Information-Sharing Between Competition Authorities

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Abstract

The increasing number of antitrust cases that affect more than one country calls for more active cooperation between competition authorities. I analyse the impact of exchange of confidential information between two authorities deciding on a multinational merger. The authorities want to clear the merger if the information sent by the firm suggests that the expected welfare in their country will be enhanced and the firm can secretly manipulate the precision with which it transmits this information. The authorities differ in their leniency towards the merger and we focus on the cases where the authorities disagree about the decision. Under no information-sharing, the firm chooses an extreme level of precision: very high (low) for the most (least) lenient authority. Under information-sharing, the firm is restricted to choose the same precision for both authorities. The firm's choice depends on the level of cooperation in the decision-making between the countries. If the authorities exert their veto power, the firm always uses the lowest level of precision. If the authorities also cooperate in the decision-making, the firm's choice of precision may be non-monotonic in the average welfare implications and intermediate levels of precision are chosen. Other situations where the model can be applied abound in industrial organisation and political economy.

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1 Introduction

> "Most officials believe that the issue of confidentiality is the chief limitation of enforcement cooperation agreements and hence it is submitted that the majority of effort should be concentrated on overcoming this particular obstruction to effective cooperation between antitrust agencies."
>
> Marsden and Whelan (2005), p.24.

With globalization, competition has had an increasingly international dimension. A clear example is the existence of international cartels, such as the vitamins cartel which took place between January 1990 and February 1999, as well as the increasing number of mergers that involve more than one jurisdiction.[1] Both examples suggest the need to enhance cooperation between competition agencies.[2]

There has been a proliferation of multilateral platforms where various policy issues are discussed such as the ICN (International Competition Network) and the OECD (Organization for Economic Cooperation and Development). Similarly, many bilateral agreements have emerged. As pointed out by the quotation above, it is believed that one of the main limitations of these agreements is the impossibility of exchanging confidential information between competition authorities. The most prominent example of this type of agreement is the one between the E.U. and the U.S.[3] A minority of competition policy agreements expressly provide for the exchange of confidential information. For instance, the bilateral agreement between the U.S. and Australia[4], the trilateral agreement between Iceland, Norway and Denmark[5] and, more recently, the agreement between competition authorities of the European Member States[6].

[1] UNCTAD (2000) shows that the share of cross-border mergers increased to 78% of the world FDI in the late 1990's.

[2] For instance, the U.S. agencies have about 120 mergers' notifications to foreign governments in a two-year period. In some 64 of them there is additional contact with the foreign agency where publicly-available information is exchanged. In about 40 cases the agencies engage in some level of cooperation, but confidential business information is only exchanged if a waiver is granted, which happens in some 16 cases. See OECD (2003).

[3] Agreement Regarding the Application of their Competition Laws, 23 Sept. 1991, 4 CMLR 823, 30 ILM 1487 and the E.U.-U.S. Positive Comity Agreement, 4th June 1998, (1998) OJ L173/28, (1999) 4 CMLR 502.

[4] Agreement on Mutual Antitrust Enforcement Assistance, available at www.apeccp.org.tw/doc/USA/Cooperation/usaus7.htm

[5] www.globalcompetitionforum.org/regions/europe/Denmark/Agreemen1.pdf

[6] E.C. Regulation 1/2003, available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri =OJ:L:2003:001:0001:0025:EN:PDF.

The issue of exchange of confidential information has been raised in many occasions. In 2002, Advanced Micro Devices (AMD) requested court documents, gathered during a U.S. antitrust case against Intel several years before, to be transferred to the European Commission as support for a complaint against Intel. AMD believed that many of the issues in the U.S. case were similar to the questions under investigation by the E.C.[7]

The goal of this paper is to explore the firm's incentives to provide precise information when two authorities decide to share this information. We describe the model in a merger control context, although it is applicable to many other settings. It naturally can be used to study information sharing between other authorities such as a sectorial regulator or central bank and a competition authority (as it is the case with mergers involving banks). But more generally, it sheds light on the vagueness of the information publicly conveyed to two different audiences. For instance, in a joint interview by different units of a firm, a project approval by different departments or a reform submitted to bicameral parliaments.

In the model, a competition authority ("she") is assessing the welfare implications of a merger from the information provided by a multinational firm ("he"). Neither the firm nor the authority have private information concerning the merger welfare effects[8]. The firm conveys the information through a noisy signal[9], from which the authority observes a random realization. The firm can choose to secretly manipulate the precision with which he transmits this information to the authority at no cost. We model this by allowing the firm to choose the variance[10] of the signal, for instance, by adding or substracting relevant documents. The choice of the noise is unobservable because the authority does not actually know how precise is the information that the firm has. A larger quantity of information does not necessarily imply more precision as some of it may be irrelevant and authorities have a limited amount of time to process it. Adding bias to the signal involes lying or withholding incriminating documents. This is very costly for a firm that is in the middle of an investigation as

[7] This request was made under 28 U.S.C. § 1782, which allows a district court to order the production of documents "for use in a proceeding in a foreign or international tribunal" upon request by "any interested person". This request was first denied by the district court and then reversed by the Ninth Circuit Court of Appeals. Intel Corp. v. Advanced Micro Devices, Inc., No. 02-572, available at: www.supremecourtus.gov/opinions/03pdf/02-572.pdf

[8] The firm is giving information about the merger's market effect or the merger's effect on third parties, for which the firm may not have more information than the competition authority. In Section 5, we discuss the implications on the firm's behavior of relaxing this assumption.

[9] The signal has a normal additive structure.

[10] Noise, variance and lack of precision are interchangeable.

with high chances he may be discovered and punished accordingly[11]; as a result the signal is unbiased.

The policy decision is binary (to clear the merger or not) and depends on the realization of the signal. The authority adopts a cut-off rule whereby, if the realization of the signal is above some threshold, she clears the merger and she blocks it otherwise.

When the firm deals with a single authority or, equivalently, when the two authorities do not share information[12], the optimal variance chosen by the firm does not depend on how good or bad the average merger is (i.e. how far the average merger is above or below the policy threshold) but rather on whether it is good or bad (i.e. above or below the threshold). In particular, if the average merger is bad, the firm chooses the risky strategy of the largest variance to have more chances to be thought good. By contrast, if the average merger is good, the firm uses the lowest variance to decrease the likelihood of obtaining an extreme realization of the signal. This strategy does not change depending on whether the authority can commit to the policy ex-ante. We improve upon the existing literature by establishing the optimal response (i.e. policy threshold) of the authority to the firm's behavior. If the authority cannot commit to a policy ex-ante, the ex-post optimal threshold when the average merger is welfare detrimental (enhancing) is stricter (more lenient) than the full information threshold. Interestingly, when there is uncertainty about the merger's undesirability, the authority's ability to commit (for instance, by issuing detailed guidelines) makes her set a more lenient threshold to induce the firm to provide more precise information. Otherwise, the authority sets the ex-post optimal threshold.

To study the consequences of information-sharing, we consider the case where one authority is more lenient than the other (i.e. their policy thresholds differ), either because their tolerance to mergers differ or because the same underlying state variable has different welfare implications in the two countries. Furthermore, for the merger to go through, the approval by both countries is needed. When the authorities commit to share information by signing an agreement, the firm can no longer choose the precision of the signal tailor-made to convice a particular authority.

[11] This behavior is punished heavily. See for instance, the "Statement of Policy on Penalties" by the UK Competition Comission.

[12] When the authorities do not share information, the goal of the firm is to convince each authority independently. To this end, the firm chooses a particular level of precision to increase the chances of convincing a given authority.

Instead, the firm makes a unique choice of variance for both authorities. Moreover, we restrict the meaning of information-sharing to the authorities observing the same realization of the signal submitted by the firm[13].

We explore the impact of the information-sharing regime on the incentives of the firm to provide precise information[14]. The agreement only has an impact on the firm's behavior when the average merger is "conflicting", that is, it is good for one country but bad for the other. This impact will depend on the particular rule that the authorities use to deal with the case of disagreement (i.e. when the realization of the signal lies between their thresholds). We consider different possible rules to deal with disagreement.

If the authorities have veto power (i.e. each country can unilaterally block the merger), then sharing information induces the firm to send a very imprecise signal, making the more lenient country strictly worse off.

Another possibility is to extend the cooperation beyond the information-sharing stage, by having some informal bargaining/persuasion process (not explicitly modelled in this paper) in the decision-taking. We model the outcome of the bargaining process as the merger being approved with some probability in case of disagreement.

First, we take this probability as being fixed and exogenous, which may be interpreted as the authorities' relative bargaining power. The choice of the variance in this case may be non-monotonic in the expected merger, and, intermediate values of variance are chosen in equilibrium. When the average merger is relatively bad for the less lenient country, the firm still chooses an extreme variance. In particular, the firm chooses high variance to increase the chances of being above the more lenient threshold (where the merger is cleared for sure). Under some conditions[15], as the average merger improves, he switches to low variance to increase the chances of being cleared at least with some probability. When the average merger is relatively less welfare detrimental for the stricter country, it becomes safer to play a riskier strategy of choosing an intermediate variance. Furthermore, this variance decreases as the average merger approaches to the policy threshold of the stricter country. This is because the chances of having the merger cleared are already high and, by reducing

[13] We discuss in the Conclusions possible implications of letting each authority observe an independent realization of the same signal.

[14] We do not let the policy thresholds change following the agreement. The policy thresholds are the same for both national and international mergers (which are a minority), so the authorities may decide not to be strategic in their choices.

[15] The countries have equal bargaining power and the authorities' policies are far apart or the lowest variance is low enough.

the variance, the probability of having it blocked by both authorities is decreased.

We also consider the case where the probability of approval depends on the particular realization of the signal. This captures the idea that the less lenient country is more willing to clear the merger if the realization falls near her threshold as compared to when it falls very far from it. In particular, we consider the case where this probability is an odd increasing function of the signal realization. From the point of view of the firm, it is as if there were a unique but uncertain threshold. Because of the rotational symmetry of the function, the firm considers the expected threshold and behaves as in the case of one authority with respect to this threshold.

To sum up, if authorities exert their veto power, then sharing information is a bad idea because the firm will submit very imprecise information. Further cooperation modifies the firm's payoff structure in such a way that the firm makes a greater use of intermediate and lower levels of noise (as compared to the veto power case) and, therefore, it can be potentially good if the lenient country is not always the same one.

1.1 Related literature

This is a signal-jamming model, like the ones used in the career concerns literature[16], where the firm jams the signal, not by manipulating its mean but by changing its variance, and hence its information content.

The choice of variability as a strategic variable has been considered in a large variety of setups. For instance, Anderson and Cabral (2007) analyze a model of R&D races where the two contestants, taking as given the level of R&D expenditure, need to choose a level of risk. Tsetlin et al. (2004) consider the choice of variability of the performance distribution in a multi-round contest. In the compensation literature, Gaba and Kalra (1999) introduce the level of dispersion of the probability distribution of sales as a choice variable besides the level of effort. The general conclusion of all these papers is that the players that are at disadvantage tend to optimally choose more risky strategies than those who are in a favorable position. We also find this "gambling for resurrection" behavior in our national merger framework. However, this behavior may disappear in the multinational merger case if authorities decide to cooperate both in the decision making as well as at the information-sharing stage.

Johnson and Myatt (2006) also consider the incentives of a firm to provide its

[16] See Holmstrom (1982, 1999) and Dewatripont et al. (1999).

potential customers with more or less precise information. They show how the seller's supply of information affects the shape of the distribution of buyers' expected valuations and hence generates rotations of the demand curve. These rotations generate a convexity in the monopolist's profits, which explains the optimality of the monopolist's extreme choices of variance in Lewis and Sappington (1994). Contrary to Johnson and Myatt (2006), in our model there is another strategic player: the competition authority. In particular, our firm will choose a level of precision in order to maximize the chances that the realization of the signal falls above the policy threshold level chosen by the authority. On the other hand, the authority will choose the threshold in order to maximize the (ex-post or ex-ante) expected welfare. In the Johnson and Myatt paper, the monopolist is choosing both the precision and the threshold (i.e. the price) in order to maximize the ex-post expected profits.

As far as we are aware, another distinctive feature of our model with respect to the previous work is that the noise (and hence, the distribution of the signal) is not observed by the receiver. In our framework, observability of the noise renders the problem trivial because the competition authority could simply condition the policy threshold on the noise and block any merger with an imprecise report.

Finally, this paper considers the consequences of information-sharing between receivers/principals and hence it is related to the literature that compares private with public communication. However, comparisons with this literature are difficult because, so far, its focus has been on frameworks of mechanism design (see, for instance, Calzolari and Pavan (2006), Maier and Ottaviani (2009)), cheap talk (see Farrell and Gibbons(1989)), and signalling (see Gertner, Gibbons and Scharfstein (1988) and Spiegel and Spulber (1997)).

The paper proceeds as follows. Section 2 introduces the model. Section 3 studies the national merger. This section first presents the results for the no-commitment case and then highlights the differences resulting from the authority's ability to commit. Section 4 introduces and analyses the multinational merger setup. Section 5 discusses the consequences of the firm having private information. Finally, Section 6 concludes. All the proofs can be found in the Appendix.

2 The model

We consider a multinational firm (M) proposing a merger that must be cleared under the competition law of the country. The welfare consequences of the merger can be summarized in the real-valued state variable θ, with support on $[-\infty, +\infty]$. The mergers with $\theta > 0$ are welfare enhancing while the ones with $\theta < 0$ are welfare detrimental. Furthermore, the higher the θ, the more desirable it is for the country to have the merger cleared by the competition regulator (R). If R were to observe the true θ (full information framework), she would like to clear the merger with probability one whenever $\theta \geq 0$ and block it otherwise. The multinational always has a positive net benefit normalized to 1 from the merger[17] and, therefore, he would like to have the merger cleared for any θ. The firm does not have private information about θ[18]. For instance, the firm may be giving information about the merger's market effect or the merger's effect on third parties, for which the firm may not have more information than the competition authority. The parameter θ is distributed according to a Normal distribution, $f(\theta)$, with mean μ and variance η^2 and this distribution is common knowledge.

The actions available to the players are the following. M sends a message containing the information about θ to R but he does so through a noisy signal[19]. In particular, the signal has the following form:

$$S = \theta + \varepsilon$$

where ε is a random variable distributed according to a Normal distribution with mean zero and variance V. M can secretly choose V, which reflects the precision with which the message is sent (the larger the V, the less informative is the realization of the signal about θ). For instance, M can add or subtract relevant documents and this choice is secret because R does not know which documents M has. For simplicity, we assume that M can only choose V within this interval $[V_L, V_H]$, where $0 < V_L < V_H$.[20] The firm cannot, however, exaggerate the welfare benefits of the merger by shifting upwards the mean of ε (i.e. lying is not possible and therefore, the signal should be on average equal to θ). This is because the chances of being

[17] Otherwise, he would not have proposed it in the first place.

[18] This assumption is standard in the career concerns literature. We discuss in Section 5 the consequences of relaxing it.

[19] The signal can be noisy, either because the production technology (i.e. the way in which the firm compiles and transmits the information about the merger) is noisy or the perception of the receiver is imperfect (for instance, Kolstad et al. (1990) analyse the optimal use of ex-ante safety regulation and ex-post tort liability. In their model, there is uncertainty about how a court will interpret whether or not the injurer met the standard of due care).

[20] There are many justifications for $V_L > 0$. For instance, nobody knows θ exactly until the merger takes place, M is not able to compile and transmit the information perfectly (e.g., it is costly) or there is uncertainty about R's interpretation of the evidence.

discovered and punished accordingly are high for a firm that is in the middle of an investigation[21]. Therefore, the distribution of the signal S, $g(s, V)$, is Normal with mean μ and variance $\eta^2 + V$ and $G(s, V)$ is the cumulative distribution.

R observes the realization of the signal s, updates her beliefs about θ, and chooses the appropriate probability of clearance $p(s)$. We consider the case where $p(s)$ is a cut-off rule[22], where $\widehat{s}$ is optimally determined by R:[23]

$$p(s) = \begin{cases} 0 \text{ if } s < \widehat{s} \\ 1 \text{ if } s \geq \widehat{s} \end{cases}$$

The timing of the game depends on whether R has the ability to commit to a particular threshold before the information is transmitted by M. Under no commitment, the timing is as follows. First, M chooses the variance with which he sends the signal. A realization of the signal, s, is observed by R. Given this realization, R updates her beliefs about θ and decides which policy threshold $\widehat{s}$ to use. Finally, the payoffs are realized. The solution of this model is a Nash equilibrium where the conjectures of each of the players are correct in equilibrium. Under commitment, first R chooses a policy threshold $\widehat{s}$ and M then chooses V. A realization of the signal, s, is observed by R. Given this realization, R clears the merger whenever s is above $\widehat{s}$. Finally, the payoffs are realized. We solve this model backwards.

[21] Another reason for abstracting from the possiblity of biasing the signal upwards is because, without penalization, the incentives for increasing the bias are clear, completely monotonic, and independent from the noise dimension. Moreover, the firm would like to bias the report in the same direction for both authorities and we want to focus on the actions that differ depending on the authority that is in charge. For a model that considers both the manipulation of the mean and the precision of the signal see Drugov and Troya-Martinez (2012). The authors analyse how the incentives of a seller to provide biased and/or imprecise advice to consumers are affected by the possibility of facing ex-post litigation, where a court will infer how much lying has taken place and penalise accordingly.

[22] The monotone likelihood ratio property (MLRP) holds in the setup. This is a sufficient condition for a cut-off rule to be optimal if the authority cannot commit to a threshold ex-ante (see Milgrom (1981)). It is not clear whether there is any loss of generality in the case where the authority can commit to a policy. Obviously, if the behaviour of the firm does not change under the more general rule $\widetilde{p}(s)$, then a cut-off rule dominates $\widetilde{p}(s)$, as it is ex-post optimal. Section 4.2.2 shows that if $\widetilde{p}(s)$ is non-decreasing, continous and odd function, the behaviour of the firm does not change. Example 1 in the Appendix provides another example where $\widetilde{p}(s) = Z(s)$ and $Z(s)$ is a cummulative Normal distribution.

For comparison purposes, we restrict ourselves to a cut-off rule also in the commitment case.

[23] R does not infer the noise used based on the unique realisation of the signal. This assumption is not restrictive because, in the no-commitment case, R has point beliefs about V which will not be affected by letting R make inferences from s. In the commitment case, it would be difficult for the authority to justify blocking the merger of an extreme positive realisation, given that all realisations can happen with positive probability and MLRP holds.

3 Benchmark: national merger

3.1 No-commitment regime

3.1.1 The problem of the firm

The firm objective is to choose a level of precision that maximizes the probability of having the merger cleared. M makes a conjecture about the policy threshold used by R, $\widehat{s}^c$, where the superscript stands for conjecture. Using Bayes rule, M maximizes the probability of having the merger cleared:

$$P(V) = \int_{\widehat{s}^c}^{+\infty} g(s, V)\, ds$$

The objective function is decreasing in V whenever the average merger is a good merger (i.e. $\widehat{s}^c < \mu$) and increasing in V when the average merger is a bad merger (i.e. $\widehat{s}^c > \mu$). Therefore, if $\widehat{s}^c < \mu$, M will choose the minimum available variance V_L. Conversely, if $\widehat{s}^c > \mu$, M will choose the maximum available variance V_H.

Lemma 1 *Under no-commitment, the optimal variance is:*

$$V^*(\mu, \widehat{s}^c) = \begin{cases} V_H \text{ if } \mu < \widehat{s}^c \\ V_L \text{ if } \mu > \widehat{s}^c \end{cases}$$

If $\widehat{s}^c = \mu$, M is indifferent between any variance in $[V_L, V_H]$.

Proof. See Appendix. ■

For simplicity, we will assume that if $\widehat{s}^c$ is exactly μ the firm will choose V_L.

The intuition supporting this optimal strategy is that, by increasing the variance, an expected bad merger obtains more chances to be thought good. By contrast, decreasing the variance cuts down an expected good merger's chance of being considered bad. Therefore, the optimal V does not depend on how far the particular μ is from $\widehat{s}^c$, only on whether μ lies below or above $\widehat{s}^c$. This is due to the "bang-bang" payoff structure created by the cut-off rule. This "gambling for resurrection" result is in line with the findings of the literature that considers the choice of variability as a strategic variable[24].

[24] See Section 1.1.

3.1.2 The problem of the competition authority

Given the realization s and the conjecture that R forms about M's choice V^c, she needs to decide whether to clear the merger or not. The ex-post expected welfare of the merger is:

$$W(s,\widehat{s}^c) = \int_{-\infty}^{+\infty} \theta f\left(\theta | \, s, V^c(\mu,\widehat{s}^c)\right) d\theta$$

If $W(s,\widehat{s}^c)$ is positive, R wants to clear the merger. Conversely, if $W(s,\widehat{s}^c)$ is negative, R blocks the merger. The authority determines the threshold $\widehat{s}$ so that she is indifferent between blocking or clearing the merger, that is, so that $W(s,\widehat{s}^c)$ is zero:

$$W(s,\widehat{s}^c) \mid_{s=\widehat{s}(\widehat{s}^c)} = \frac{\widehat{s}(\widehat{s}^c)\eta^2 + \mu V^c(\mu,\widehat{s}(\widehat{s}^c))}{\eta^2 + V^c(\mu,\widehat{s}(\widehat{s}^c))} = 0 \tag{1}$$

Denote the solution of equation (1) as $\widehat{s}(\widehat{s}^c)$. The equilibrium threshold $\widehat{s}^*$ is, then, the fixed point of this solution:

$$\widehat{s}(\widehat{s}^*) = \widehat{s}^*$$

Proposition 1 *Under no commitment, the equilibrium threshold* $\widehat{s}^*$ *is:*

$$\widehat{s}^* = \begin{cases} \frac{-\mu V_H}{\eta^2} & \text{if } \mu < 0 \\ \frac{-\mu V_L}{\eta^2} & \text{if } \mu \geq 0 \end{cases}$$

Proof. It is straightforward to solve equation (1). ■

Figure 1 depicts the optimal threshold $\widehat{s}^*$ as a function of the average merger μ.[25] If the bulk of mergers are bad mergers ($\mu < 0$), then the authority increases the standard of proof of a good merger by setting the policy threshold above the neutral merger 0. Conversely, when the average merger is welfare enhancing ($\mu > 0$), the authority sets a very lenient standard of proof, tolerating even negative signals.

Finally, note that as V_L tends to 0, the report becomes extremely informative and $\widehat{s}^*$ increases to zero (i.e. R becomes stricter with the on average good mergers as the probability of "unlucky realizations", that is, $s < \theta$, decreases). Similarly, as V_H tends to $+\infty$, the report submitted by M becomes uninformative and $\widehat{s}^*$ tends to $+\infty$, so all the mergers that may raise competition issue on average will be blocked.

[25] By Lemma 1, above the 45^o line, $\widehat{s}^* > \mu$, so the firm chooses V_H and below the 45^o line, $\widehat{s}^* \leq \mu$, so M chooses V_L. By Proposition 1, the optimal threshold, $\widehat{s}^*$, has the opposite sign to the average merger and increases in absolute value with the average merger and $V^*(\mu,\widehat{s}^*)$.

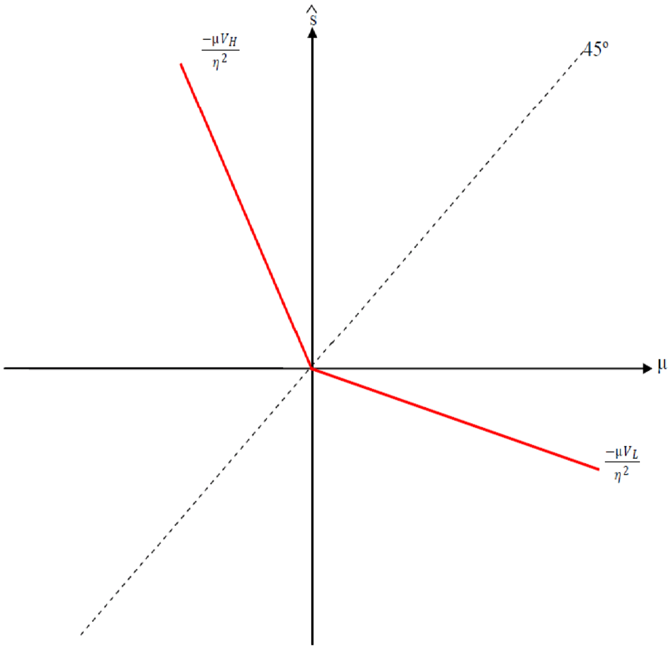

Figure 1: Optimal threshold under no commitment

3.2 Commitment regime

3.2.1 The problem of the firm

Suppose that R can commit in advance to a policy threshold $\widehat{s}$, for instance, by issuing very detailed merger guidelines. Then, M chooses V taking into account the actual $\widehat{s}$ instead of the conjecture $\widehat{s}^c$. The problem is identical to the one solved in Section 3.1.1 and therefore it is omitted here. The optimal variance is as in Lemma 1:

$$V^*(\mu, \widehat{s}) = \begin{cases} V_H \text{ if } \mu < \widehat{s} \\ V_L \text{ if } \mu > \widehat{s} \end{cases} .$$

If $\widehat{s} = \mu$, M is indifferent between any variance in $[V_L, V_H]$. Again, let us break indifference by assuming that M will choose V_L.

3.2.2 The problem of the competition authority

When the competition authority can commit to the policy, she chooses $\widehat{s}$ to maximize the ex-ante expected welfare, taking into account the behavior of the firm:

$$
\begin{aligned}
EW(\widehat{s}, V^{*}(\mu,\widehat{s})) &= \int_{\widehat{s}}^{+\infty}\left(\frac{s\eta^{2}+\mu V^{*}(\mu,\widehat{s})}{\eta^{2}+V^{*}(\mu,\widehat{s})}\right) g\left(s, V^{*}\left(\mu,\widehat{s}\right)\right) ds \qquad (2)\\
\text{subject to} &: \; V^{*}(\mu,\widehat{s}) = \begin{cases} V_{H} \text{ if } \mu < \widehat{s} \\ V_{L} \text{ if } \mu \geq \widehat{s} \end{cases}
\end{aligned}
$$

where the term in brackets is the expected welfare given a realization s, $W(s,\widehat{s})$.[26]

Proposition 2 *There exist $\widetilde{\mu}$ such that, under commitment, the optimal threshold $\widehat{s}^{**}$ is:*

$$
\widehat{s}^{**} = \begin{cases} \frac{-\mu V_{H}}{\eta^{2}} & \text{if } \mu < \widetilde{\mu} \\ \mu & \text{if } \mu \in [\widetilde{\mu}, 0] \\ \frac{-\mu V_{L}}{\eta^{2}} & \text{if } \mu > 0 \end{cases}
$$

$\widehat{s}^{**}$ is non-monotonic in the expected welfare and $\widetilde{\mu}$ strictly increases (decreases) with V_L (V_H).

Proof. See Appendix. ■

As in Figure 1, we depict $\widehat{s}^{**}$ as a function of μ in Figure 2.

Note that the authority values the level of precision of the signal as this allows her to make fewer mistakes when deciding whether to clear the merger or not.

When the average merger is welfare enhancing ($\mu > 0$), by Lemma 1, M chooses V_L. Since, this is as informative as the report can be, R sets the ex-post optimal threshold found in Section 3.1.2.

By the same Lemma, when the average merger is welfare detrimental, M chooses V_H. This introduces a new trade-off for the competition authority because she may decide to distort the ex-post optimal policy upwards in order to extract more precise information from the firm. Indeed, we find that, when there is substantial uncertainty about the undesirability of the average merger (μ is negative and close to zero, i.e., $\mu \in [\widetilde{\mu}, 0]$), then R gains from committing to a more lenient threshold (not only more lenient than the ex-post optimal threshold but also than the full information threshold) in order to induce M to reduce his equilibrium variance from V_H to V_L. On the other hand, if the merger is on average clearly welfare detrimental ($\mu < \widetilde{\mu}$), the authority will again set the ex-post optimal threshold found in Section 3.1.2.

[26] The objective function is equivalent to $\int_{-\infty}^{+\infty} \theta f\left(\theta | s, V^{*}(\mu,\widehat{s})\right) d\theta$, where $f\left(\theta | s, V^{*}(\mu,\widehat{s})\right)$ is the posterior distribution of θ.

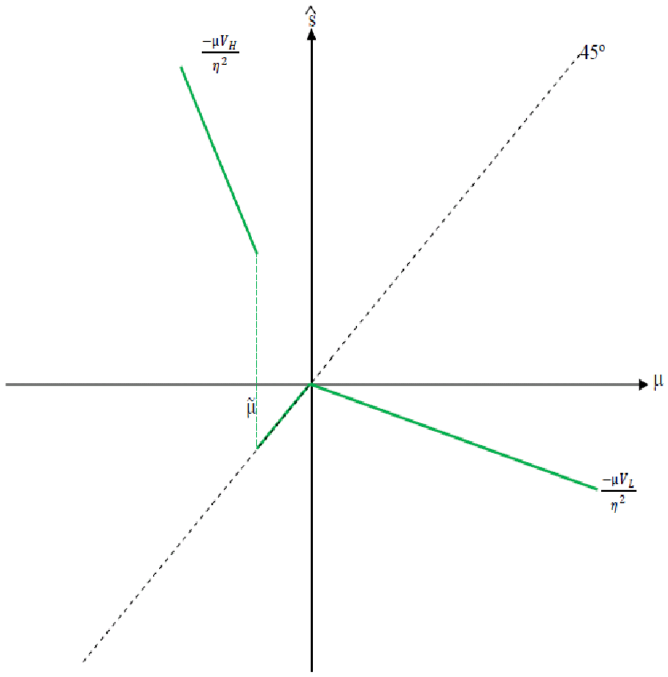

Figure 2: Optimal threshold under commitment

Therefore in some cases, the authority, by gaining commitment power, decides to distort her policy by decreasing her standards (in an ex-post non-optimal way) in order to fix the information problem (i.e. to improve the informativeness of the signal).

Corollary 1 *Policy comparison:*
$\widehat{s}^* = \widehat{s}^{**}\ \forall \mu \in (-\infty, \widetilde{\mu}) \cup (0, +\infty)$ *and* $\widehat{s}^* > \widehat{s}^{**} \forall \mu \in [\widetilde{\mu}, 0]$.

Finally, note that if V_L increases, the range of mergers for which the authority is more lenient than the ex-post optimal, $[\widetilde{\mu}, 0]$, shrinks as there is less gain from obtaining a less precise signal. Similarly, this range will expand if V_H increases.

4 Multinational merger

In this section we consider the situation where a multinational wants to undertake the same merger in two different countries (or jurisdictions) and these countries differ in terms of their policies. The policies are the same for national and multinational mergers. Since the multinational mergers are a minority, we abstract from strategic policy changes to take into account the international dimension. Without loss of generality, we assume that Country 1 will block the merger if the signal is below $\widehat{s}_1$ and clear it otherwise, while Country 2 will do the same using the threshold $\widehat{s}_2$, where $\widehat{s}_1 < \widehat{s}_2$.

The difference in thresholds can be interpreted as Country 1 being in general more lenient in its merger policy than Country 2.[27] For instance, if the welfare function of Country i is $a_i + b_i\theta$, where $i = 1, 2$, then $a_1 > a_2$ and $b_2 > b_1 > 0$[28], where a_i could be interpreted as how lenient is the authority and b_i how sensitive is the authority to the welfare's changes.[29]

In practice, some mergers may raise competition issues at a national (or sub-national) level that can be solved by a local action (for instance, to impose a remedy that forces the firm to undertake a national divestiture if the merger is cleared somewhere else) without the need to reach an agreement with other competition authorities. In this paper we focus on the type of mergers that do need the agreement of all the jurisdictions in order for the merger to happen. An example of such a merger was the one proposed between two U.S.-based companies, General Electric and Honeywell, with the E.U. prohibiting the merger,[30] and the U.S. Department of Justice approving it[31].[32]

Since what drives the variance decision is how μ compares with the threshold, we focus on the case where the information-sharing agreement makes a difference in the firm's choice. This occurs when there is a conflicting merger in the sense that an average merger is good for Country 1 but bad for Country 2, that is, $\widehat{s}_1 < \mu < \widehat{s}_2$.[33]

When the competition authorities do not share information about the firm, the

[27] Another possible justification is that the merger is expected to have different competitive effects, for instance because the market concentration levels or the likelihood of coordinated interaction are different.

[28] To be precise, we need $\frac{a_1}{b_1} > \frac{a_2}{b_2}$.

[29] It is easy to check that the resulting equilibrium threshold under no-commitment is:

$$\widehat{s}_i = \begin{cases} -\mu\frac{V_H}{\eta^2} - \frac{a_i}{b_i}\frac{\eta^2+V_H}{\eta^2} & \text{if } \mu < -\frac{a_i}{b_i} \\ -\mu\frac{V_L}{\eta^2} - \frac{a_i}{b_i}\frac{\eta^2+V_L}{\eta^2} & \text{if } \mu \geq -\frac{a_i}{b_i} \end{cases}$$

Under commitment, if the ratio $\frac{a_1}{b_1}$ is very close to $\frac{a_2}{b_2}$ there may be a region of μ where both authorities will coincide in setting $\widehat{s}_i = \mu$. To focus on the interesting cases, we assume that the welfare functions are different enough so that this does not occur and $\widehat{s}_1 < \widehat{s}_2$ for all μ.

[30] *GE/Honeywell*, Case No COMP/M.2220, European Commission Decision available at http://www.ec.europa.eu/competition/mergers/cases/decisions/m2220_en.pdf

[31] Subject to GE divesting Honeywell's helicopter engine business and licensing a new competitor to maintain and repair certain Honeywell engines.

[32] See Muris (2001) for more detail.

[33] Note that if $\mu < \widehat{s}_1$ (or $\widehat{s}_2 < \mu$), the firm chooses V_H (or V_L) in both countries and the information-sharing agreement makes no difference.

problem of the multinational is separable and we are back to the national merger case. The multinational needs to convince each authority individually, regardless of the way in which authorities reach an agreement ex-post. In other words, he chooses a level of precision for each country so as to maximize the probability of having the merger cleared in each country. By Lemma 1, the firm will choose V_L in Country 1 and V_H in Country 2.

When the authorities share information, they receive the same realization of the signal, thus the problem of the multinational is no longer separable. The multinational needs to choose a unique level of precision so as to maximize the probability of having the merger cleared. This probability will depend on the process by which a final decision on the international merger is reached and we consider several possibilities below. In what follows, we analyze the impact that information-sharing has on the behavior of the firm, keeping the competition authorities policies fixed, that is, we consider the firm's reaction to $(\widehat{s}_1, \widehat{s}_2)$.

4.1 Information-sharing with veto power

Consider first the case where the authorities only cooperate in exchanging information but not in their decision process, i.e. the authorities use their veto power. The only disagreement that can arise is that Country 1 wants to clear the merger, while Country 2 does not want this. Country 2 using its veto power translates into the merger being cleared only if both competition authorities agree that the merger should be cleared (i.e. if the signal is above $\widehat{s}_2$) and as a result the firm chooses V_H.

4.2 Information-sharing with cooperation in the decision-making

We turn now to the case where there is a bargaining or persuasion process taking place between the authorities, for example, due to the repeated interaction between them. We model this decision as taking place in two stages: first, the competition authorities decide unilaterally whether they should clear the merger and, then, if the decisions differ, they discuss their arguments until they reach an agreement.[34] From

[34] For instance, in the WorldCom / Sprint merger review, the co-operation between the Europan Commission and the US Department of Justice involved such an extensive sharing of information (thanks to a confidentiality waiver granted by the parties) that allowed both case teams to discuss in-depth the merits of the case and to reach consistent assessments of the competitive impact of the transaction on the area of joint concern. For this, and many more examples where information-

the point of view of the firm, the outcome of this bargaining is a conflicting merger being cleared with some probability. We consider two ways of how this probability is determined.

4.2.1 Constant probability

We first analyze the case where, if there is disagreement, the merger is cleared with probability α (even though Country 2 does not want this) and blocked with probability $1-\alpha$. The parameter α can be interpreted as a measure of the bargaining power of the authority in Country 1 versus the one in Country 2. M maximizes the probability of having the merger cleared:

$$P^{\alpha}(V) = \alpha \int_{\widehat{s}_1}^{\widehat{s}_2} g(s, V)\, ds + \int_{\widehat{s}_2}^{+\infty} g(s, V)\, ds \tag{3}$$

for $\alpha \in (0, 1)$.

Since μ lies in between the thresholds, the first part of his objective function is decreasing in V, while the second part is increasing in V. In other words, when the firm chooses a high variance, this decreases the mass of the probability distribution of the signal in the interval $[\widehat{s}_1, \widehat{s}_2]$, but at the same time increases the mass in the tails, so the chances that the realization lies in the interval $[\widehat{s}_2, +\infty)$ increase. Sharing information, makes the firm face a new trade-off between choosing V so as to maximize the probability in the interval $[\widehat{s}_1, \widehat{s}_2]$ or in the interval $[\widehat{s}_2, +\infty)$.

Denote the middle point of the interval $[\widehat{s}_1, \widehat{s}_2]$ by $s_M = \frac{\widehat{s}_1 + \widehat{s}_2}{2}$. The behavior of the multinational for $\mu \in [\widehat{s}_1, \widehat{s}_2]$ is summarized in the next Proposition.

Proposition 3 *For $\mu \in [\widehat{s}_1, \widehat{s}_2]$, the choice of variance may be non-monotonic in μ. In particular, for $\mu \in [\widehat{s}_1, s_M)$, M chooses either V_L or V_H. For $\mu \in (s_M, \widehat{s}_2]$, M may choose some intermediate variance $V(\mu, \alpha) = \frac{(\widehat{s}_2 - \mu)^2 - (\mu - \widehat{s}_1)^2}{2 \ln\left(\frac{1-\alpha}{\alpha} \frac{\widehat{s}_2 - \mu}{\mu - \widehat{s}_1}\right)} - \eta^2$ (provided $V(\mu, \alpha) \in (V_L, V_H)$) where $\frac{dV\left(\mu, \frac{1}{2}\right)}{d\mu} < 0$.*

Proof. See Appendix. ■

This result relies on the fact that the curvature of the firm's objective function depends on μ. In particular, the objective function is quasi-convex in V for $\mu \in (\widehat{s}_1, s_M)$ and quasi-concave in V for $\mu \in (s_M, \widehat{s}_2)$.

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sharing has lead to a more active cooperation that have resulted in decisions to clear mergers, see OECD (2001).

Thus, for $\mu \in (\widehat{s}_1, s_M)$, M chooses either V_H for all μ or it starts with V_H and then switches to V_L if the following condition holds:

$$\underbrace{1 - G(\widehat{s}_2; V_H) - (1 - G(\widehat{s}_2; V_L))}_{\text{Relative cost of choosing } V_L} <$$
$$\underbrace{\alpha\left[G(\widehat{s}_2; V_L) - G(\widehat{s}_1; V_L) - (G(\widehat{s}_2; V_H)) - G(\widehat{s}_1; V_H)\right]}_{\text{Expected relative benefit of choosing } V_L}$$

This condition states that, by choosing V_L, as opposed to V_H, M loses chances of being cleared with probability 1 but may increase the chances of being cleared with probability α if μ is close enough to s_M and depending on how far away from μ is the crossing point between $g(s; V_L)$ and $g(s; V_H)$. The switch happens more often when α is larger.

The following two corollaries state the precise variance that the firm chooses, when the authorities have equal bargaining power, that is, for $\alpha = \frac{1}{2}$. Denote $c(V_L, V_H)$ as the distance between μ and the crossing point of $g(s; V_L)$ and $g(s; V_H)$.

Corollary 2 *For $\mu \in (\widehat{s}_1, s_M)$ and $\alpha = \frac{1}{2}$, a sufficient condition for M to choose V_H for any $\mu \in (\widehat{s}_1, s_M)$ is:*

$$\widehat{s}_2 - \mu < c(V_L, V_H)$$

where $c(V_L, V_H)$ increases with V_H and V_L.

There exists a threshold $\overline{\mu}$ such that a sufficient condition for M to first choose V_H until $\mu = \overline{\mu}$ and then switch to V_L for $\mu \in (\overline{\mu}, s_M)$ is:

$$c(V_L, V_H) < \mu - \widehat{s}_1$$

These conditions are not necessary.

Proof. See Appendix. ■

Figure 3 depicts this result.

Note from Corollary 2 that for a given pair of policy thresholds $\{\widehat{s}_1, \widehat{s}_2\}$, the larger V_H, the larger $c(V_L, V_H)$ and hence, the more likely it is that we are in the case where the firm chooses V_H for all $\mu \in (\widehat{s}_1, s_M)$. In the same way, the smaller V_L or the larger the conflict between authorities $(\widehat{s}_2 - \widehat{s}_1)$, the more likely it is that we are in the regime where the firm chooses first V_H and then V_L. Therefore, if the authorities have equal bargaining power and their conflict is large (or it is possible

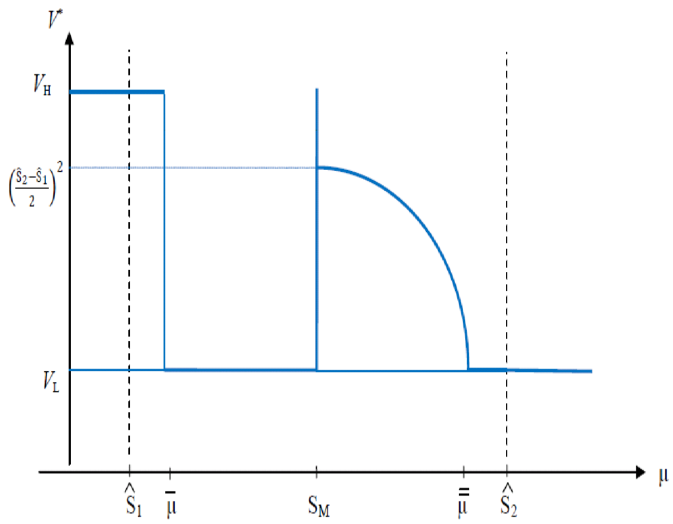

Figure 3: Optimal choice of variance with constant probability

to send very precise reports), the choice of the variance for the conflicting mergers is non-monotonic in the average merger. This non-monotonicity is the result of the trade-off between maximizing the probability at the interval $[\widehat{s}_1, \widehat{s}_2]$ or at the interval $[\widehat{s}_2, +\infty)$.

The intuition behind the choice of variance is the following. For the average merger μ between $\widehat{s}_1$ and s_M, the objective function is quasi-convex in V. Therefore, the firm chooses an extreme variance. First consider the average merger at the left endpoint, $\mu = \widehat{s}_1$. For this μ, the probability that the realization of the signal is above $\widehat{s}_1$ is $\frac{1}{2}$ for all the values of V. However, the larger the variance, the higher the probability of obtaining a realization above $\widehat{s}_2$ where the merger is cleared with probability 1 rather than $\frac{1}{2}$. Therefore, he will choose V_H. By continuity, the same intuition holds for the average mergers that are in between $\widehat{s}_1$ and $\overline{\mu}$, where $\overline{\mu}$ is defined in equation (13). If the minimum variance is low enough (or the conflict between authorities is high enough), then it is optimal for the firm to switch to V_L after $\overline{\mu}$ in order to maximize the chances of being cleared at least by Country 1. It is at this point that the new trade-off becomes effective.

The firm with an average merger just in the middle, $\mu = s_M$, is indifferent between any variance. The reason for this is that the probability of having the merger cleared is $\frac{1}{2}$ for all possible values of V due to the symmetry of the probability function at this point.

As μ exceeds s_M, the objective function of the firm becomes quasi-concave in V.

Because of the proximity of μ with the interval $[\widehat{s}_2, +\infty)$, it becomes safer to play a riskier strategy by increasing V (without reaching the maximum level). Finally, as μ keeps increasing towards $\widehat{s}_2$, the value of this optimal intermediate variance decreases.[35] This is because the chances of having the realization in the interval $[\widehat{s}_1, +\infty)$ are already high and, by reducing the variance, the probability of having the realization in the tail $(-\infty, \widehat{s}_1)$ is decreased. The variance decreases until it hits the minimum level at $\overline{\overline{\mu}}$.[36]

Finally, when the average merger is at the right endpoint, $\mu = \widehat{s}_2$, the probability of having a realization of the signal below $\widehat{s}_2$ is $\frac{1}{2}$; however the higher the variance, the higher the probability that the realization of the signal is below $\widehat{s}_1$ where the merger is blocked, rather than cleared with probability $\frac{1}{2}$. As a result, the firm chooses V_L.

The information-sharing agreement has modified the payoff structure, which is no longer "bang-bang" as in Section 3. As a result, the firm makes a greater use of intermediate levels of variability in a non-monotonic way.

4.2.2 Increasing probability

Now we consider the case where the bargaining power of Country 1 increases monotonically with the particular realization s. This reflects the fact that the closer s is to $\widehat{s}_2$, the less reluctant will Country 2 be about clearing the merger as compared to a realization s very close to $\widehat{s}_1$. We consider the case of a continuous, increasing and odd (with respect $\left(s_M, \frac{1}{2}\right)$) function $\rho(s)$. The expected probability of clearance then becomes:

$$P^c(V) = \int_{\widehat{s}_1}^{\widehat{s}_2} \rho(s) g(s, V) ds + \int_{\widehat{s}_2}^{+\infty} g(s, V) ds$$

Contrary to the previous case, now increasing the variance does not unambiguously decrease the probability of being cleared if the realization s falls in the interval $(\widehat{s}_1, \widehat{s}_2)$ because these realizations have attached different probabilities of clearance.

[35] Note that:

$$\frac{dV\left(\mu, \frac{1}{2}\right)}{d\mu} = \frac{-(\widehat{s}_2 - \widehat{s}_1)\left[2\ln x - x + \frac{1}{x}\right]}{2(\ln x)^2}$$

where $x = \frac{\widehat{s}_2 - \mu}{\mu - \widehat{s}_1}$. Since we focus on $\mu \in (s_M, \widehat{s}_2]$, then $0 < x < 1$ and $\frac{dV\left(\mu, \frac{1}{2}\right)}{d\mu} < 0$.

[36] Since M would like to choose a variance at $\widehat{s}_2$ equal to $-\eta^2$, there exists $\overline{\overline{\mu}}$ such that:

$$V\left(\overline{\overline{\mu}}, \frac{1}{2}\right) = \frac{(\widehat{s}_2 - \overline{\overline{\mu}})^2 - (\overline{\overline{\mu}} - \widehat{s}_1)^2}{2\ln\left(\frac{\widehat{s}_2 - \overline{\overline{\mu}}}{\overline{\overline{\mu}} - \widehat{s}_1}\right)} - \eta^2 = V_L$$

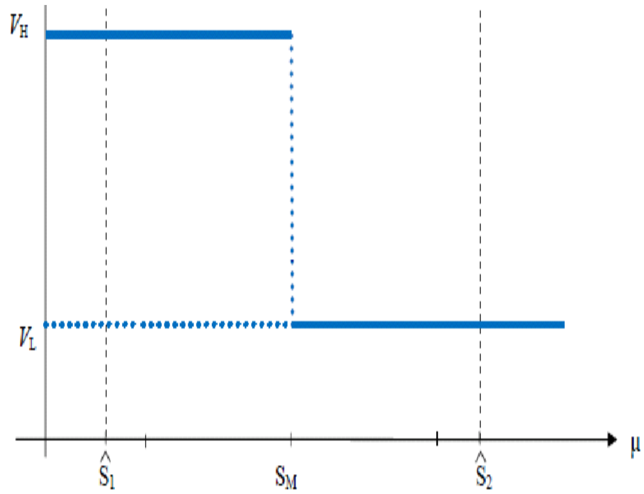

Figure 4: Optimal choice of variance with increasing probability

Proposition 4 *The optimal variance chosen by M is:*

$$V^*(\mu, s_M) = \begin{cases} V_H \text{ if } \mu < s_M \\ V_L \text{ if } \mu > s_M \end{cases}$$

If $\mu = s_M$*, then M is indifferent between any variance in* $[V_L, V_H]$*.*

Proof. See Appendix. ■

See Figure 4. When μ is below s_M, increasing the variance increases the probability of falling above $\widehat{s}_2$ and decreases the probability of having realizations in the first half of $[\widehat{s}_1, \widehat{s}_2]$, where the probability of clearance is very low anyway. This makes increasing the variance less damaging, so the firm chooses V_H. Instead, when μ is above s_M, increasing the variance decreases the probability of having realizations in the second half of $[\widehat{s}_1, \widehat{s}_2]$, where the probability of clearance is large and increasing, so the firm chooses V_L as a result. From the point of view of the firm, it is as if there were a unique threshold but there is uncertainty about where exactly this lies. Because of the symmetry of $\rho(s)$ around $\left(s_M, \frac{1}{2}\right)$, the firm takes the expectation and behaves as in the national merger case with respect to this unique threshold. That is, the firm uses high variance whenever he thinks the merger is not going to pass through ($\mu < s_M$) and low variance otherwise.

4.3 Information-sharing with cooperation in the policy-making

So far, we have assumed that each authority is fixing its policy threshold unilaterally. In this section, we consider the situation where the authorities fix a unique threshold, $\widehat{s}^J$, for both countries, for instance, in the European case, this would correspond to the European Commission setting a common policy. This policy will be chosen so that their joint ex-post welfare is maximized:

$$W(s,\widehat{s}^J)\mid_{s=s(\widehat{s}^c)}=\gamma\left[a_1+b_1\left(\frac{s\eta^2+\mu V^*(\mu,s)}{\eta^2+V^*(\mu,s)}\right)\right]+(1-\gamma)\left[a_2+b_2\left(\frac{s\eta^2+\mu V^*(\mu,s)}{\eta^2+V^*(\mu,s)}\right)\right]$$

where γ and $1-\gamma$ are the weights given to the welfare of Country 1 and 2, respectively. It is easy to check that, given the firm's behavior in Lemma 1, the optimal threshold is:

$$\widehat{s}^J=\begin{cases}-\mu\frac{V_H}{\eta^2}-\frac{\gamma a_1+(1-\gamma)a_2}{\gamma b_1+(1-\gamma)b_2}\frac{\eta^2+V_H}{\eta^2} & \text{if } \mu<-\frac{\gamma a_1+(1-\gamma)a_2}{\gamma b_1+(1-\gamma)b_2}\\ -\mu\frac{V_L}{\eta^2}-\frac{\gamma a_1+(1-\gamma)a_2}{\gamma b_1+(1-\gamma)b_2}\frac{\eta^2+V_L}{\eta^2} & \text{if } \mu\geq-\frac{\gamma a_1+(1-\gamma)a_2}{\gamma b_1+(1-\gamma)b_2}\end{cases}$$

4.4 Discussion

It stands from the previous analysis that if the competition authorities have veto power over the decision, then sharing information is never beneficial as Country 1 is strictly worse off due to the imprecise submitted information (while Country 2 is indifferent).

If the authorities also cooperate in the decision taking stage, then whether sharing information is desirable ultimately depends on the average merger that the authorities are facing and on the particular rule used to reach a decision. To illustrate this point, imagine that the merger's welfare consequences in Country 1 are $3+\theta$ while in Country 2 are θ. Imagine that the firm can choose a variance on the range $[2,10]$ and that $\eta^2=4$.

If the ex-ante average merger is $\mu=-0.5$, then the authorities would set the national thresholds $\widehat{s}_1=-2$ and $\widehat{s}_2=1.25$, so in the absence of information-sharing, the firm chooses variance 2 for Country 1 and variance 10 for Country 2. Imagine now that the authorities share information and the persuasion process is such that the probability of clearance in case of disagreement is constant and equal to 0.5. Then, given that $s_M=-1.5$, the firm chooses an intermediate variance equal to 3.22 and the ex-ante expected welfare is 1.822 and 0.058 for Country 1 and 2, respectively. Instead, if the probability of clearance is increasing and linear $\left(\rho(s)=\frac{s-s_1}{s_2-s_1}\right)$, the firm chooses a variance of 2 and the expected welfare of Country 1 and 2 are 2.088 and 0.193, respectively. Therefore, the authorities are better-off if their bargaining process is such that the probability of clearing a conflicting merger is increasing and linear. Obviously, the lowest joint expected welfare is obtained when the countries have veto power (1.404) and the largest when the authorities coordinate on the policy threshold (2.540, with $\gamma = 0.5$) where $\widehat{s}^J = -2$ and the firm uses variance 2.

Let us consider instead an ex-ante average merger $\mu = -2$. The thresholds set by the authorities are $\widehat{s}_1 = -3.5$ and $\widehat{s}_2 = 5$. Since $s_M = 0.75$, in the constant probability case the firm chooses minimum variance (condition (11) is satisfied) and expected welfare of Country 1 and 2 are 0.641 and -0.456, respectively. If instead the probability of clearance is linear, then the firm choose variance 10 and ex-ante expected welfare are 0.567 and -0.251. Hence, the authorities are jointly better off with the constant probability case. Again, the lowest expected welfare is under the veto regime (0.117) and the highest under the coordination of policies (0.445) where $\widehat{s}^J = -0.25$ and the firm chooses variance 10.

We have not considered how $\widehat{s}_1$ and $\widehat{s}_2$ adjust to take into account the international dimension of the problem. If the authorities were only facing conflicting international mergers and could not commit to a policy then Country 1 would like to set $\widehat{s}_1 = -\infty$ while Country 2 $\widehat{s}_2 = +\infty$, to counteract the other country's interference. Since, authorities also apply their policies to national mergers, this extreme decisions would not be optimal. It is left for future work to explore how the international dimension impacts on the policies to which the countries commit to.

5 Private information about the welfare effects[37]

In this Section, we explore the robustness of our results in the assumption that the firm is not more informed than the competition authority about the merger's welfare effects.

If we assume that θ is the private information of the firm then, qualitatively, the firm's behavior does not change. The optimal variance chosen by the firm will depend on the merger's type θ in the same way that it was depending before on the average merger μ. In particular, in the case of the national merger, a firm with a bad merger will choose the risky strategy of high variance, while a firm with a good merger will choose low variance to increase the likelihood of obtaining a high

[37]The proofs for this section can be found in Troya-Martinez (2008).

realization of the signal. In the same way, in the case of the multinational merger, the information-sharing agreement will have no impact on the types of merger that are either good or bad for both countries at the same time. However, for those firms whose merger is good for one country but bad for the other, the choice of the variance may be non-monotonic in their type in the same way as was found in Proposition 3.

However, with this new assumption, there is a significant change in the authority's behavior because the monotone likelihood ratio property (MLRP) does not generally hold, due to the way in which the firm optimally responds to the threshold rule. In particular, a very large s is more likely to come from a (bad) merger below the threshold because the distribution of the signal sent by such a merger has fatter tails. If the MLRP does not hold, then the cut-off rule may not be optimal. However, if we nonetheless restrict the authority to using the cut-off rule, then we can show that the equilibrium threshold, when the average merger is welfare detrimental, is stricter than the full information threshold and, contrary to what we found in Section 3, it does not change with the authority's ability to commit.

The intuition for this result is as follows. There are two types of effects following an increase in the commitment threshold, $\widehat{s}^{**}$: the direct and the strategic effect. The direct effect is the result from the trade-off between the benefit of decreasing the clearance probability of a bad merger against the cost of decreasing the clearance probability of a good merger. The direct benefit can be interpreted as a type II error of clearing a merger that should be blocked. By increasing $\widehat{s}^{**}$ we make this error less likely. Similarly, the direct cost can be interpreted as a type I error of blocking a merger when in fact it should be allowed and by increasing $\widehat{s}^{**}$ we make this error more likely.

The strategic (or indirect) effect is the result of the change in the firm's strategy resulting from moving merger types from above to below the threshold (i.e. when the firm switches from V_L to V_H, a good type θ has less chances of being cleared). Given that the authority values precision, as this allows her to take more informed decisions, the fact that in this new framework she chooses the same threshold regardless of whether or not she can commit to a policy may be puzzling. It seems natural to think that the mechanism highlighted in the Corollary 1 would still apply (that is, if under no commitment, the authority sets a threshold $\widehat{s}^{*}$, she would gain from committing to a lower threshold $\widehat{s}^{**}$ as this would induce the types in the interval $[\widehat{s}^{**}, \widehat{s}^{*}]$ to reduce their equilibrium variance from V_H to V_L). However, when the authority is considering a marginal decrease in the threshold, she only takes into account the strategic effects of the marginal type $\widehat{s}^*$ which consists in decreasing the variance from V_H to V_L. However, for $\widehat{s}^*$ (the type at the margin) the probability that the realization of the signal is above $\widehat{s}^*$ is $\frac{1}{2}$ in both cases. Therefore, since the marginal change in the firm's behavior generated by the ability to commit cancels out, the criterion used to set such a threshold is the same under both regimes. In particular, by lowering the threshold, the authority only trades off the increase in the type II error and the decrease in the type I error (i.e. the direct effect).

6 Conclusions

The goal of this paper has been to study the impact of an information-sharing agreement on the incentives of the firm to provide precise information to the authorities. We find that the agreement has no impact on the firm with an average merger that is welfare enhancing for both countries at the same time. This would explain why in some cases, where the firm is sure that a merger does not raise competition issues, he voluntarily grants a confidentiality waiver to the authorities. However, the agreement affects the behavior of the firm whose average merger is welfare enhancing for one country but welfare detrimental for the other. The impact in terms of information provision will depend on how authorities reach an agreement in the case of disagreement.

If there is no further cooperation and authorities exert their veto power, then the firm sends very imprecise information to both authorities. If the authorities cooperate further, and if they have equal bargaining power, then the choice of the variance may be non-monotonic in the average merger. Furthermore, despite the choice of variance being costless, intermediate levels of precision are chosen in equilibrium. Finally, if the probability is increasing on the particular report then the firm behaves as in the national merger case where the new cut-off rule is the expectation of the countries' rules.

Given their policies, do the agencies benefit from the agreement? The authorities value the level of precision because this allows them to make more accurate decisions; therefore, sharing information but retaining their veto power makes the authorities strictly worse off. If there is further cooperation, the firm makes more use of intermediate and lower variances. Therefore, only the less lenient country benefits from the agreement because, before, she was receiving information with the minimum level of precision. The more lenient country will not benefit from the agreement because, without the agreement, she was receiving the information with the maximum level of precision. However, if the lenient country is not always the same one, information-sharing and cooperation can potentially be beneficial.

In our analysis, we ignore a very important cost attached to the exchange of confidential information: the danger of leakage of commercially sensitive information to third parties. This can be clearly an issue when cooperation involves competition agencies in countries where the law for protecting confidential information is weak or where the credibility of the agency is low. We also ignore many benefits. For instance, the exchange of information facilitates the discussion about the case and minimizes the possibility of missing an issue that needs an enforcement action. In the merger cases, it also eliminates conflicting decisions and remedies.[38]

A possible way to enrich the setup is to let each authority receive a different realization from the same random signal[39]. In this context, sharing information increases the quantity of information on which to base their decisions and allows them to better infer the level of precision used by the firm. Thus, noise becomes more costly and firms with bad average mergers will have their behavior affected. There is room for the more lenient authority to benefit from the agreement.

We compared the no-information-sharing regime with the information-sharing regime, keeping the policies of the competition authorities fixed, as we were interested in exploring the changes in the firm's behavior following the agreement. The other motivation for proceeding this way was that these agreements do not usually contemplate changes in policies. Therefore, one possible direction of future work would be to enrich the model by allowing the competition agencies to strategically adapt their policies to the new regime. This would allow us to assess the total impact of the information-sharing regime, which not only includes the change in the firm's behavior but also the change in the authority's policy.

Finally, the lessons from this model can be applied to a variety of situations in industrial organization and political economy that involve binary decisions. For instance, the model can apply to the information submitted to a sectorial regulator or central bank and a competition authority (as is the case with the mergers involving

[38] A successful example of a merger involving cooperation between agencies that illustrates these points was the Holnam/Lafarge case. A waiver granted by the parties allowed the U.S. and Canadian agencies to effectively improve the coordination, which ended up in a more informed decision-making (see Valentine (2000)).

[39] This could be the case if information-sharing happens at a late state of the investigation process, where the different signal's realisations can be interpreted as the information obtained from the particular questions (interviews, questionnaires, etc.) carried out by each authority.

banks), to interviews in a recruitment process with two interviewers, to a project approval by different departments within a firm, to reforms submitted to bicameral parliaments or, more generally, to a politician trying to gain support for a policy in front of two audiences with different opinions about the policy.

7 Appendix

Example 1 *Assume that R commits to clear the merger with probability $Z(s)$, where $Z(s)$ is the cumulative distribution of $z(s) \sim N(m, v)$ and m and v are optimally chosen by R. M chooses V to maximize the probability of clearance:*

$$\underset{V}{Max} \int_{-\infty}^{+\infty} Z(s) g(s, V) ds$$

The first order condition is:

$$\begin{aligned} \frac{\partial}{\partial V} &= \int_{-\infty}^{+\infty} Z(s) \frac{\partial g(s, V)}{\partial V} ds \\ &= -\frac{1}{2} \frac{\partial r(m)}{\partial m} \end{aligned}$$

where the second line follows from integrating by parts and $r(m) \sim N(\mu, v + \eta^2 + V)$. Hence we observe the same behavior as in Section 3.1.1: if $\mu < m$, $\frac{\partial}{\partial V} > 0$ and so the optimal variance is V_H; if $\mu = m$, $\frac{\partial}{\partial V} = 0$ and M is indifferent between any variance and if $m < \mu$, $\frac{\partial}{\partial V} < 0$ and so M chooses V_L. Since the behavior of the firm only depends on how m compares to μ (i.e. it is independent of v), R chooses the ex-post optimal v, that is $v = 0$. It is then easy to show that the optimal m is equal to the cut-off $\widehat{s}^{**}$ found in Proposition 2.

Proof of Lemma 1. The first derivative of $P(V)$ with respect to V is:

$$\frac{\partial P(V)}{\partial V} = \int_{\widehat{s}^c}^{+\infty} \frac{\partial g(s, V)}{\partial V} ds \tag{4}$$

Using the fact that $\frac{\partial g(s,V)}{\partial V} = \frac{1}{2} \frac{\partial^2 g(s,V)}{\partial s^2}$, we can integrate (4) to obtain:

$$\frac{\partial P(V)}{\partial V} = \frac{\partial g(\widehat{s}^c, V)}{\partial s}$$

The optimal V is determined by the slope of $g(s,V)$ at the conjectured policy parameter, which give us Lemma 1. ■

Proof of Proposition 2. The logic of the proof is as follows. We first solve the authority's problem ignoring the constraint about the firm's behavior. Then, we find under which conditions the constraint will be binding.

Ignoring the constraint; the first order condition for a given variance $V^*(\mu,\widehat{s})$ is:

$$\frac{\partial EW(\widehat{s})}{\partial \widehat{s}} = -\frac{\widehat{s}\eta^2 + \mu V^*(\mu,\widehat{s})}{\eta^2 + V^*(\mu,\widehat{s})} g\left(\widehat{s}, V^*\left(\mu,\widehat{s}\right)\right) = 0 \tag{5}$$

And the second order condition is:

$$\begin{aligned}\frac{\partial^2 EW(\widehat{s})}{\partial \widehat{s}^2} &= \frac{\widehat{s}\eta^2 + \mu V^*(\mu,\widehat{s})}{\eta^2 + V^*(\mu,\widehat{s})} g\left(\widehat{s}, V^*\left(\mu,\widehat{s}\right)\right) \frac{\widehat{s}-\mu}{\eta^2+V} \\ &\quad -\frac{\eta^2}{\eta^2 + V^*(\mu,\widehat{s})} g\left(\widehat{s}, V^*\left(\mu,\widehat{s}\right)\right) < 0\end{aligned}$$

The second order condition is locally satisfied because the first term is zero when the first order condition is satisfied and the second term is always negative.

Note that (5) is zero only if $\widehat{s}\eta^2 + \mu V^*(\mu,\widehat{s}) = 0$, hence $\widehat{s}^{**} = \widehat{s}^*$. When $\mu > \widehat{s}$, by Lemma 1, the firm chooses V_L. The signal has the maximum level of informativeness, therefore the constraint in (2) does not bind and the solution is equal to $\widehat{s}^*$. Conversely, when $\mu < \widehat{s}$, the firm chooses V_H and R may prefer the constrained solution $\widehat{s}^{**} = \mu$ (by Lemma 1, this is the minimum threshold that induces the firm to choose V_L instead of V_H) due to the resulting increase in the informativeness of the signal. In particular, the constrained solution will be chosen if the authority's objective function evaluated at this point is larger than evaluated at $\widehat{s}^*$:

$$\int_{\frac{-\mu V_H}{\eta^2}}^{+\infty} \frac{s\eta^2 + \mu V_H}{\eta^2 + V_H} g\left(s, V_H\right) ds < \int_{\mu}^{+\infty} \frac{s\eta^2 + \mu V_L}{\eta^2 + V_L} g\left(s, V_L\right) ds \tag{6}$$

Let us show that (6) is satisfied for $\mu > \widetilde{\mu}$ and not satisfied for $\mu < \widetilde{\mu}$, where $\widetilde{\mu}$ is to be defined. Integrating by parts, rewrite (6) as:

$$\mu\left[\frac{1}{2} - G\left(\frac{-\mu V_H}{\eta^2}, V_H\right)\right] < \eta^2\left[\frac{1}{\sqrt{2\pi(\eta^2+V_L)}} - g\left(\frac{-\mu V_H}{\eta^2}, V_H\right)\right]$$

We want to determine whether there exists some value of μ in the interval $(-\infty, 0]$ for which (6) is satisfied. Note that (6) is trivially satisfied when $\mu = 0$ as the left-hand side is zero and $g(0,V_L) - g(0,V_H) > 0$. Conversely, when $\mu \to -\infty$, the left-hand side tends to $+\infty$ while the right-hand side tends to $\frac{\eta^2}{\sqrt{2\pi(\eta^2+V_L)}}$. Therefore the inequality is violated. This means that there exists at least one value of μ, $\widetilde{\mu}$, such that the expected welfare are equal:

$$\int_{\frac{-\widetilde{\mu}V_H}{\eta^2}}^{+\infty} \frac{s\eta^2 + \widetilde{\mu}V_H}{\eta^2 + V_H} g(s,V_H)ds = \int_{\widetilde{\mu}}^{+\infty} \frac{s\eta^2 + \widetilde{\mu}V_L}{\eta^2 + V_L} g(s,V_L)ds \tag{7}$$

Note that $\widetilde{\mu} \neq 0$. In order to show that this value is unique, we need to show that the slope of the difference of expected welfare is strictly decreasing at $\mu = \widetilde{\mu}$:

$$\left.\frac{\partial\left(\mu\left[\frac{1}{2} - G\left(\frac{-\mu V_H}{\eta^2}, V_H\right)\right] - \eta^2\left[\frac{1}{\sqrt{2\pi(\eta^2+V_L)}} - g\left(\frac{-\mu V_H}{\eta^2}, V_H\right)\right]\right)}{\partial\mu}\right|_{\mu=\widetilde{\mu}}$$

$$\begin{aligned}
&= \frac{1}{2} - G\left(\frac{-\mu V_H}{\eta^2}, V_H\right) - \mu g\left(\frac{-\mu V_H}{\eta^2}, V_H\right)\left[\frac{-V_H}{\eta^2} - 1\right] + \\
&\quad \eta^2 g\left(\frac{-\mu V_H}{\eta^2}, V_H\right)\left[\frac{-V_H}{\eta^2}\frac{\left(-\left(\frac{-\mu V_H}{\eta^2} - \mu\right)\right)}{\eta^2 + V_H} + \frac{\left(\frac{-\mu V_H}{\eta^2} - \mu\right)}{\eta^2 + V_H}\right] \\
&= \frac{1}{2} - G\left(\frac{-\mu V_H}{\eta^2}, V_H\right) < 0
\end{aligned}$$

This expression is negative for $\widetilde{\mu} < 0$, therefore there is a unique $\widetilde{\mu}$ for which condition (7) holds.

The comparative statics with respect to V_L:

$$\frac{d\widetilde{\mu}}{dV_L} = \frac{\eta^2}{\left[G\left(\frac{-\widetilde{\mu}V_H}{\eta^2}, V_H\right) - \frac{1}{2}\right] 2(\eta^2 + V_L)\sqrt{2\pi(\eta^2 + V_L)}} > 0$$

and with respect to V_H:

$$\frac{d\widetilde{\mu}}{dV_H} = \frac{g\left(\frac{-\widetilde{\mu}V_H}{\eta^2}, V_H\right)\left[\frac{\widetilde{\mu}^2 2\left(\eta^2+V_H\right)+\eta^4}{2\eta^2(\eta^2+V_H)}\right]}{\frac{1}{2} - G\left(\frac{-\widetilde{\mu}V_H}{\eta^2}, V_H\right)} < 0$$

noting that $\widetilde{\mu} < 0$ and that therefore $G\left(\frac{-\widetilde{\mu}V_H}{\eta^2}, V_H\right) - \frac{1}{2} > 0$ give us the signs. ■

Proof of Proposition 3. We compute the first and the second order conditions and show that $P^\alpha(V)$ is quasi-convex until $\mu = s_M$ and then quasi-concave. The first derivative of $P^{\alpha}(V)$ with respect to V is:

$$\frac{\partial P^{\alpha}(V)}{\partial V}=-\frac{1}{2}\left(\alpha\frac{\partial g(\widehat{s}_1,V)}{\partial s}+(1-\alpha)\frac{\partial g(\widehat{s}_2,V)}{\partial s}\right)$$

where $g(s,V)$ is always non-decreasing at $\widehat{s}_1$ and non-increasing at $\widehat{s}_2$. When $\mu=s_M$, then:[40]

$$\frac{\partial P^{\alpha}(V)}{\partial V}=\frac{\widehat{s}_2-\widehat{s}_1}{4(\eta^2+V)}g(\widehat{s}_2,V)\left[1-2\alpha\right]$$

so the sign will depend on α.

From $\frac{\partial P^{\alpha}(V)}{\partial V}=0$, we find the "critical variance":

$$V(\mu,\alpha)=\frac{(\widehat{s}_2-\mu)^2-(\mu-\widehat{s}_1)^2}{2\ln\left(\frac{(1-\alpha)(\widehat{s}_2-\mu)}{\alpha(\mu-\widehat{s}_1)}\right)}-\eta^2 \tag{8}$$

The second derivative is:

$$\begin{aligned}\frac{\partial^2 P^{\alpha}(V)}{\partial V^2} &= \frac{\alpha\frac{\partial g(\widehat{s}_1,V)}{\partial V}(s1-\mu)+(1-\alpha)\frac{\partial g(\widehat{s}_2,V)}{\partial V}(s2-\mu)}{2(\eta^2+V)}\\ &\quad-\frac{\alpha g(\widehat{s}_1,V)(s1-\mu)+(1-\alpha)g(\widehat{s}_2,V)(s2-\mu)}{2(\eta^2+V)^2}\end{aligned}$$

which evaluated at the first order condition, give us:

$$\begin{aligned}\left.\frac{\partial^2 P^{\alpha}(V)}{\partial V^2}\right|_{\frac{\partial P^{\alpha}(V)}{\partial V}=0} &= \frac{\alpha g(\widehat{s}_1,V)(\widehat{s}_1-\mu)^3+(1-\alpha)g(\widehat{s}_2,V)(\widehat{s}_2-\mu)^3}{(\eta^2+V)^2}\\ &\propto (1-\alpha)(\widehat{s}_2-\mu)^3\left(\frac{1-\alpha}{\alpha}\frac{\widehat{s}_2-\mu}{\mu-\widehat{s}_1}\right)^{\frac{-(\widehat{s}_2-\mu)^2}{(\widehat{s}_2-\mu)^2-(\mu-\widehat{s}_1)^2}}\\ &\quad-\alpha(\mu-\widehat{s}_1)^3\left(\frac{1-\alpha}{\alpha}\frac{\widehat{s}_2-\mu}{\mu-\widehat{s}_1}\right)^{\frac{-(\mu-\widehat{s}_1)^2}{(\widehat{s}_2-\mu)^2-(\mu-\widehat{s}_1)^2}}\end{aligned} \tag{9}$$

where the last line follows from plugging in $V(\mu,\alpha)$ from (8). The sign of (9) depends on how $\left(\frac{\widehat{s}_2-\mu}{\mu-\widehat{s}_1}\right)^3$ compares to $\frac{\widehat{s}_2-\mu}{\mu-\widehat{s}_1}$. When $\mu=s_M$, both $\left(\frac{\widehat{s}_2-\mu}{\mu-\widehat{s}_1}\right)^3$ and $\frac{\widehat{s}_2-\mu}{\mu-\widehat{s}_1}$ are equal to one, hence (9) is zero. When $\mu\in(\widehat{s}_1,s_M)$, $\frac{\widehat{s}_2-\mu}{\mu-\widehat{s}_1}$ is $\left(\frac{\widehat{s}_2-\mu}{\mu-\widehat{s}_1}\right)^3$, therefore, (9) is positive. Conversely, when $\mu\in(s_M,\widehat{s}_2)$, $\frac{\widehat{s}_2-\mu}{\mu-\widehat{s}_1}$ is larger and, thus, (9) is negative. ■

Proof of Corollary 2. First note that for $\alpha=\frac{1}{2}$, (3) can be rewritten as:

$$P^{\frac{1}{2}}(V)=1-\frac{1}{2}\left[G\left(\widehat{s}_1,V\right)+G\left(\widehat{s}_2,V\right)\right]$$

[40]Note that: $g(\widehat{s}_2,V)=g(\widehat{s}_1,V)$ when $\mu=s_M$.

From Proposition 3, if $\mu \in (\widehat{s}_1, s_M)$, the optimal variance is either maximum or minimum variance. In particular, M chooses V_L whenever:

$$G(\widehat{s}_1, V_H) + G(\widehat{s}_2, V_H) > G(\widehat{s}_1, V_L) + G(\widehat{s}_2, V_L) \tag{10}$$

Using the symmetry of $g(s, V)$ around μ, (10) becomes:

$$G(\widehat{s}_1, V_H) - G(2\mu - \widehat{s}_2, V_H) > G(\widehat{s}_1, V_L) - G(2\mu - \widehat{s}_2, V_L) \tag{11}$$

Note that $2\mu - \widehat{s}_2 \leq \widehat{s}_1$ for all $\mu \in (\widehat{s}_1, s_M)$.

Define $\widetilde{s}$ as the smallest value of s at which $g(s, V_H)$ and $g(s, V_L)$ intersect:

$$\widetilde{s} = \mu - \sqrt{\frac{(V_L + \eta^2)(V_H + \eta^2)}{V_H - V_L} \ln\left(\frac{V_H + \eta^2}{V_L + \eta^2}\right)} \tag{12}$$

Rewrite $\widetilde{s}$ as $\widetilde{s} = \mu - c(V_L, V_H)$. It can be shown that $c(V_L, V_H)$ increases with V_H and decreases when V_L decrease.

We are only able to determine M's choices when $\widetilde{s} < 2\mu - \widehat{s}_2$ and when $\widehat{s}_1 < \widetilde{s}$; therefore, the conditions that follow are sufficient but not necessary.[41]

V_H will be chosen for all $\mu \in (\widehat{s}_1, s_M)$ if $\widetilde{s} < 2\mu - \widehat{s}_2$ as the area under $g(s, V_H)$ is unambiguously smaller than under $g(s, V_L)$ for the relevant range of integration (from $2\mu - \widehat{s}_2$ to $\widehat{s}_1$). See Figure 5 for an example. This condition implies:

$$\widehat{s}_2 - \mu < c(V_L, V_H)$$

V_L will be chosen if $\widehat{s}_1 < \widetilde{s}$, or equivalently, if:

$$c(V_L, V_H) < \mu - \widehat{s}_1.$$

Since $c(V_L, V_H) > 0$, this condition cannot hold for the smallest possible μ (i.e. $\widehat{s}_1$ in the limit); thus, when μ is close to $\widehat{s}_1$ M always chooses V_H. By continuity, there is a value $\overline{\mu}$ such that the firm is indifferent between V_H and V_L:

$$G(\widehat{s}_1, V_H) - G(2\overline{\mu} - \widehat{s}_2, V_H) = G(\widehat{s}_1, V_L) - G(2\overline{\mu} - \widehat{s}_2, V_L) \tag{13}$$

[41] If $\widetilde{s} \in (2\mu - \widehat{s}_2, \widehat{s}_1)$, we cannot say how the area under $g(s, V_H)$ compares to the area under $g(s, V_L)$ for the relevant range of integration.

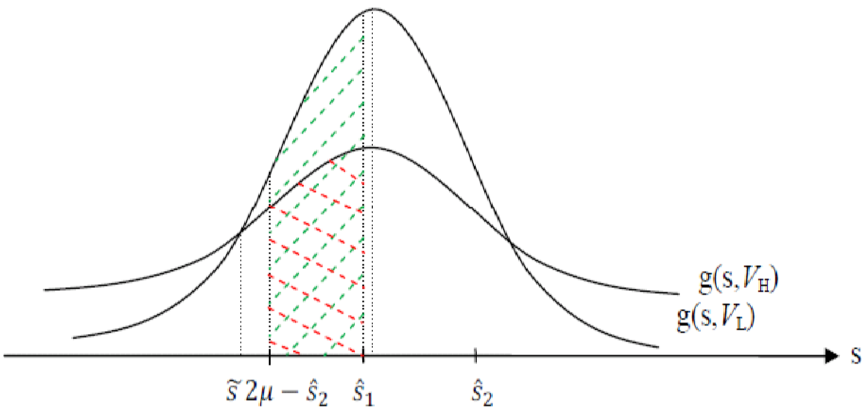

Figure 5: $\mu = \widehat{s}_1 + \Delta$ and $\widetilde{s} < 2\mu - \widehat{s}_2$

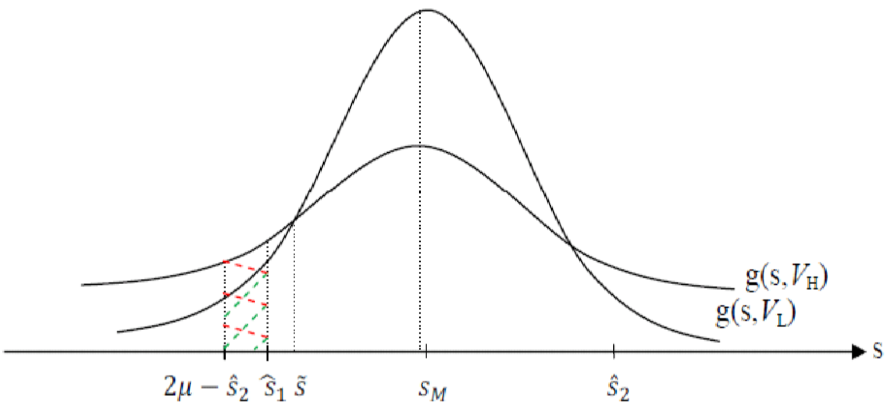

Figure 6: $\mu = s_M - \Delta$ and $\widehat{s}_1 < \widetilde{s}$

Figure 6 depicts an example and shows how the area under $g(s, V_H)$ is always larger than under $g(s, V_L)$ for the relevant range of integration.

Figure 7 depicts the parameter space for which we can determine M's choices. In the are with triangles, M chooses V_H, in the area with inverted triangles, M chooses V_L and finally in the shaded area, M will choose either V_H or V_L, but it is not possible to draw the exact choice boundary analytically. ■

Proof of Proposition 4. Note that, using the continuity of $\rho(s)$, we can rewrite the objective function as: $P^c(V) = 1 - \int_{\widehat{s}_1}^{\widehat{s}_2} \rho'(s) \int_{-\infty}^{s} g(\widetilde{s}, V) d\widetilde{s} ds$. Then, the first derivative

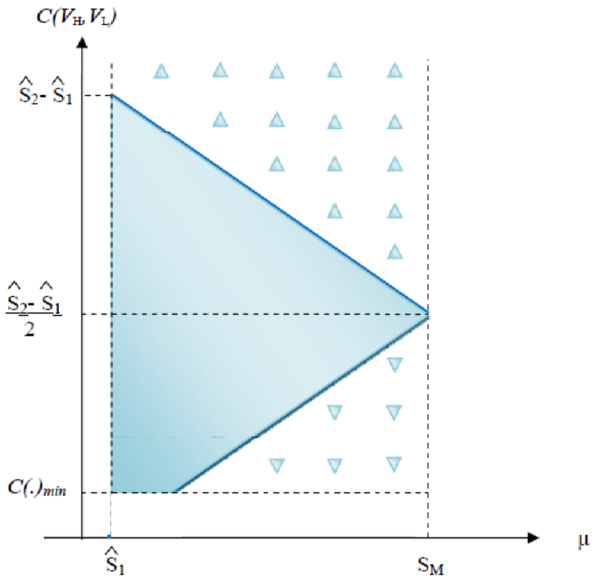

Figure 7: Choice of variance

is:

$$\frac{\partial P^c(V)}{\partial V} = -\int_{\widehat{s}_1}^{\widehat{s}_2} \rho'(s) \int_{-\infty}^{s} \frac{\partial g(\widetilde{s}, V)}{\partial V} d\widetilde{s} ds$$

$$= -\frac{1}{2}\int_{\widehat{s}_1}^{\widehat{s}_2} \rho'(s) \frac{\partial g(s, V)}{\partial s} ds$$

Since $\rho(s)$ has a rotational symmetry with respect to $\left(s_M, \frac{1}{2}\right)$, $\rho(s)+\rho(2s_M-s) = 1\forall s$ and $\rho'(s) = \rho'(2s_M - s)\forall s$, where $\rho'(s)$ is even and positive. Using the second line, we can show that:

- If $\mu = s_M$ then $\frac{\partial P^c(V)}{\partial V} = 0$. This is because $\rho'(s)$ is even (and hence symmetric around s_M) and positive and $g'(s)$ is odd with s_M as the origin.
- If $\mu = \widehat{s}_1$ then $\frac{\partial P^c(V)}{\partial V} > 0$. This is because $\rho'(s)$ is positive and $g'(s) \leq 0\forall s\,[\widehat{s}_1, \widehat{s}_2]$.
- If $\mu = \widehat{s}_2$ then $\frac{\partial P^c(V)}{\partial V} < 0$. This is because $\rho'(s)$ is positive and $g'(s) \geq 0\forall s\,[\widehat{s}_1, \widehat{s}_2]$.

Now we need to prove that $\frac{\partial^2 P^c(V)}{\partial V \partial \mu} < 0 \forall \mu$.

$$\begin{aligned}
\frac{\partial^2 P^c(V)}{\partial V \partial \mu} &= -\frac{1}{2}\int_{s_1}^{s_2} \rho'(s) \frac{\partial^2 g(s,V)}{\partial s \partial \mu} ds \\
&= \frac{1}{2}\int_{s_1}^{s_2} \rho'(s) \frac{\partial^2 g(s,V)}{\partial s^2} ds
\end{aligned}$$

since $\rho'(s)$ is positive, a sufficient condition for $\frac{\partial^2 P^c(V)}{\partial V \partial \mu} < 0$ is $\frac{\partial^2 g(s,V)}{\partial s^2} < 0$, which happens when $\mu - \sqrt{\eta^2 + V} < \{s_1, s_2\} < \mu + \sqrt{\eta^2 + V}$. The requirement of and to be close together is by no means necessary. For instance, it is easy to check that if $\rho(s) = \frac{s - \widehat{s}_1}{\widehat{s}_2 - \widehat{s}_1}$, $\frac{\partial^2 P}{\partial V \partial \mu} < 0 \forall \{s_1, s_2\}$. Example 1 provides another instance where $s_1 = -\infty$ and $s_2 = +\infty$. ■

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