OPTIMAL MEDIA CENSORSHIP

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Abstract. We study the problem of media control by the government. For a large class of environments, the optimal media control policy is simple. It takes the form of an upper censorship, where the government censors all the media outlets whose editorial policies are more adversarial than a selected threshold. The model is an application of optimal Bayesian persuasion with a privately informed receiver.

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1. Introduction

We study the problem of media control by the government. In the contemporary world, people obtain information about the government state of affairs through various media sources such as television, newspapers, and internet blogs. Without the media, most people would not know what policies and reforms the government pursues and how effective they are. Media outlets have different positions on the political spectrum and differ substantially in how they select and present facts to cover the same news. People choose their sources of information based on their political ideology and socioeconomic status. This information is valuable for significant individual decisions in migration, investment, occupation, and voting, to name a few. Individuals do not fully internalize externalities that their decisions impose on the society. Likewise, the government may not have the society's best interest at heart. To further its goals, the government then wishes to influence individual decisions by manipulating the information through media. In autocracies and countries with weak checks and balances, the government has power to control the media content.

A specific illustration of this practice is Russian crackdown on independent media outlets in 2014. By measuring the frequency with which media outlets use keywords and phrases that tend to discredit government actions, a pro-Kremlin news site Politonline.ru on March 31, 2014, published a list of top-20 most disloyal media outlets in Russia.[1] A Russian political scientist and government adviser, Aleksandr Dugin, suggested that this list should be the order in which the government shuts down these media outlets. Using the broadly formulated legislation on combating extremism, the governmental media watchdog Roskomnadzor has taken actions to effectively shut down a number of media outlets at the top of the disloyalty list. An opposition leader and former chess champion, Garry Kasparov, tweeted in response to the crackdown: "These are huge news sites, not political groups. Giant Echo of Moscow site now just gone. Grani, EJ, Navalny's blog, all blocked in Russia."[2] Russia's leading opposition television channel, Dozhd, lost its main cable and satellite providers. "The government says they didn't close Dozhd—in reality they did," the channel's owner said to the Financial Times. "We fully believe that the operators didn't decide to shut us off voluntarily but that this was done under pressure."[3] In December 2014, the Guardian reported: "Several news companies have had their editors fired while others have lost studio space." Before a Siberian TV channel, TV-2, was forced to shut down in December 2014, its owner said to the Guardian: "We were under constant pressure to change our editorial policies. We're not an opposition channel; we simply give everyone an opportunity to speak."[4]

The government's problem of media control can be represented as a Bayesian persuasion problem. We provide conditions for the optimality of simple censorship policies that shut down all media outlets except the most pro-government ones. In other

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[1] http://www.politonline.ru/comments/15966.html

[2] https://twitter.com/Kasparov63/status/444219035304337408

[3] http://www.ft.com/cms/s/0/ef0398b0-8dba-11e3-bbe7-00144feab7de.html

[4] http://www.theguardian.com/world/2014/dec/29/russian-authorities-siberian-tv2-off-air

words, to act optimally, the government needs no sophisticated instruments of information disclosure other than censorship. We also show that the government increases censorship if influencing society decisions becomes relatively more important than maximizing individual welfare. Furthermore, the government increases censorship if the society experiences an ideology shock in favor of the government.

Related Literature. This paper is related to the literature on media capture that addresses the problem of media control by the government and other influential parties and lobbying groups. Besley and Prat (2006) study how the government incentives to censor the media depend on the transaction cost of bribing the media and plurality (the number of media outlets). In their model, media outlets are identical and all voters have common interest, and the government's optimal decision reduces to either capturing all media outlets or none. Corneo (2006) studies a model with a privately owned monopoly media outlet and heterogeneous voters and shows that ownership concentration makes media slant more severe. Petrova (2008) considers a similar model where voters are heterogeneous in their wealth and vote for provision of a public good that is more useful for poor than rich. Voters can learn about an uncertain value of the public good from an informed media outlet. Petrova (2008) shows that, in countries with weak institutions where it is cheaper to bribe the media, the rich will bribe the media outlet to make it understate value of the public good, thus leading to its underprovision. Gehlbach and Sonin (2014) consider a setting with a government-influenced monopoly media outlet that exploits the trade-off between the government's objective to "mobilize" the population for some collective goal and to collect the revenue from subscribers who demand informative news. Gehlbach and Sonin (2014) show that the presence of the "mobilization" objective increases the news bias, whereas the subscription revenues reduce the bias but can cause the government to nationalize the media outlet.

The above literature restricts attention to two states of the world and simple information disclosure mechanisms. The main difference of this paper is its generality: there is a continuum of states and, as in Kamenica and Gentzkow (2011), we do not restrict the set of information disclosure mechanisms. It is not an assumption, but a conclusion of the paper that optimal information disclosure can take a simple form of censorship. Addressing the problem at this level of generality was made possible due to recent developments in the theory of Bayesian persuasion. This paper builds upon Kolotilin et al. (2017). A novel element is that we consider a heterogeneous population of receivers, and we allow for the payoffs to depend on the aggregate action of the population, a feature that is absent in Kolotilin et al. (2017).

In this paper, we assume that media outlets have fixed editorial policies (media slant). There is a literature that considers media outlets that make strategic decisions about producing biased news, so the media slant is endogenously determined. A media outlet can deliver biased news to cater for the tastes of readers with confirmation bias (Mullainathan and Shleifer, 2005, and Gentzkow and Shapiro, 2006) or political ideology (Chan and Suen, 2008). Alternatively, media slant can be driven by the selfish interests of media owners (Baron, 2006, and Corneo, 2006).

This paper is also related to Alonso and Câmara (2016) why study a Bayesian persuasion problem where a politician designs an experiment to influence voting decisions of a finite group of voters. The sender's payoff is binary, it depends on whether or not a certain majority quota has been obtained. The essence of the optimal design in this paper is in finding an optimal pivotal coalition to persuade. In our paper, the sender's payoff is non-binary and depends on both the aggregate action of receivers and their individual actions. This difference in the payoff structure leads to an optimal persuasion mechanism that is conceptually different from that in Alonso and Câmara (2016).

2. Model

We present a stylized model with a government, media outlets, and readers. Our model has standard ingredients from the theoretical media literature. The novelty of the model is that the government can censor media outlets.

The government's state of affairs is a random variable ω drawn from $[0,1]$ according to a distribution F. There is a continuum media outlets indexed by $s \in [0,1]$. A media outlet s has an editorial policy that endorses the government (sends message $m_s = 1$) if $\omega \geq s$ and criticizes it (sends message $m_s = 0$) if $\omega < s$.[5] The cutoff s can be interpreted as a slant or political bias of the outlet against the government and can be empirically measured as the frequency with which the outlet uses anti-government language.[6]

There is a continuum of heterogeneous readers indexed by $r \in [0,1]$ distributed with G that admits a density g. Each reader observes endorsements of all available media outlets[7] and chooses between action ($a = 1$) and inaction ($a = 0$). A reader's utility is equal to

$$u(\omega, r, a, \bar{a}) = a(\omega - r) + \bar{a}\xi(r),$$

where $\bar{a}$ denotes the average action in the society, and $\xi(r)$ is a type-specific externality term that captures the impact of the average action $\bar{a}$ on the reader's utility but does not affect the reader's optimal action. The government's utility is equal to

$$\int_R u(\omega, r, a_r, \bar{a})\mathrm{d}G(r) + \bar{a}\gamma = \int_R \Big(a_r(\omega - r) + \bar{a}(\xi(r) + \gamma)\Big)\mathrm{d}G(r),$$

where a_r denotes an action of type r reader, and γ is the term that captures the government's intrinsic benefit from the average action. Let the parameter $\rho \in \mathbb{R}$

[5] As in Suen (2004), Chan and Suen (2008), and Chiang and Knight (2011), binary media reports that communicate only whether the state of affairs ω is above some standard s can be justified by a cursory reader's preference for simple messages such as positive or negative opinions and yes or no recommendations.

[6] Gentzkow and Shapiro (2010) construct such a slant index for U.S. newspapers. Empirical findings of their paper suggest that the editorial policies of media outlets are driven by reader preferences, justifying our assumption of the existence of a large variety of editorial policies.

[7] This will be compared to Chan and Suen (2008) where each reader observes a single media outlet and does not communicate with other readers.

summarize the impact of the average action $\bar{a}$ from the two sources,

$$\rho = \int_R (\xi(r) + \gamma)\mathrm{d}G(r).$$

We will refer to ρ to as the government's *bias*.

The government's censorship policy is a closed subset of the media outlets $S \subset [0,1]$ that are permitted to broadcast. Readers observe messages from the permitted media outlets in S and update their beliefs about the state ω.

The timing is as follows. First, the government chooses a set of permitted media outlets. Second, the state of affairs is realized, and every permitted media outlet endorses or criticizes the government, according to its editorial policy. Finally, readers observe messages of the permitted media outlets and decide whether to act or not.

Let us briefly discuss interpretations of important components of the model. We can interpret a reader's type r as his ideological position. A reader who is more supportive of the government has a smaller r.[8] There are various interpretations of the reader's action a, such as refraining from emigration, investing in domestic stocks, volunteering for military service, and voting for the government.

The government can be biased relative to the population of readers ($\rho \neq 0$) for two reasons. First, the government may want the society to act more (or less) than what they would prefer under complete information about the state for personal benefit (abuse of power, corruption, etc.), captured by the parameter γ. Second, the government may want to internalize the externality factor that affects the social utility but is external to readers' decision making, captured by the component $\int_R \xi(r)G(r)$. Our model permits to consider a benevolent government that wishes to negate an externality in the society ($\gamma = 0$), or a selfish government that cares little about the society ($\xi(r) = 0$ and large γ), or any combination of the two.

3. Persuasion mechanisms

We begin the analysis by solving a richer problem, where the government is permitted to use general persuasion mechanisms. The government is allowed to approach each reader individually and send him a private message that depends on the reader's reported type and a realized state. Building upon Kolotilin et al. (2017), we derive the conditions for an optimal persuasion mechanism implementable by a censorship policy. Persuasion mechanisms may be hard to implement in practice, but they serve as a benchmark of what the government could possibly achieve if it had full information control.

[8] This media censorship problem can be applied to spatial voting models, as in Chiang and Knight (2011). Consider the government party ($p = G$) and opposition party ($p = O$) competing in an election. If party p wins, a voter with ideological position r gets utility $w_p - (r - r_p)^2$, where w_p is the quality or valence of party p, and r_p is the ideology or policy platform of party p. Voters know the parties' ideologies and obtain information about the parties' qualities from all available media outlets. Each voter supports the party that maximizes his expected utility. Our analysis applies, because the voter's utility difference between the government and opposition parties is proportional to $\omega - r$, where $\omega = \left(w_G - w_O + r_O^2 - r_G^2\right)/2(r_O - r_G)$ represents the state.

A *persuasion mechanism* π is a measurable function that maps a realized state ω and a reader's report $\hat{r}$ about his type to a probability $\pi(\omega, \hat{r})$ with which action $a = 1$ is recommended. Each reader can observe only his own recommendation and cannot share information with other readers.

Note that a reader's decision between actions 0 and 1 does not depend on the externality term, $\bar{a}\xi(r)$. Thus, for a given bias ρ of the government, without loss of generality we can set $\xi(r) = 0$ for all r, and $\gamma = \rho$, so $u(\omega, r, a, \bar{a}) = a \cdot (\omega - r)$.

A persuasion mechanism is *incentive compatible* if each reader prefers to report his true type and to obey the mechanism's recommendation. Consider a reader of type $r \in R$ who reports $\hat{r} \in R$ and takes actions $a_0 \in \{0, 1\}$ and $a_1 \in \{0, 1\}$ after recommendations $\hat{a} = 0$ and $\hat{a} = 1$, respectively. This reader's interim utility is given by

$$U_\pi(r, \hat{r}, a_0, a_1) = \int_0^1 \left(a_0(1 - \pi(\omega, \hat{r})) + a_1 \pi(\omega, \hat{r})\right)(\omega - r)\mathrm{d}F(\omega).$$

The interim utility of the truthful ($\hat{r} = r$) and obedient ($a_0 = 0$ and $a_1 = 1$) reader is equal to

$$U_\pi(r) = U_\pi(r, r, 0, 1) = \int_0^1 \pi(\omega, r)(\omega - r)\mathrm{d}F(\omega).$$

By the revelation principle, we focus on mechanisms that satisfy the incentive compatibility constraint

$$U_\pi(r) \geq U_\pi(r, \hat{r}, a_0, a_1) \text{ for all } r, \hat{r} \in [0, 1] \text{ and } a_0, a_1 \in \{0, 1\}. \tag{IC}$$

Consider an incentive-compatible persuasion mechanism π. Let $\bar{a}_\pi(\omega)$ be the average action conditional on ω, and let $q_\pi(r)$ be the interim action of type r,

$$\bar{a}_\pi(\omega) = \int_0^1 \pi(\omega, r)\mathrm{d}G(r) \quad \text{and} \quad q_\pi(r) = \int_0^1 \pi(\omega, r)\mathrm{d}F(\omega).$$

The government's expected utility is

$$V_\pi = \int_{[0,1]^2} \big((\omega - r)\pi(\omega, r) + \rho\bar{a}_\pi(\omega)\big)\mathrm{d}F(\omega)\mathrm{d}G(r) = \int_0^1 \big(U_\pi(r) + \rho q_\pi(r)\big)\mathrm{d}G(r).$$

A mechanism is called *optimal* if it solves the government's problem

$$\max_\pi V_\pi \quad \text{subject to (IC).} \tag{P}$$

An *upper-censorship* mechanism is a mechanism that reveals the states below ω^* and pools the states above ω^* for some threshold $\omega^* \in \Omega$,

$$\pi(\omega, r) = \begin{cases} \mathbf{1}_{\{r \leq \omega\}}, & \text{if } r \leq \omega^*, \\ \mathbf{1}_{\{r \leq \mathbb{E}[\tilde{\omega}|\tilde{\omega} > \omega^*]\}}, & \text{if } r > \omega^*, \end{cases}$$

where $\mathbf{1}_{\{\cdot\}}$ denotes the indicator function. This mechanism can be interpreted as a broadcasting device that sends to all readers the same message $m(\omega) = \omega$ if $\omega < \omega^*$ and $m(\omega) = \mathbb{E}[\tilde{\omega}|\tilde{\omega} > \omega^*]$ if $\omega > \omega^*$. A *lower-censorship* mechanism is defined symmetrically. This broadcasting device sends message $m(\omega) = \omega$ if $\omega > \omega^*$ and $m(\omega) = \mathbb{E}[\tilde{\omega}|\tilde{\omega} < \omega^*]$ if $\omega < \omega^*$ for some $\omega^* \in \Omega$.

Proposition 1. *An upper-censorship (lower-censorship) mechanism is optimal for all distributions F and all biases $\rho \in \mathbb{R}$ if and only if g is log-concave (log-convex) on Ω.*

Proof. We prove Proposition 1 using the following auxiliary results.

Lemma 1. *Let π be an incentive compatible persuasion mechanism. Then*

$$V_\pi = \rho \mathbb{E}[\omega] g(0) + \int_R U_\pi(r) I(r) \mathrm{d}r,$$

where

$$I(r) = g(r) + \rho g'(r).$$

Proof. By Lemma 1 in Kolotilin et al. (2017), the incentive compatibility of π implies that $U'_\pi(r) = -q_\pi(r)$, $U_\pi(1) = 0$, and $U_\pi(0) = \mathbb{E}[\omega]$. Hence, by integration by parts,

$$\begin{aligned} V_\pi &= \int_0^1 \Big(U_\pi(r) + \rho q_\pi(r) \Big) \mathrm{d}G(r) = \int_0^1 U_\pi(r) g(r) \mathrm{d}r - \int_0^1 \rho U'_\pi(r) g(r) \mathrm{d}r \\ &= -\rho U_\pi(r) g(r) \Big|_0^1 + \int_0^1 (g(r) + \rho g'(r)) U_\pi(r) \mathrm{d}r = \rho \mathbb{E}[\omega] g(0) + \int_0^1 I(r) U_\pi(r) \mathrm{d}r. \end{aligned}$$

□

Lemma 2. *An upper-censorship (lower-censorship) mechanism is optimal for all F if and only if I crosses the horizontal axis at most once and from above (from below) on Ω.*

Proof. The 'if' part follows from Lemma 1 above and Theorem 2 in Kolotilin et al. (2017). To prove the 'only if' part, suppose that it is *not* the case that I crosses the horizontal axis at most once and from above on Ω. Then there exist $0 \leq r_1 < r_2 < r_3 \leq 1$ such that I is negative on (r_1, r_2) and positive on (r_2, r_3) (since by assumption I is continuous and nonzero almost everywhere). Therefore, by the 'if' part of this lemma, for any F that has support only on $[r_1, r_3]$ a lower-censorship mechanism is optimal. Moreover, every upper-censorship mechanism is strictly suboptimal. The analogous argument applies for I that does not cross the horizontal axis at most once and from below on Ω. □

To complete the proof of Proposition 1, note that function $I(r) = g(r) + \rho g'(r)$ crosses the horizontal axis at most once and from above (from below) on Ω for all $\rho \in \mathbb{R}$ if and only if $g'(r)/g(r)$ is nonincreasing (nondecreasing) on Ω by Proposition 1 of Quah and Strulovici (2012). □

4. Optimal Censorship Policies

Assume that the density g of the readers' types is log-concave. In particular, it implies that g has a single peak or is monotone. This is a rather standard assumption, as many commonly-used density functions are log-concave (Bagnoli and Bergstrom 2005).[9] Under this assumption, by Proposition 1, an optimal persuasion mechanism

[9] The case of log-convex g is fully symmetric. We comment on it in Section 5.

must have an upper censorship structure. Notice, however, that a upper censorship mechanism with a threshold ω^* can be replicated by a government's censorship policy $S = [0, \omega^*]$. In words, an upper censorship policy with a threshold ω^* permit all media outlets equal to or below ω^* and prohibits all media outlets strictly above ω^*. In particular, $\omega^* = 0$ means that all media outlets are prohibited (no disclosure mechanism) and $\omega^* = 1$ means that all media outlets are permitted (full disclosure mechanism).

Corollary 1. *Let g be log-concave. Then, the government's optimal censorship policy is an upper censorship.*

Note that a media outlet with a higher editorial policy cutoff is more disloyal to the government, in the sense that it criticizes the government on a larger set of states. Corollary 1 says that, under the assumption of log-concave g, it is optimal for the government to prohibit all sufficiently disloyal media outlets from broadcasting.

Corollary 1 allows for a sharp comparative statics analysis on the amount of information that is optimally disclosed by the government. First, the government increases censorship if influencing society decisions becomes relatively more important than maximizing the welfare of individuals in the society. Second, the government increases censorship if the society experiences an ideology shock in favor of the government.

Suppose that the government has a bias towards the reader's action $a = 1$, $\rho > 0$. Also, suppose that, for a given small $\varepsilon > 0$ and for all $\beta \in (-\varepsilon, \varepsilon)$,

$$g(r) + \beta \text{ is log-concave on the domain } (-\varepsilon, 1 + \varepsilon). \tag{1}$$

We say that a family G_t of distributions of the reader's type is ordered w.r.t. *parallel shift* if

$$G_t(r) = G(r - t) \quad r \in [0, 1], \quad t \in (-\varepsilon, \varepsilon).$$

An increase of t represents an upward shift of the distribution function, so that the population of readers becomes more "opposing" to the government.

Let $\bar{r}$ be the mean type,

$$\bar{r} = \int_0^1 r \mathrm{d}G(r).$$

We say that a family G_β of distributions of the reader's type is ordered w.r.t. *linear rotation order on interval* $[a, b]$, where $a \le \bar{r} \le b$, if

$$G_\beta(r) = G(r) - \beta(r - \bar{r}), \quad r \in [a, b], \quad \beta \in (-\varepsilon, \varepsilon).$$

An increase in β results in a clockwise rotation of a segment of the distribution function around the mean, so the population of readers become more dispersed around the mean type.

We analyze how the optimal censorship threshold changes in response to a modification of three parameters (one at a time): the government's bias ρ, the distribution shift parameter t, and the distribution rotation parameter β. Note that, by our assumption (1), the density of the reader's type is log-concave for all parameter changes. Thus, an upper-censorship policy is optimal by Corollary 1.

Denote by $\omega^*(\rho, t, \beta)$ the optimal upper-censorship threshold for given parameters. Also denote by $\omega^{**}(\rho, t, \beta)$ the posterior mean state when $\omega > \omega^*(\rho, t, \beta)$,

$$\omega^{**}(\rho, t, \beta) = \mathbb{E}\big[\omega \big| \omega > \omega^*(\rho, t, \beta)\big].$$

We now show that the government optimally discloses more information (the optimal censorship threshold goes up) when the government is less biased relative to readers (ρ decreases), when the population is more opposing (t increases), and when the population is more dispersed (β increases).

Proposition 2. *For all $\rho > 0$, all $t \in (-\varepsilon, \varepsilon)$, and all $\beta \in (-\varepsilon, \varepsilon)$ such that $\omega^*(\rho, t, \beta) \in (0, 1)$ and G_β is ordered by the linear rotation order on interval $[a, b]$ with $a < \omega^*(\rho, t, \beta) < \omega^{**}(\rho, t, \beta) < b$,*

(a) *$\omega^*(\rho, t, \beta)$ is strictly decreasing in ρ,*
(b) *$\omega^*(\rho, t, \beta)$ is strictly increasing in t.*
(c) *$\omega^*(\rho, t, \beta)$ is strictly increasing in β.*

The proof is in the Appendix.

The intuition for part (a) is that for a smaller ρ, the government puts more weight on the readers' utility, so it optimally endows the population with a higher utility by shutting down fewer media outlets, thus disclosing more information.

The intuition for part (b) is that for a higher t, each type of the reader has a greater opportunity cost of action $a = 1$, so to persuade the same type of the reader, the government needs to increase the posterior $\mathbb{E}[\omega|\omega > \omega^*]$ by shrinking the pooling interval of states $[\omega^*, 1]$.

5. Discussion

If the set of media outlets is finite, we can redefine the state to be the posterior mean of ω given the messages of all media outlets. To characterize the optimal censorship policy, we will need to adjust the analysis in Section 3 and in the relevant proofs in in Kolotilin et al. (2017) to allow for discrete distributions of the state.

This result relies on the linearity of $\bar{a}\xi(r)$ and $\bar{a}\gamma$ in $\bar{a}$. Suppose instead that the externality term is $\xi(\bar{a}, r)$ and the government's intrinsic benefit is $\gamma(\bar{a})$, where $\xi(\bar{a}, r)$ and $\gamma(\bar{a})$ need not be linear in $\bar{a}$. Then, for any censorship policy S, we can still express the government's expected utility as $\int_R \tilde{I}(r) U_S(r) \mathrm{d}r$, where U_S is the reader's interim utility net of the externality term, and $\tilde{I}$ is a function independent of S. In particular, if the government's intrinsic benefit $\gamma(\bar{a})$ is reverse S-shaped, as under a majoritarian voting system, then the government's optimal censorship policy still corresponds to an upper-censorship mechanism.

This government's censorship policy is optimal among all persuasion mechanisms. In particular, the government would not be better off if it could restrict each reader to follow a single media outlet of his choice and ban readers from communicating with one another, as in Chan and Suen (2008). Nor would the government be better off if it could create more complex mechanisms that aggregate information from multiple media outlets and add noise.

A log-convex g captures the situation where the society is polarized, with large masses of readers' types at the extreme ends ("pro-government" and "opposition") and a smaller mass in the middle. It is curious that in this case, the optimal censorship shuts down loyal media outlets and allows disloyal ones to broadcast. This is because the large mass of pro-government readers would act the way the governments wants anyway, and the only chance to convince the large mass of opposition readers is to give them access to media outlets that are informative and can make difference for them.

Enikolopov et al. (2011) study the effect of voters' access to NTV, the only independent national TV channel, on the regional results of the 1999 Russian parliamentary elections. They show that local access to NTV substantially decreased the regional aggregate vote for the government party. Entertaining the possibility that access to NTV is controlled by the government, rather than exogenous as argued by Enikolopov et al. (2011), our paper suggests a different interpretation of their findings. In our model, the government optimally permits access to NTV only in the regions with low initial support of the government. Thus, access to NTV in these regions may be a consequence, not a cause, of low electoral support of the government.

Appendix

Proof of Proposition 2. Consider an upper censorship mechanism with threshold $\omega^* \in [0,1]$, denoted by π_{ω^*}. Denote by ω^{**} the posterior mean state conditional on being above the threshold,

$$\omega^{**} = \mathbb{E}[\omega|\omega > \omega^*].$$

Let H_{ω^*} be the distribution of the posterior mean state,

$$H_{\omega^*}(\omega) = \begin{cases} F(\omega), & \text{if } \omega \le \omega^*, \\ F(\omega^*), & \text{if } \omega^* < \omega \le \omega^{**}, \\ 1, & \text{if } \omega > \omega^{**}. \end{cases}$$

Since a reader of type r will choose $a = 1$ if and only if the posterior mean state is above r, the government's expected payoff is equal to

$$\begin{aligned} V_{\pi_{\omega^*}} &= \int_0^1 \left(\int_{-T}^{\omega} (\omega - r + \rho) g_t(r) \mathrm{d}r \right) \mathrm{d}H_{\omega^*}(\omega) \\ &= \int_0^{\omega^*} J_t(\omega)\mathrm{d}F(\omega) + (1 - F(\omega^*)) J_t(\omega^{**}) \end{aligned}$$

where, using integration by parts and $G_t(-T) = 0$,

$$J_t(\omega) = \int_{-T}^{\omega} (\omega - r + \rho) g_t(r) \mathrm{d}r = \int_{-T}^{\omega} \left(G_t(r) + \rho g_t(r) \right) \mathrm{d}r.$$

Let us take the derivative of $V_{\pi_{\omega^*}}$ w.r.t. ω^*. We have

$$\frac{\mathrm{d}\omega^{**}}{\mathrm{d}\omega^*} = \frac{f(\omega^*) \left(\int_{\omega^*}^1 \omega \mathrm{d}F(\omega) - \omega^*(1 - F(\omega^*)) \right)}{(1 - F(\omega^*))^2} = \frac{f(\omega^*)}{1 - F(\omega^*)} (\omega^{**} - \omega^*).$$

Thus,

$$\begin{aligned}\frac{\partial V_{\pi_{\omega^*}}}{\partial \omega^*} &= f(\omega^*)(J_t(\omega^*) - J_t(\omega^{**})) + (1 - F(\omega^*))J_t'(\omega^{**})\frac{\mathrm{d}\omega^{**}}{\mathrm{d}\omega^*} \\ &= f(\omega^*)\left(J_t(\omega^*) - J_t(\omega^{**}) + (\omega^{**} - \omega^*)J_t'(\omega^{**})\right) \\ &= f(\omega^*)\left(-\int_{\omega^*}^{\omega^{**}}(G_t(r) + \rho g_t(r))\mathrm{d}r + \int_{\omega^*}^{\omega^{**}} J_t'(\omega^{**})\mathrm{d}r\right) \\ &= f(\omega^*)\int_{\omega^*}^{\omega^{**}}\big(G_t(\omega^{**}) - G_t(r) + \rho(g_t(\omega^{**}) - g_t(r))\big)\mathrm{d}r \qquad (2)\end{aligned}$$

Consider ρ and t such that the optimal censorship threshold $\omega^* = \omega^*(\rho, t) \in (0,1)$. Then, the first-order condition must hold, $\frac{\partial}{\partial \omega^*}V_{\pi_{\omega^*}} = 0$, so

$$\int_{\omega^*}^{\omega^{**}}\big(G_t(\omega^{**}) - G_t(r)\big)\mathrm{d}r = -\rho\int_{\omega^*}^{\omega^{**}}\big(g_t(\omega^{**}) - g_t(r)\big)\mathrm{d}r, \qquad (3)$$

or equivalently,

$$\int_{\omega^*}^{\omega^{**}}(J_t'(\omega^{**}) - J_t'(r))\mathrm{d}r = 0. \qquad (4)$$

Part (a). By (2) and (3) and our assumption that $\rho > 0$, we have

$$\frac{\mathrm{d}^2 V_{\pi_{\omega^*}}}{\mathrm{d}\omega^*\mathrm{d}\rho} = f(\omega^*)\int_{\omega^*}^{\omega^{**}}(g_t(\omega^{**}) - g_t(r))\mathrm{d}r = -\frac{f(\omega^*)}{\rho}\int_{\omega^*}^{\omega^{**}}\big(G_t(\omega^{**}) - G_t(r)\big)\mathrm{d}r < 0.$$

So, ω^* is strictly decreasing in ρ by Theorem 1 of Edlin and Shannon (1998).
Part (b). Notice that

$$\frac{\mathrm{d}G_t(r)}{\mathrm{d}t} = -g_t(r) \quad \text{and} \quad \frac{\mathrm{d}g_t(r)}{\mathrm{d}t} = -g_t'(r).$$

Thus,

$$\begin{aligned}\frac{\mathrm{d}^2 V_{\pi_{\omega^*}}}{\mathrm{d}\omega^*\mathrm{d}t} &= -f(\omega^*)\int_{\omega^*}^{\omega^{**}}\big(g_t(\omega^{**}) - g_t(r) + \rho(g_t'(\omega^{**}) - g_t'(r))\big)\mathrm{d}r \\ &= -f(\omega^*)\int_{\omega^*}^{\omega^{**}}\big(J_t''(\omega^{**}) - J_t''(r)\big)\mathrm{d}r \\ &= f(\omega^*)\left(J_t'(\omega^{**}) - J_t'(\omega^*)\right) - f(\omega^*)J_t''(\omega^{**})(\omega^{**} - \omega^*).\end{aligned}$$

Since $J_t''(r)$ is nonzero almost everywhere, J_t' is not constant on (ω^*, ω^{**}). Moreover, because g_t is log-concave, by Proposition 1 of Quah and Strulovici (2012), $J_t''(r) = g_t(r) + \rho g_t'(r)$ crosses the horizontal axis at most once and from above, so $J_t'(r)$ is quasiconcave. Therefore, (4) implies that $J_t''(\omega^{**}) < 0$ and $J_t'(\omega^{**}) > J_t'(\omega^*)$; so $\mathrm{d}^2 V/\mathrm{d}\omega^*\mathrm{d}t > 0$, and ω^* is strictly increasing in t by Theorem 1 of Edlin and Shannon (1998).
Part (c). By the definition of the linear rotation on interval $[a, b]$ that contains the interval $[\omega^*, \omega^{**}]$, we have

$$\frac{\partial}{\partial\beta}G_\beta(r) = \bar{r} - r \quad \text{and} \quad \frac{\partial}{\partial\beta}g_\beta(r) = -1, \quad r \in [\omega^*, \omega^{**}].$$

By (2), we have

$$\frac{\mathrm{d}^2 V_{\pi_{\omega^*}}}{\mathrm{d}\omega^*\mathrm{d}\beta} = f(\omega^*)\int_{\omega^*}^{\omega^{**}} \big((\bar{r}-\omega^{**})-(\bar{r}-r)\big)\mathrm{d}r = -f(\omega^*)\int_{\omega^*}^{\omega^{**}} \big(\omega^{**}-r\big)\mathrm{d}r < 0.$$

So, ω^* is strictly decreasing in β by Theorem 1 of Edlin and Shannon (1998).

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