Errors in Project Approval and Mandatory Review*

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Abstract

We compare two processes for society to review projects: one that is entirely based upon the initiative of interested parties, and one that first submits projects to a nonpartisan and mandatory review. In the first case, the default outcome is approval and projects are carried out without prior authorization. In the second case, the mandatory review results in either approval or rejection of submitted projects. In both cases, private parties can contest the outcome and initiate a definitive review. Since the second review overrules the first one, the mandatory review may seem redundant. However, the mandatory review can improve the decision of private parties to initiate a definitive review. Thanks to private parties’ improved decision making, mandatory review can lead to a reduction of both type I and type II errors.

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1 Introduction

Suppose society needs to decide whether to approve a project brought forward by an applicant. If approved, good projects yield a net social benefit and bad projects yield a net social loss. All projects benefit the applicant, but harm another party (e.g., a competitor). To separate the wheat from the chaff, society needs to review projects. We study the performance of a project reviewing system that is entirely based upon the initiative of interested parties and ask whether the system can be improved on by imposing a mandatory prior review carried out by a non-partisan body, resulting in approval or rejection. Interested parties can contest the outcome of the mandatory review and initiate a second review whose outcome overrules the previous one. Can mandatory review efficiently complement the decision of private parties to contest or defend a project?

We show that the combined system that includes a mandatory review and the possibility to appeal is the most efficient for the society. We assess the efficiency of the system by the number of type I (rejecting welfare-enhancing projects) and type II errors (approving welfare-decreasing projects) it generates. The combined system often produces fewer of both types of errors than any of the two other systems. The superior efficiency of a combined reviewing system stems from the possible improvement of private parties’ decision making: mandatory prior review leads them to revise their beliefs about the type of the project under consideration and thereby increases the amount of information on which they base their decisions to initiate review.

To see how a mandatory prior review can improve project selection, suppose first that projects can be launched without prior authorization, and can be stopped only if a review is initiated by a private party (the liberal system). If the project is bad, the mandatory prior review provides an additional opportunity to keep the project from going through, which quite naturally reduces erroneous approvals. For the same reason, however, we might expect that mandatory review also makes it more difficult for a good project to be approved. As we will show in the paper, this is not necessarily the case. In the absence of mandatory review, competitors who are harmed by a proposed project will often have incentives to request a review regardless of their private information about whether the project is good or bad. A
mandatory review provides additional information that can induce them to initiate a review only in those cases in which they have strong reasons to believe the project is bad. Moreover, applicants who are confident that their project is good can appeal an initial rejection. It follows that when private parties’ information is sufficiently accurate, mandatory prior review not only decreases erroneous approvals but also erroneous rejections.

We assess the performance of the reviewing system by the number of type I (rejecting welfare-enhancing projects) and type II errors (approving welfare-decreasing projects) it generates. We show that a combined reviewing system, involving first a mandatory review and second a review that can be initiated by interested parties, often produces fewer of both types of error than any of the two procedures on a stand-alone basis. The superior performance of a combined reviewing system stems from the possible improvement of private parties’ decision making: mandatory prior review leads them to revise their beliefs about the type of the project under consideration and thereby increases the amount of information on which they base their decisions to initiate review.

To see how a mandatory prior review can improve project selection, suppose first that projects can be launched without prior authorization, and can be stopped only if a review is initiated by a private party. If the project is bad, the mandatory prior review provides an additional opportunity to keep the project from going through, which quite naturally reduces erroneous approvals. For the same reason, however, we might expect that mandatory review also makes it more difficult for a good project to be approved. As we show below, this is not necessarily the case. In the absence of mandatory review, competitors who are harmed by a proposed project will often have incentives to request a review regardless of their private information about whether the project is good or bad. A mandatory review provides additional information that can induce them to initiate a review only in those cases in which they have strong reasons to believe the project is bad. Moreover, applicants who are confident that their project is good can appeal an initial rejection. It follows that when private parties’ information is sufficiently accurate, mandatory prior review not only decreases erroneous approvals but also erroneous rejections.

In practice, many systems of project approval involve a mandatory review performed by a
non-partisan body. Consider the marketing of a new drug in the United States. First, the drug developer must go through the review of his product by the Food and Drug Administration (FDA). Based on its assessment, the FDA allows or refuses the marketing. When approved, the developer still faces a risk of litigation by claimed injured users. The patenting process is another example. The US Patent and Trademark Office (USPTO) must examine all demands for patents before granting or rejecting them. After a patent is granted, patentees asserting their patents against alleged infringers can still have their patents invalidated by the courts. A third and final example is the merger control process. Proposed mergers must be reported to the Premerger Notification Office (PNO) and will then be reviewed by either the Federal Trade Commission (FTC) or the Department of Justice (DoJ). The decisions handed down by these agencies can subsequently be appealed and overturned by a court of justice.

What are the rationales traditionally advanced for the implementation of a mandatory review conducted by an independent agency? Such a procedure may have several advantages. First, it can play a preventive role by keeping bad projects from coming to market. Even though a sufficiently large fine for wrongdoing at the litigation stage should give agents the right incentives for choosing good projects even without the ex ante review, this argument does not apply if the penalties that the court can order on wrongdoers are bounded by limited liability. This justifies the joint use of ex ante regulation and ex post liability, as pointed out by Shavell (1984). A similar point is made by Kolstad et al. (1990), who show that when liability is determined according to a negligence rule and there is a large amount of uncertainty about the legal standard, liability alone will lead to insufficient care.1

Second, ex ante review can lower the number of projects that will be tried in court. It is reasonable to assume that running the nonpartisan review involves only a fixed cost per project. The cost of the court system is related to the number of people that are harmed: in the absence of class-action lawsuits, the number of trials should be proportional to the total population affected by the project. Thus, having an ex ante review is beneficial for societies

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1Key to their result is that they define uncertainty about the legal standard as a mean-preserving spread of the probability distribution. If the distribution is sufficiently spread out, decreasing the level of care below the optimal level increases the probability of being found liable only slightly while yielding substantial cost savings.
with sufficiently large populations (Mulligan and Shleifer, 2005).

Glaeser and Shleifer (2003) point out a third possible reason for ex ante regulation, which is related to corruption. Since companies only face litigation in the event of an accident, the probability of going to court is relatively small. A large fine is thus needed to induce optimal care ex ante. Of course, the larger the fine, the greater the incentives to subvert the judge. By contrast, regulatory authorities may intervene more frequently, reducing the fine that is needed to ensure compliance. Such a smaller fine is less likely to be the subject of subversion.

For the three examples of combined reviewing systems mentioned above – approval of new drugs, patent examination, and merger control – none of these rationales seems to be entirely convincing. If we take the case of the patenting process, for example, it is difficult to argue that limited liability on the part of patent holders or the risk of subversion of judges justify patent examination, at least for the U.S. Moreover, thanks to a decision by the US Supreme Court, the number of trials is independent of the number of technology users. This takes away the basis of the argument according to which mandatory review benefits large populations, which relies on the number of court trials being proportional to population size.

We propose an alternative rationale for the prevalence of mandatory prior review that is based on the superior performance of such a system in correctly identifying good and bad projects. To show this, we develop a model that generalizes the setup of Sah and Stiglitz (1986). Sah and Stiglitz (1986) compare two different organizations of decision making. In a hierarchy, a project is implemented if it is approved by all the hierarchical levels. In a polyarchy, each individual has the right to accept a project, and projects rejected by one are evaluated by the other. Compared to a system with a single review, a polyarchy reduces the number of erroneous rejections but increases the number of erroneous approvals. In contrast, a hierarchy increases the number of erroneous rejections but reduces the number of erroneous approvals. Thus, neither of them clearly dominates a single review. By contrast, we show that a system in which the first review is mandatory, while the second review only takes place

\footnote{The court ruled that if one technology user successfully challenges the validity of a patent in court, other users can rely on this decision and do not have to pay royalties, even if they previously signed a license contract with the patent holder. See Blonder-Tongue Labs, Inc. v. University of Illinois Foundation, 402 US 313, 350 (1971).}
when initiated by interested parties, can generate fewer of both types of error.

The paper most closely related to ours is Shavell (1995) who studies the desirability of the appeals process. In our terminology, Shavell compares the performance of a system with mandatory review only to a system combining mandatory review (trial court) and private initiative (appeals court). In contrast to us, Shavell assumes that the state can expend resources to reduce the probability of judicial error. He shows that, if litigants obtain an informative signal about whether or not error occurred at trial, the appeals process is a cost-effective way of reducing error. This is because the state can set the fee or subsidy for appeals at such a level that only litigants who believe that an error was made will appeal. A major difference with our model is that Shavell assumes that the probabilities of type I and type II error by the trial court are equal, and that the probability that the appeals court overturns a trial court decision is greater for erroneous decisions than for correct ones, again independently of the type of error. Thus, the result that appeals courts reduce error is, to some extent, an assumption rather than a result. By contrast, we assume that decisions by reviewing bodies depend on the type of project (good or bad) under consideration. Erroneous rejections at the mandatory review do not have the same probability of being overturned as erroneous approvals; it may even be the case that a correct decision to approve a project has a greater probability of being overturned than of being upheld at the second review. Nevertheless, we show that a combined system can be superior to either a system with mandatory review only or a system relying solely on private initiative.

The remainder of the paper is organized as follows. In Section 2, we generalize Sah and Stiglitz’s (1986) model while keeping the probabilities of review exogenous. In Section 3, we endogenize these probabilities. In Section 4, we consider the cost of initiating review as a policy variable. Section 5 concludes.

2 A simple model of project review

There are two types $\theta$ of projects: good projects ($\theta = G$), yielding a net social benefit, and bad projects ($\theta = B$), causing a net loss. The type of a project is initially unobservable. When reviewed by an independent evaluator, a good project is approved with probability
A bad project is approved with some probability \( p^B > 0 \). We set \( p^G > p^B \), in line with our assumption that review is useful to differentiate projects. Errors of two different types can occur in this model: good projects being rejected (type I error), and bad projects being approved (type II error). Were projects simply selected through this review without the opportunity for private parties to contest rulings, the type I error would be \( 1 - p^G \), while the type II error would be \( p^B \).

In this context, we compare the performance of two systems of project review with respect to the errors they generate. First, we look at a reviewing system relying on the initiative of interested parties. We assume that all projects are carried out unless someone opposes the project and initiates a review. Good projects are opposed with probability \( y_G \), and bad projects with probability \( y_B \). The \( y \) probabilities reflect the moves of private parties. For the moment, we treat these moves as exogenous. Moreover, throughout the paper we assume that the evaluator is non Bayesian: whatever the stage at which review is initiated and whatever the identity of the initiator, the evaluator always has the same probabilities of approving good and bad projects (\( p^G \) and \( p^B \)). The evaluator does not take into account the statistical characteristics of the case, which determine the conditional probability that a project is good given that a review has been initiated. A justification for this approach is Bourjade et al. (2009) who show that the possibility of pre-trial settlement bargaining implies that Bayesian decision-making by the courts will lead to complete pooling of good and bad defendants. To favor screening, courts should not rely on background information when weighing the evidence.\(^3\)

We denote \( \alpha_{1r} \) the type I and \( \beta_{1r} \) the type II errors generated by a reviewing system relying solely on the initiative of interested parties. We have

\[
\alpha_{1r} = y_G (1 - p^G) \\
\beta_{1r} = 1 - y_B (1 - p^B).
\]

Compared to a situation where an independent agency reviews all projects and private parties cannot contest the agency’s decisions, a reviewing system relying on the initiative of private

\(^3\)Similar points have been made by Shavell (1995) and Daughety and Reinganum (2000).
parties always produces more type II errors: \( \beta_{1r} > p^B \) (since \( \beta_{1r} \) is a convex combination of \( p^B \) and 1). However, it always produces fewer type I errors since \( \alpha_{1r} \leq 1 - p^G \).

Second, we consider a system that involves all projects going through a mandatory review implemented by an independent agency. The latter either approves (decision \( d = A \)) or rejects the projects (decision \( d = R \)). Private parties can then demand a second review whose outcome overrules the decision of the independent agency. Private parties initiate the second review with probability \( x_{\theta d} \). For instance, \( x_{GA} \) is the probability that there is a competitive review for a good project that was approved by the agency. Probabilities of approval at any stage of review are as before \( p^G \) and \( p^B \). Note that the two basic organizational forms considered by Sah and Stiglitz (1986) are extreme cases of this setup. In a polyarchy, a project undergoes a second review if and only if it is first rejected (\( x_{GA} = x_{BA} = 0 \) and \( x_{GR} = x_{BR} = 1 \)). In a hierarchy, a project undergoes a second review if and only if it is first approved (\( x_{GA} = x_{BA} = 1 \) and \( x_{GR} = x_{BR} = 0 \)).

Denote \( \alpha_{2r} \) the type I and \( \beta_{2r} \) the type II errors of the combined reviewing system. For general \( x_{\theta d} \), we have

\[
\alpha_{2r} = p^G x_{GA}(1 - p^G) + (1 - p^G)[1 - x_{GR}p^G]
= (1 - p^G)[1 - p^G(x_{GR} - x_{GA})]
\tag{1}
\]

and

\[
\beta_{2r} = p^B(1 - x_{BA}(1 - p^B)) + (1 - p^B)x_{BR}p^B
= p^B[1 - (1 - p^B)(x_{BA} - x_{BR})].
\tag{2}
\]

The combination of a mandatory review and an optional review relying on private initiative reduces both type I and type II errors compared to the performance of a single mandatory review if and only if \( x_{GA} < x_{GR} \) and \( x_{BA} > x_{BR} \): in that case, \( \alpha_{2r} < 1 - p^G \) and \( \beta_{2r} < p^B \).\(^4\)

These conditions mean that the probabilities \( x_{\theta d} \) need to depend on whether the first stage decision was correct, so that the decision to initiate a second review provides information about the type of the project. Specifically, a review must be more likely to be initiated when

\(^4\)Note that these conditions remain sufficient if the second stage of review is more accurate than the first stage.
a good project is rejected than when it is approved, and more likely to be initiated when a bad project is approved than when it is rejected.\textsuperscript{5}

Compared to the system without mandatory review, relying solely on private initiative, the combined reviewing system produces fewer type II errors if \( x_{BA} > x_{BR} \), i.e., \( \beta_{1r} > p^B > \beta_{2r} \). It also produces more type I errors if the following condition holds:

\[
\alpha_{2r} \leq \alpha_{1r} \iff 1 - p^G(x_{GR} - x_{GA}) \leq y_G. \tag{3}
\]

In words, adding a mandatory review decreases type I error only if \( y_G \), the probability that a good project is contested in the absence of mandatory review, is sufficiently large. The results are summarized in the following proposition.

**Proposition 1.** The combination of a mandatory review and an optional review relying on private initiative generates fewer type II errors than a reviewing system without mandatory review for any \( y_B \in [0,1] \) if \( x_{BA} > x_{BR} \). It produces fewer type I errors if and only if \( x_{GR} > x_{GA} \) and \( y_G > \hat{y} \). The threshold is defined by \( \hat{y} \equiv 1 - p^G(x_{GR} - x_{GA}) \) and is always strictly lower than 1.

Two preliminary conclusions emerge from this analysis. First, the informativeness of private initiative is crucial to the superiority of a combined reviewing system. If the \( x_{th} \)’s do not satisfy the stated inequalities, the mandatory review is useless at best and counterproductive at worst. It is thus important to study under what conditions these inequalities are likely to hold. Second, it is important to know how \( y_G \) is related to \( p^G \), \( x_{GR} \) and \( x_{GA} \). Answering these questions requires an endogenization of private parties’ decision to initiate review. This is the subject of the next section.

### 3 Initiating a review

This section takes a simple approach to modeling the probabilities of initiating a review described in the previous section. Assume that a private party (hereafter the “applicant”)\textsuperscript{6}

\textsuperscript{6}In a polyarchy, \( x_{GA} < x_{GR} \) and \( x_{BA} < x_{BR} \). A polyarchy decreases type I error but at the same time increases type II error. In a hierarchy, \( x_{GA} > x_{GR} \) and \( x_{BA} > x_{BR} \). A hierarchy decreases type II error but at the same time increases type I error.
has a vested interest in the approval of the project, and that another private party (hereafter the “challenger”) would benefit from the rejection of the project. These interested parties have private information about the type of the project. Specifically, each private party receives a signal $\sigma \in \{G, B\}$ which is correct with probability $\nu > 1/2$ (that is, $\nu \equiv Pr[\theta = \sigma | \sigma]$).

For simplicity, assume that ex ante a project is equally likely to be good or bad, so that $Pr[\sigma = \theta | \theta] = \nu$ as well. A favorable decision yields a payoff of 1 to the winning party and a payoff of 0 to the loser. A party incurs an initiating cost $c$ when it asks for a review. Let us examine how the probabilities to initiate a review (the $y_\theta$’s and $x_\theta d$’s) depend on $c$.

In a system without mandatory prior review, only the challenger has an incentive to initiate a review since the default outcome is approval. When he receives a bad signal $\sigma = B$, the challenger initiates a review if and only if

$$c \leq (1 - \nu)(1 - p^G) + \nu(1 - p^B).$$

When he receives a good signal $\sigma = G$, the challenger nonetheless initiates a review if and only if

$$c \leq \nu(1 - p^G) + (1 - \nu)(1 - p^B).$$

Indeed, even after a good signal, there is a chance that the evaluator rejects the project. If the cost $c$ is not too large, the challenger thus gambles on an error by the evaluator.

In the case of a combined reviewing system, private parties condition their decision to appeal on both their signal and the nonpartisan agency’s decision. Denote $\rho_{\sigma d}$ their posterior belief (derived from Bayes’ rule) that the project is valid after signal $\sigma$ and decision $d$. For example, a challenger who receives a bad signal and observes that the applicant’s project passes the mandatory review believes that the applicant’s project is good with probability $\rho_{BA} \equiv Pr[\theta = G | \sigma = B, d = A] = \frac{(1 - \nu)p^G}{\nu p^G + (1 - \nu)p^B}$. Table 1 provides an overview of posterior beliefs.

Table 1 provides an overview of posterior beliefs.

If the project passes the mandatory review, only the challenger has an incentive to appeal. The challenger initiates a second review after $d = A$ and $\sigma = B$ if

$$c \leq \rho_{BA} (1 - p^G) + (1 - \rho_{BA})(1 - p^B),$$

We assume that they cannot communicate their information to the evaluator, or that the rules of evidence preclude the evaluator from taking their information into account.
Table 1: Private parties’ posterior beliefs

<table>
<thead>
<tr>
<th>Signal</th>
<th>Approval</th>
<th>Rejection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>$\rho_{GA} = \frac{\nu p^G}{\nu p^G + (1-\nu)p^B}$</td>
<td>$\rho_{GR} = \frac{\nu(1-p^G)}{\nu(1-p^G) + (1-\nu)(1-p^B)}$</td>
</tr>
<tr>
<td>Bad</td>
<td>$\rho_{BA} = \frac{(1-\nu)p^G}{\nu p^B + (1-\nu)p^B}$</td>
<td>$\rho_{BR} = \frac{(1-\nu)(1-p^G)}{(1-\nu)(1-p^B) + \nu(1-p^B)}$</td>
</tr>
</tbody>
</table>

Table 2: Cost thresholds depending on the nonpartisan agency’s decision $d$

<table>
<thead>
<tr>
<th>$d$</th>
<th>$c^1_d$</th>
<th>$c^0_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>$c^1_N = \nu(1-p^G) + (1-\nu)(1-p^B)$</td>
<td>$c^0_N = (1-\nu)(1-p^G) + \nu(1-p^B)$</td>
</tr>
<tr>
<td>A</td>
<td>$c^1_A = \rho_{GA} (1-p^G) + (1-\rho_{GA})(1-p^B)$</td>
<td>$c^0_A = \rho_{BA} (1-p^G) + (1-\rho_{BA})(1-p^B)$</td>
</tr>
<tr>
<td>R</td>
<td>$c^1_R = \rho_{BR} p^G + (1-\rho_{BR})p^B$</td>
<td>$c^0_R = \rho_{GR} p^G + (1-\rho_{GR})p^B$</td>
</tr>
</tbody>
</table>

and does so after $\sigma = G$ if

$$c \leq \rho_{GA} (1-p^G) + (1-\rho_{GA})(1-p^B).$$  \hspace{1cm} (7)$$

If the project fails the mandatory review, only the applicant has an incentive to appeal. The applicant initiates a second review after $d = R$ and $\sigma = G$ if

$$c \leq \rho_{GR} p^G + (1-\rho_{GR})p^B,$$  \hspace{1cm} (8)$$

and does so after $\sigma = B$ if

$$c \leq \rho_{BR} p^G + (1-\rho_{BR})p^B.$$  \hspace{1cm} (9)$$

To summarize the previous results and perform the analysis that follows, it is convenient to introduce some additional notation for the threshold values of $c$. Let $c^1_d$ denote the threshold value of $c$ below which the probability of initiating a review is 1, conditional on the outcome of the mandatory review $d \in \{A, R, N\}$ (where $N$ denotes no decision, which applies to the system without mandatory review). Similarly, let $c^0_d$ denote the threshold value of $c$ above which the conditional probability of initiating a review is 0.

If $c$ is below $c^1_d$, the interested private party always initiates a review after decision $d$, regardless of its signal. If $c$ is above $c^0_d$, the concerned party never initiates a review after decision $d$. And if $c$ is in between the two, the party bases its decision on its signal $\sigma$, i.e.,
it only initiates a screen if it receives a signal that is favorable to its cause. For example, if
\( c \leq c_A^1 \), the challenger always appeals the agency’s decision, if \( c > c_A^0 \), he never appeals, and
if \( c_A^1 < c \leq c_A^0 \), he appeals if and only if he receives a signal indicating the project is bad,
\( \sigma = B \). The cost thresholds are easily deduced from inequalities (4) through (9). For easy
reference they are reproduced in table 2.

Having defined these thresholds, we can characterize the probabilities \( y_\theta \) and \( x_{bd} \) of initi-
ating a definitive review. Figure 1 provides an overview.

Recall from Proposition 1 that the combined reviewing system dominates the one without
mandatory review in terms of both types of error, if three conditions are satisfied:

(i) \( x_{BA} > x_{BR} \),

(ii) \( x_{GR} > x_{GA} \), and

(iii) \( y_G > 1 - p^G(x_{GR} - x_{GA}) \).
Figure 2: Set of parameters for which a combined system dominates a system without mandatory review when $p^G + p^B < 1$ and $p^G > 1/2$

The following lemma characterizes the range of cost $c$ for which all of these three conditions hold.

Lemma 1. Private parties’ decisions to initiate a review satisfy conditions (i), (ii), and (iii) if and only if

$$c \in [\max\{c_1^A, c_1^R\}, \min\{c_1^N, c_0^A, c_0^R\}]$$

Proof: See the Appendix.

We are now ready to state the main result of this section.

Proposition 2. There exists a nonempty set of parameters in the $(\nu, c)$ space for which a combined reviewing system dominates a system without mandatory review, in the sense of reducing both type I and type II errors, if and only if one of the following holds: either $p^G + p^B < 1$ and $p^G > 1/2$, or $p^G + p^B \geq 1$ and $p_B < 1/(4p^G)$.
Proof: See the Appendix.

Proposition 2 establishes the conditions under which there exists a range of the cost and signal-quality parameters for which the combined reviewing system dominates the strictly competitive one. There are two cases to be considered. The first is when the nonpartisan agency makes more type I than type II errors, i.e. \( p^B < 1 - p^G \). For the set of parameters to be nonempty, \( p^G \) must be greater than \( 1/2 \). Since the proportion of good projects in the population is \( 1/2 \), random approval would lead to \( p^G = 1/2 \), so this seems like a rather mild condition. The case where \( p^G + p^B < 1 \) and \( p^G > 1/2 \) is illustrated in figure 2. The shaded area represents the set of parameters satisfying conditions (i) through (iii). The set is characterized by a cutoff value \( \hat{\nu} \) (defined in the proof of Proposition 2) above which there exists a range of \( c \) such that a combined reviewing system dominates. If private parties receive a sufficiently precise signal, there is a range of the cost parameter such that their decisions to initiate a definitive review are informative in a combined reviewing system but not in a system without mandatory review. For this range, the additional information provided by a mandatory prior review is crucial for a private party to reveal its signal through its decision to initiate review. Without mandatory review, a private party initiates review regardless of its signal.

The second case is when the nonpartisan agency makes more type II than type I errors, i.e., \( p^B > 1 - p^G \). Having a nonempty set then requires \( p^B \) not to be too large relative to \( p^G \). For example, if \( p^G = 3/4 \), \( p^B \) cannot be larger than \( 1/3 \). This condition is more restrictive than in the previous case. The intuition is that if \( p^B \) is large, too many bad projects pass the mandatory review. As a result, the mandatory review does not generate enough information to deter challengers with a signal that the project is good from initiating another review. It follows that a combined review can never reduce type I error compared to one without mandatory review. The case where \( p^G + p^B > 1 \) and \( p^B < 1/(4p^G) \) is illustrated in figure 3. The shaded area again represents the set of parameters satisfying conditions (i) through (iii). The set is characterized by cutoff values \( \tilde{\nu} \) and \( \hat{\nu} \) (defined in the proof of Proposition 2) between which there exists a range of \( c \) such that a combined reviewing system dominates. The reason why there is now also an upper bound on the quality of the signal is the following.
Figure 3: Set of parameters for which a combined system dominates a system without mandatory review when $p^G + p^B < 1$ and $p^B < 1/(4p^G)$

When the signal is very precise, challengers decisions are informative even in the absence of mandatory review. This means that mandatory review cannot improve on the information to be garnered from private parties’ decisions, and therefore cannot reduce type I error.

4 Cost as a policy variable

So far we have implicitly assumed that the cost of initiating a review is exogenously given. This makes sense in many situations. But sometimes the government may be able to control the cost by charging a fee or giving a subsidy to private parties initiating review. If the cost is optimally chosen by the government, which system performs better?

Answering this question requires putting more structure on the problem than answering the previous one because when the cost is optimally chosen (conditional on the reviewing system in place), no single system dominates the others according to our previous criterion (i.e., fewer type I and type II errors). Some systems produce more type I and fewer type
II errors, and some produce more type II and fewer type I errors. To see this, note that conditional on having a system relying on private initiative in place, and for a given $\nu$, it is not optimal to choose $c$ such that it falls within the shaded region in Figures 2 and 3. Such a $c$ does not use the information contained in the signal received by private parties. But this is the only region of the parameter space for which the combined reviewing system would improve both types of error.

If instead we want to use social welfare as a criterion, we need to define the social harm of each type of error. In fact, without making assumptions on the relative social harm of type I and type II error, any system can be optimal. If type I error is extremely harmful relative to type II error, for example, a system without any review performs best: it avoids type I error entirely. In what follows, we use the total error, i.e., the sum of type I and type II errors, denoted by $\varepsilon = \alpha + \beta$, as our criterion. Thus, we implicitly assume that both types of error produce equal social harm.\(^7\)

The cost $c$ determines firms’ decisions to initiate review, and thus the total error produced by a given reviewing system. In a system relying on private initiative, there are three possible regimes (depending on how a social planner chooses $c$):

(P1) if $c < c_N^1$, there is always a review, so total error is $\varepsilon^{(P1)} = 1 - p^G + p^B$;

(P2) if $c_N^1 < c < c_N^0$, review is initiated whenever the signal is $B$. Total error is $\varepsilon^{(P2)} = (1 - \nu)(1 - p^G) + 1 - \nu(1 - p^B)$;

(P3) if $c > c_N^0$, there is never any review. There is no type I error but type II error is 1, so total error is $\varepsilon^{(P3)} = 1$.

In a combined reviewing system, we have to distinguish two cases. Consider first the case where $p^G + p^B < 1$. There are several different regimes, depending on $\nu$. If $\nu < \hat{\nu}$, we have $c_R^1 < c_R^0 < c_A^1 < c_A^0$ (see Figure 2). Therefore,

(C1) if $c < c_R^1$, there is always a second review. The mandatory prior review is redundant, so this cannot be optimal. Formally, it is equivalent to (P1);\(^7\) Recall that projects are equally likely to be good or bad.
(C2) if \( c_R^1 < c < c_R^0 \), a review is always initiated after approval, and is initiated after rejection if and only if \( \sigma = G \). That is, \( x_{GA} = x_{BA} = 1 \), \( x_{GR} = \nu \), and \( x_{BR} = 1 - \nu \). Total error is \( \varepsilon^{(C2)} = (1 - p^G)(1 + p^G(1 - \nu)) + p^B(1 - (1 - p^B)\nu) \);

(C3) if \( c_A^0 < c < c_A^1 \), a review is initiated if and only if there is approval (a hierarchy). Total error is \( \varepsilon^{(C3)} = (1 - p^G)(1 + p^G) + (p^B)^2 \);

(C4) if \( c_A^1 < c < c_A^0 \), review is never initiated after rejection, and is initiated after approval if and only if \( \sigma = B \). That is, \( x_{GR} = x_{BR} = 0 \), \( x_{GA} = 1 - \nu \), and \( x_{BA} = \nu \). This is equivalent to (C2);

(C5) if \( c > c_A^0 \), there is only the mandatory review. This is equivalent to (P1).

If \( \nu > \bar{\nu} \), we have \( c_R^1 < c_A^1 < c_R^0 < c_A^0 \). There is only one additional regime to consider:

(C6) if \( c_A^1 < c < c_R^0 \), a review is initiated after approval if and only if \( \sigma = B \) and after rejection if and only if \( \sigma = G \). That is, \( x_{GA} = x_{BR} = 1 - \nu \) and \( x_{GR} = x_{BA} = \nu \). Total error is \( \varepsilon^{(C6)} = (1 - p^G)(1 - p^G(2\nu - 1)) + p^B(2 - p^B - 2\nu(1 - p^B)) \).

The equivalence of (C2) and (C4) is due to the fact that, by (1) and (2), what matters for the total error are only the differences \( x_{GR} - x_{GA} \) and \( x_{BA} - x_{BR} \), which are equal in both cases.

Next, consider the case where \( p^G + p^B > 1 \). Again, the possible regimes depend on \( \nu \). If \( \nu < \bar{\nu} \), we have \( c_A^1 < c_A^0 < c_R^1 < c_R^0 \) (see Figure 3). Excluding the regimes where \( c \) is lower (higher) than the lowest (highest) of these thresholds, we are left with the following:

(C7) if \( c_A^1 < c < c_A^0 \), a review is always initiated after rejection, and is initiated after approval if and only if \( \sigma = B \). That is, \( x_{GR} = x_{BR} = 1 \), \( x_{GA} = 1 - \nu \), and \( x_{BA} = \nu \). Total error is \( \varepsilon^{(C7)} = (1 - p^G)(1 - \nu p^G) + p^B(2 - p^B - \nu(1 - p^B)) \);

(C8) if \( c_A^0 < c < c_R^1 \), a review is initiated if and only if there is rejection (a polyarchy). Total error is \( \varepsilon^{(C8)} = (1 - p^G)^2 + p^B(2 - p^B) \);

(C9) if \( c_R^1 < c < c_R^0 \), review is never initiated after approval, and is initiated after rejection if and only if \( \sigma = G \). This is equivalent to (C7).
If \( \nu > \hat{\nu} \), we have \( c_1^A < c_1^R < c_0^A < c_0^R \). There is only one additional regime to consider:

(C10) if \( c_1^R < c < c_0^A \), a review is initiated after approval if and only if \( \sigma = B \) and after rejection if and only if \( \sigma = G \). This is equivalent to (C6).

Conditional on a combined reviewing system being in place, when will the social planner choose a regime exploiting the information of private parties (C6) over a hierarchy (C3), a polyarchy (C8), and the other possible regimes, (C2) and (C7)? And when will he prefer such a system over a system relying on private initiative? The following proposition shows that, if regime (C6) is possible, it is the total-error minimizing one within the set of regimes available in a combined reviewing system. The proposition identifies conditions under which it also produces a lower total error than a system relying on private initiative.

**Proposition 3.** Suppose \( p^B < 1/2 < p^G \) and \( \nu \geq \max\{\hat{\nu}, \bar{\nu}\} \). Then, a planner whose objective is to minimize total error and who controls the cost of initiating review will choose regime (C6) in a combined reviewing system. The planner will prefer the combined system to one relying on private initiative if and only if

\[
2\nu \left[ 1 - p^G(1-p^G) - p^B(1-p^B) - \frac{p^G + p^B}{2} \right] < 1 - p^G(1-p^G) - p^B(1-p^B) - p^B. \quad (10)
\]

A sufficient condition for (10) is \( p^G \geq 1 - \sqrt{p^B(1-p^B)} \).

**Proof:** See the Appendix.

Figure 4 shows the set of parameter values in \((p^B, p^G)\) space such that the sufficient condition holds. As is clear from the figure, this is the case for most of the parameter space.

## 5 Conclusion

We have compared two systems for society to review projects: one in which the default is approval, and one in which all projects undergo a mandatory prior review. In both systems, private parties can then initiate a definitive review. We have evaluated these systems based on the incidence of type I and type II errors. Our analysis has produced three main results. First, taking the probabilities of review being initiated as exogenously given, we have shown
that a system with mandatory review can reduce both type I and type II errors compared to one relying solely on private initiative if (a) parties’ decisions to contest the initial ruling depend on whether or not the ruling was correct, and (b) there are enough non-meritorious challenges in the absence of mandatory review. Second, endogenizing the probabilities of review being initiated, we have identified conditions on the quality of the private signal and the cost of initiating review under which (a) and (b) are satisfied. Finally, considering the cost of initiating review as a variable controlled by the social planner, we have shown that if private parties’ signal is sufficiently precise, a planner minimizing total error will choose a combined reviewing system over one relying solely on private initiative for most of the parameter space.

To conclude, we briefly discuss two limitations of our analysis. First, we do not take into account the cost of performing mandatory review. To assess the desirability of mandatory review, one needs to know not only that it reduces the errors, but also what the social value of reducing error is. This would require specifying the social harm caused by errors in project
approval. One could then find a threshold level of harm above which mandatory review would be worthwhile. Second, our analysis neglects damages or fines that could be imposed on the losing party. These damages or fines could be used to fine-tune the private initiative. Whether this would affect the results in favor of or against mandatory review is an interesting question that is left for future research.
APPENDIX

Proof of Lemma 1

From figure 1 it is straightforward to see that for condition \(i\) to be satisfied, it must not be the case that either \(x_{BA} = 1\) or \(x_{BR} = 0\); in all other cases, \(x_{BA} > x_{BR}\). The range of \(c\) for which neither is the case is \(c_1^A \leq c < c_0^A\). Similarly, for condition \(ii\) to be satisfied, it must not be the case that either \(x_{GR} = 0\) or \(x_{GA} = 1\); in all other cases, \(x_{GR} > x_{GA}\). The range of \(c\) for which neither is the case is \(c_1^A \leq c < c_0^A\). Combining these two conditions, we have \(c \in [\max\{c_1^A, c_1^R\}, \min\{c_0^A, c_0^R\}]\) and thus \(x_{BA} = x_{GR} = \nu\) and \(x_{GA} = x_{BR} = 1 - \nu\). For condition \(iii\) to be satisfied, it must not be the case that \(y_G \leq 1 - \nu\). Suppose \(y_G = 1 - \nu\). Then, condition (iii) is \(1 - \nu > 1 - p^G(2\nu - 1)\), which can never be satisfied since \(\nu\) and \(p_G\) must be smaller or equal to 1. Hence, condition (iii) requires \(c \leq c_N^1\). ■

Proof of Proposition 2

By Lemma 1 and Proposition 1, \([\max\{c_1^A, c_1^R\}, \min\{c_1^N, c_0^A, c_0^R\}]\) is the set of parameters for which a combined reviewing system dominates a strictly competitive one. Let us derive the conditions for the set to be nonempty. In a first step, we neglect \(c_1^N\). From tables 1 and 2 we obtain, after simplification,

\[
\begin{align*}
    c_A^1(p^G, p^B, \nu) &= \frac{\nu p^G(1 - p^G) + (1 - \nu)p^B(1 - p^B)}{\nu p^G + (1 - \nu)p^B} \\
    c_A^0(p^G, p^B, \nu) &= \frac{\nu p^B(1 - p^B) + (1 - \nu)p^G(1 - p^G)}{\nu p^B + (1 - \nu)p^G} \\
    c_R^1(p^G, p^B, \nu) &= \frac{\nu p^B(1 - p^B) + (1 - \nu)p^G(1 - p^G)}{\nu(1 - p^B) + (1 - \nu)(1 - p^G)} \\
    c_R^0(p^G, p^B, \nu) &= \frac{\nu p^G(1 - p^G) + (1 - \nu)p^B(1 - p^B)}{\nu(1 - p^G) + (1 - \nu)(1 - p^B)}.
\end{align*}
\]

Notice the identities \(c_A^1(p^G, p^B, \nu) = c_A^0(p^G, p^B, 1 - \nu)\) and \(c_R^1(p^G, p^B, \nu) = c_R^0(p^G, p^B, 1 - \nu)\), as well as \(c_R^1(p^G, p^B, \nu) = c_A^1(1 - p^B, 1 - p^G, \nu)\) and \(c_R^0(p^G, p^B, \nu) = c_A^0(1 - p^B, 1 - p^G, \nu)\).
Differentiating \( c_A^1 \) with respect to \( \nu \), we have
\[
\frac{\partial c_A^1(p^G, p^B, \nu)}{\partial \nu} = \frac{[p^G(1-p^G) - p^B(1-p^B)] (\nu p^G + (1-\nu)p^B)}{(\nu p^G + (1-\nu)p^B)^2} - \frac{\nu p^G (1-p^G) + (1-\nu)p^B (1-p^B) (p^G - p^B)}{(\nu p^G + (1-\nu)p^B)^2} = -\frac{p^G p^B (p^G - p^B)}{(\nu p^G + (1-\nu)p^B)^2} < 0
\]
from which we deduce
\[
\frac{\partial c_R^0(p^G, p^B, \nu)}{\partial \nu} = -\frac{(1-p^G)(1-p^B)(p^G - p^B)}{(\nu(1-p^B) + (1-\nu)(1-p^G))^2} < 0.
\]
We conclude that \( c_A^1 \) and \( c_R^0 \) are decreasing in \( \nu \) and that, from the above identities, \( c_A^0 \) and \( c_R^0 \) must thus be increasing in \( \nu \).

These monotonicity properties imply that, first, if
\[
\max\{c_A^1(p^G, p^B, \nu), c_R^1(p^G, p^B, \nu)\} \leq \min\{c_A^0(p^G, p^B, \nu), c_R^0(p^G, p^B, \nu)\}
\]
for some \( \nu \), then
\[
\max\{c_A^1(p^G, p^B, \nu'), c_R^1(p^G, p^B, \nu')\} < \min\{c_A^0(p^G, p^B, \nu'), c_R^0(p^G, p^B, \nu')\}
\]
for all \( \nu' > \nu \). Second, because \( c_A^1(p^G, p^B, 1/2) = c_R^0(p^G, p^B, 1/2) \) and \( c_A^1(p^G, p^B, 1/2) = c_R^0(p^G, p^B, 1/2) \), \( c_A^1 < c_A^0 \) and \( c_R^1 < c_R^0 \) for all \( \nu > 1/2 \). Third, because \( c_A^1 \) decreases and \( c_R^0 \) increases with \( \nu \), there exists \( \hat{\nu} \) such that \( c_A^1 < c_R^0 \) for all \( \nu > \hat{\nu} \); similarly, because \( c_R^1 \) decreases and \( c_A^0 \) increases with \( \nu \), there exists \( \tilde{\nu} \) such that \( c_R^1 < c_A^0 \) for all \( \nu > \tilde{\nu} \). Solving for \( \hat{\nu} \) and \( \tilde{\nu} \), we obtain
\[
\hat{\nu} = \frac{1/2 - p^B}{p^G - p^B},
\]
\[
\tilde{\nu} = \frac{p^G - 1/2}{p^G - p^B}.
\]
From these expressions, \( \hat{\nu} > 1/2 > \tilde{\nu} \) if and only if \( p^G + p^B < 1 \) and \( \hat{\nu} < 1/2 < \tilde{\nu} \) if and only if \( p^G + p^B > 1 \). Hence, \( \max\{\hat{\nu}, \tilde{\nu}\} \geq 1/2 \). It follows that for all \( \nu > \max\{\hat{\nu}, \tilde{\nu}\} \), we have
\[
\max\{c_A^1(p^G, p^B, \nu), c_R^1(p^G, p^B, \nu)\} < \min\{c_A^0(p^G, p^B, \nu), c_R^0(p^G, p^B, \nu)\}.
\]
What remains to be shown is when \( \max\{\hat{\nu}, \tilde{\nu}\} < 1 \). If \( p^G + p^B < 1 \), \( \hat{\nu} > \tilde{\nu} \). In order to have \( \hat{\nu} < 1 \), we need \( p^G > 1/2 \). If \( p^G + p^B > 1 \), \( \hat{\nu} > \tilde{\nu} \). In order to have \( \tilde{\nu} < 1 \), we need \( p^B < 1/2 \).
Finally, we turn to \( c_{1}^{1}N \). In the \((\nu, c_{1}^{1})\) space, \( c_{1}^{1}N \) is a straight line running from \( 1 - p_{B} \) (at \( \nu = 0 \)) to \( 1 - p_{G} \) (at \( \nu = 1 \)). At those two points, it coincides with \( c_{1A}^{1} \). We now show that \( c_{1A}^{1} \) is convex and therefore always below \( c_{1}^{1}N \) for \( \nu \in [1/2, 1] \). Taking the second derivative of \( c_{1A}^{1} \) with respect to \( \nu \) yields

\[
\frac{\partial^{2}c_{1A}^{1}(p_{G}, p_{B}, \nu)}{\partial\nu^{2}} = \frac{2p_{G}p_{B}(p_{G} - p_{B})^{2}}{(\nu p_{G} + (1 - \nu)(p_{B})^{3})} > 0,
\]

establishing convexity. Concerning \( c_{1R}^{1} \), two cases have to be distinguished. The \( c_{1R}^{1} \) curve runs from \( p_{G} \) (at \( \nu = 0 \)) to \( p_{B} \) (at \( \nu = 1 \)). It is also convex:

\[
\frac{\partial^{2}c_{1R}^{1}(p_{G}, p_{B}, \nu)}{\partial\nu^{2}} = \frac{2(1 - p_{G})(1 - p_{B})(p_{G} - p_{B})^{2}}{(\nu - p_{B}) + (1 - \nu)(1 - p_{B})^{3}} > 0.
\]

Therefore, if \( p_{G} + p_{B} \leq 1 \), the \( c_{1R}^{1} \) curve is always below the \( c_{1}^{1}N \) curve.

If \( p_{G} + p_{B} > 1 \), this argument does not hold. The values of \( \nu \) solving the equation

\[
c_{1R}^{1}(p_{G}, p_{B}, \nu) = c_{1N}^{1}(p_{G}, p_{B}, \nu)
\]

delimit the interval for which \( c_{1}^{1}N \geq c_{1R}^{1} \). The upper bound of this interval is given by

\[
\hat{\nu} = \frac{(1 - 2p_{B}) + \sqrt{(1 - 2p_{B})^{2} - 4(1 - p_{G})(p_{B} + p_{G} - 1)}}{2(p_{G} - p_{B})}.
\]

For the set \([\max\{c_{1A}^{1}, c_{1R}^{1}\}, \min\{c_{1N}^{1}, c_{0A}^{1}, c_{0R}^{1}\}]\) to be nonempty when \( p_{G} + p_{B} > 1 \), \( \hat{\nu} \) must exist (i.e., the term under the square root must be nonnegative) and it must be the case that \( \tilde{\nu} < \hat{\nu} \), or

\[
\frac{p_{G} - 1/2}{p_{G} - p_{B}} < \frac{(1 - 2p_{B}) + \sqrt{(1 - 2p_{B})^{2} - 4(1 - p_{G})(p_{B} + p_{G} - 1)}}{2(p_{G} - p_{B})}
\]

\[
\iff 4(p_{G} + p_{B} - 1)^{2} < (1 - 2p_{B})^{2} - 4(1 - p_{G})(p_{B} + p_{G} - 1)
\]

\[
\iff p_{G} < \frac{1}{4p_{B}}.
\]

This condition is sufficient for existence of \( \tilde{\nu} \) and (together with \( p_{B} < p_{G} \)) implies \( p_{B} < 1/2 \).

\[\blacksquare\]

**Proof of Proposition 3**

From Proposition 2, we know that \( p_{B} < 1/2 < p_{G} \) is sufficient for \( \max\{\tilde{\nu}, \hat{\nu}\} < 1 \), and that \( \nu \geq \max\{\tilde{\nu}, \hat{\nu}\} \) is then sufficient for regime (C6) to be feasible. We will show first that under
these assumptions, (C6) produces the lowest total error of all regimes in a combined reviewing system. Then, we derive condition (10) and the stated sufficient condition for it to hold.

Consider first the case $p^G + p^B < 1$. Let us compare the total error of regimes (C2) and (C3). We have

$$
\varepsilon^{(C2)} \leq \varepsilon^{(C3)} \iff (1 - p^G)(1 + p^G(1 - \nu)) + p^B(1 - (1 - p^B)\nu) \leq (1 - p^G)(1 + p^G) + (p^B)^2
$$

$$
\iff \nu \geq \frac{p^B(1 - p^B)}{p^G(1 - p^G) + p^B(1 - p^B)}.
$$

Turning to the comparison of (C2) with (C6), we have

$$
\varepsilon^{(C6)} \leq \varepsilon^{(C2)} \iff (1 - p^G)(1 - p^G(2\nu - 1) + p^B(2 - p^B - 2\nu(1 - p^B)) \leq (1 - p^G)(1 + p^G(1 - \nu)) + p^B(1 - (1 - p^B)\nu)
$$

$$
\iff \nu \geq \frac{p^B(1 - p^B)}{p^G(1 - p^G) + p^B(1 - p^B)}.
$$

Since the two conditions coincide, we conclude that $\varepsilon^{(C6)} \leq \varepsilon^{(C2)} \leq \varepsilon^{(C3)}$ if $\nu \geq p^B(1 - p^B)/[p^G(1 - p^G) + p^B(1 - p^B)]$. We now show that this condition is always satisfied when $\nu \geq \hat{\nu}$. In fact,

$$
\hat{\nu} = \frac{1/2 - p^B}{p^G - p^B} > \frac{p^B(1 - p^B)}{p^G(1 - p^G) + p^B(1 - p^B)}
$$

$$
\iff p^G(1 - p^G)(1/2 - p^B) > p^B(1 - p^B)(p^G - 1/2)
$$

$$
\iff p^G(1 - p^G)\hat{\nu} > p^B(1 - p^B)\hat{\nu},
$$

where the last equivalence is obtained by dividing both terms by $(p^G - p^B)$ and using the definition of $\hat{\nu}$ and $\hat{\nu}$. Examining condition (15), note that the function $f(x) = x(1 - x)$ is maximized for $x = 1/2$. By assumption, $p^B < 1 - p^G < 1/2 < p^G < 1 - p^B$, implying $p^G(1 - p^G) > p^B(1 - p^B)$. Moreover, from Proposition 2, if $p^G + p^B < 1$, then $\hat{\nu} > \hat{\nu}$. It follows that (15) must hold.

Now consider the case where $p^G + p^B > 1$. Let us compare the total error of regimes (C7) and (C8). We have

$$
\varepsilon^{(C7)} \leq \varepsilon^{(C8)} \iff (1 - p^G)(1 - \nu p^G) + p^B(2 - p^B - \nu(1 - p^B)) \leq (1 - p^G)^2 + p^B(2 - p^B)
$$

$$
\iff \nu \geq \frac{p^G(1 - p^G)}{p^G(1 - p^G) + p^B(1 - p^B)}.
$$
Turning to the comparison of (C7) with (C6), we have

\[ \varepsilon(C6) \leq \varepsilon(C7) \iff (1-p^G)(1-p^G(2\nu-1)) + p^B(2-p^B-2\nu(1-p^B)) \leq (1-p^G)(1-\nu p^G) + p^B(2-p^B-\nu(1-p^B)) \]

\[ \iff \nu \geq \frac{p^G(1-p^G)}{p^G(1-p^G) + p^B(1-p^B)}. \]

Since the two conditions coincide, we conclude that \( \varepsilon(C6) \leq \varepsilon(C7) \leq \varepsilon(C8) \) if \( \nu \geq p^G(1-p^G) / [p^G(1-p^G) + p^B(1-p^B)] \). We now show that this condition is always satisfied when \( \nu \geq \tilde{\nu} \). In fact,

\[ \tilde{\nu} = \frac{p^G - 1/2}{p^G - p^B} > \frac{p^G(1-p^G)}{p^G(1-p^G) + p^B(1-p^B)} \]

\[ \iff p^G(1-p^G)(1/2 - p^B) < p^B(1-p^B)(p^G - 1/2) \]

\[ \iff p^G(1-p^G)\tilde{\nu} < p^B(1-p^B)\tilde{\nu}, \quad (16) \]

where the last equivalence is obtained by dividing both terms by \((p^G - p^B)\) and using the definition of \( \tilde{\nu} \) and \( \hat{\nu} \). We have by assumption \( 1-p^G < p^B < 1/2 < 1-p^B < p^G \), implying \( \nu^G(1-p^G) < p^B(1-p^B) \). Moreover, from Proposition 2, if \( p^G + p^B > 1 \), then \( \tilde{\nu} < \hat{\nu} \). It follows that (16) must hold.

We now turn to the total error in a system without mandatory review. Since regime (P1) produces a total error lower than 1, we can exclude (P3). Moreover, Proposition 2 has shown that a combined reviewing system dominates private initiative when \( c < c^1_N \), so (P1) cannot be optimal. We can thus restrict attention to (P2). Comparing the total error of (P2) and (C6), we have

\[ \varepsilon(P2) \geq \varepsilon(C6) \]

\[ \iff (1-\nu)(1-p^G) + 1 - \nu(1-p^B) \geq (1-p^G)(1-p^G(2\nu-1)) + p^B(2-p^B-2\nu(1-p^B)), \]

which is equivalent to (10). The right-hand side of (10) is greater than zero for any \((p^G, p^B)\) under our maintained assumption that \( p^B < 1/2 < p^G \). The expression in square brackets on the left-hand side, \( 1 - p^G(1-p^G) - p^B(1-p^B) - \frac{p^G+p^B}{2} \), is negative when \( p^B \) is close to 1/2. In that case, condition (10) is automatically satisfied (for it to be violated would require \( \nu < 0 \)). The interesting case is when the expression in square brackets is positive. Then, we can divide both sides by it to obtain

\[ \nu < \frac{1 - p^G(1-p^G) - p^B(1-p^B) - p^B}{2 \left[ 1 - p^G(1-p^G) - p^B(1-p^B) - \frac{p^G+p^B}{2} \right]} \equiv \nu^*. \]
A sufficient condition for (10) to hold is thus $\nu^* \geq 1$, or

$$1 - p^G (1 - p^G) - p^B (1 - p^B) - p^B \geq 2 \left[ 1 - p^G (1 - p^G) - p^B (1 - p^B) - \frac{p^G + p^B}{2} \right],$$

which is equivalent to $p^G > 1 - \sqrt{p^B (1 - p^B)}$. ■

References


