figure 3: Percentage of welfare in term of welfare from technocratic policy with respect to the prior belief with $d_0 = 10$, $d = 1$, $b = 2$, $e_0 = 10$, $c = 5$, $C = 0.5$, $q^* = 0.3$, $p^* = 0.97$, $\alpha = 1.829$ and $P = 0.647$.

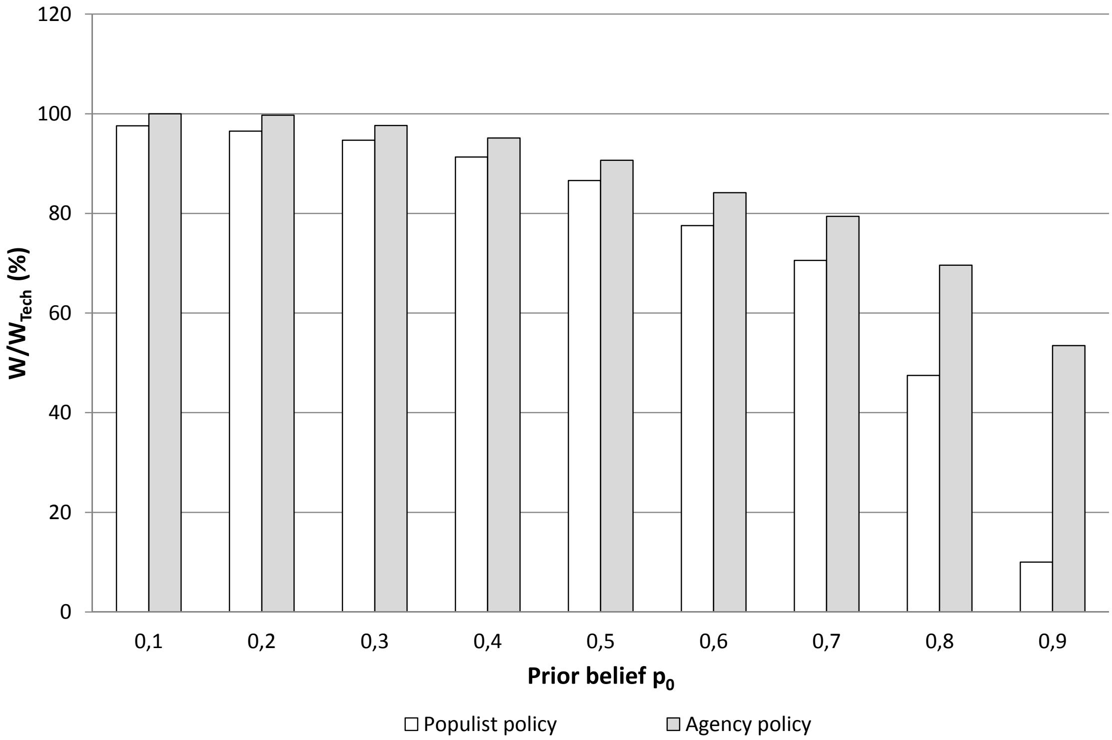
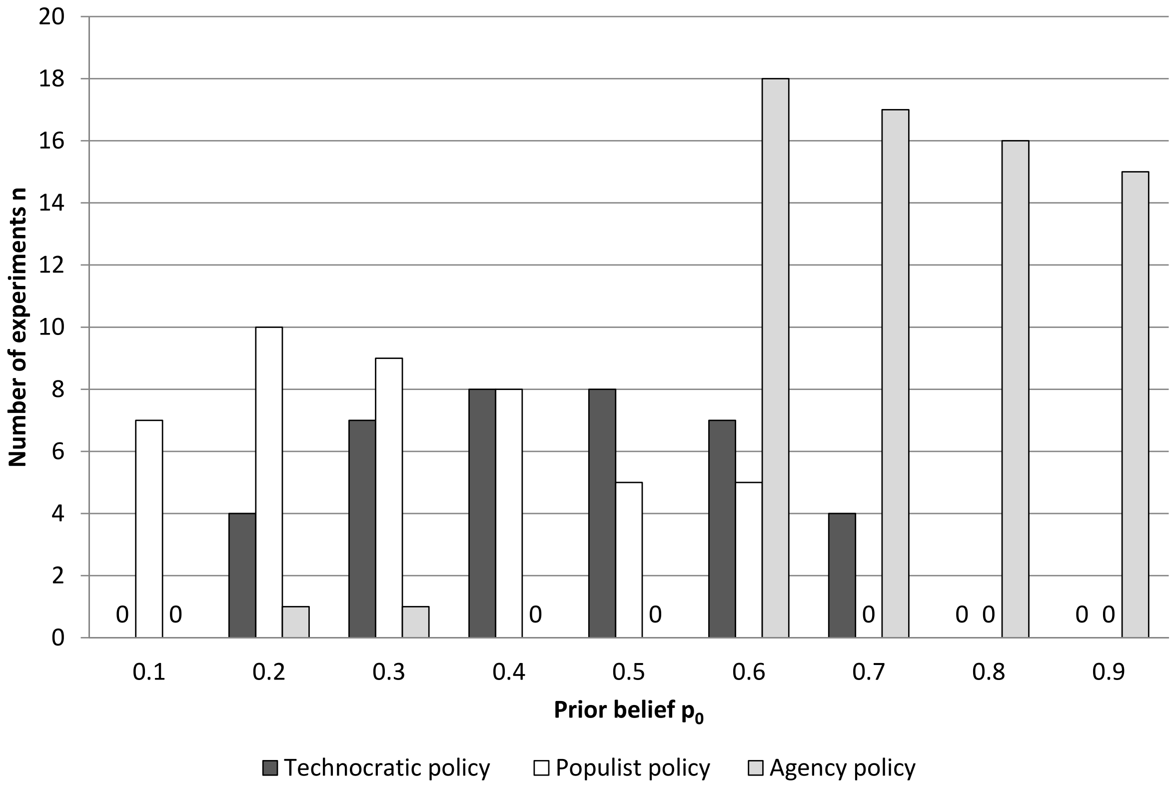


Figure 4: Percentage of welfare in term of welfare from technocratic policy with respect to the prior belief with $d_0 = 10$, $d = 1$, $b = 2$, $e_0 = 10$, $c = 5$, $C = 0.5$, $q^* = 0.3$, $p^* = 0.97$, $\alpha = 1.829$ and $P = 0.647$.



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