Antidumping as a signaling device under the WTO's ADA non-disclosure clause

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Abstract. Under the WTO Antidumping Agreement (ADA) non-disclosure clause, the investigating AD authority cannot disclose the confidential information it obtains. This paper analyzes how non-disclosure of confidential information leads the government to use the magnitude of the AD duty to signal this information, in casu the costs of the firm under investigation, to the domestic industry. We obtain three main results: First the AD authority sets lower tariffs compared the full information because it has an incentive to signal that the foreign firm is less efficient. Second, signaling is welfare decreasing relative to full disclosure. Third, a weakly (strongly) efficient foreign firm ends up investing more (less) in R&D than under full disclosure when it anticipates the signaling motives of the AD authority.

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1 Introduction

The WTO Antidumping Agreement (ADA)[1] stipulates the **non-disclosure of confidential information** by the antidumping (AD) authority. Article 6.5 of the ADA states that:

Any information which is by nature confidential (for example, because its disclosure would be of significant competitive advantage to a competitor or because its disclosure would have a significantly adverse effect upon a person supplying the information or upon a person from whom that person acquired the information), or which is provided on a confidential basis by parties to an investigation shall, upon good cause shown, be treated as such by the authorities. Such information shall not be disclosed without specific permission of the party submitting it.

The justification for confidentiality in AD investigations is that they require sensitive business information to be submitted to the importing country's AD authority, especially regarding pricing and costing. Of course, exporting firms under investigation will show great reluctance to provide such information if it will fall in the hands of their competitors. On the other hand, correct information is crucial to conduct an AD investigation properly and fairly. Article 6.5 attempts to strike a balance to between these two opposing forces[2].

Over the past two decades the non-disclosure clause has received hefty criticism, especially when AD authorities have substantial discretion to decide which information is confidential. Horlick and Vermulst (2005) point out that one of the major problems with the WTO provisions is that it deprives interested parties from a meaningful way to defend their interests, because too much information is in practice treated as confidential. These concerns seem to be particularly acute in the way the European Union applies the non-disclosure clause[3]. Horlick and Vermulst (2005) propose a shift to the system of disclosure of confidential information under Administrative Protective Order (APO) as practiced in the United States and Canada. As described by King (2009), under the APO the lawyers of the parties can have access to confidential disclosure. However, the APO obligations include non-disclosure of confidential information by lawyers to the interested parties and the destruction of such information within a specified time period. If the confidentiality is misused, then the APO provides sanctions depending on the seriousness of the violation.

This paper draws attention to a potentially overlooked drawback of strictly adhering to the non-disclosure clause. When the AD authority is bound not to disclose business sensitive information (e.g. cost information) regarding the exporting firm, it may nonetheless be tempted to signal this information indirectly to the domestic import competing industry by letting the AD duty depend on the non-disclosed information. We develop a simple model to analyze the incentives of the AD authority to use antidumping policy as a signaling device to reveal sensitive information, in this case marginal cost information, of the foreign exporter to its domestic import competing industry. Our model first develops the following questions: Will an AD authority that cares about domestic welfare reveal the non-disclosed information about the foreign, and if so, how will it do so? Would domestic welfare be higher in the absence of the non-disclosure clause?

We show that different AD duties are set under a non-disclosure regime compared to the full disclosure case. This is done by showing the existence and uniqueness of a separating equilibrium as set out by Mailath (1987). In this equilibrium the antidumping duty is biased downward as the AD authority is tempted to have the home firm believe that the foreign firm is relatively inefficient. Importantly we show that signaling leads to a welfare loss: eliminating

[1]On the implementation of Article VI of GATT 1994.

[2]This argument is elaborated in UNCTAD 2006: http://unctad.org/en/Docs/ditctncd20046_en.pdf

[3]See for instance the position paper by the Foreign Trade Association (2015).

the non-disclosure clause from the ADA increases total surplus in the Home country, as the AD authority no longer needs to distort its AD duties to signal information to the Home firm.

We then extend our model to study how the signaling behavior of the AD authority affects (dynamic) investment decisions of foreign exporters. In sectors in which technology changes rapidly, firms tend to have incomplete information about the level of technology used by their rivals. Niels (2000) states that R&D intensive sectors are often subject to AD duties, and hence AD policy is expected to impact R&D investment decisions of exporting firms. In the model, the foreign firm engages in process-improving R&D before it is subject to an AD duty under the non-disclosure clause, as described above. We show that, when AD action is used as a signaling device, a relatively (in) efficient foreign firm, endowed with a low R&D investment cost, will end-up investing (more) less in R&D relative to the case of perfect information.

In an attempt to keep the model simple and to focus purely on the signaling potential of AD duties, we assume that the AD authorities impose duties solely based on the knowledge that the foreign firm has invested in cost reducing R&D. In other words, duties are imposed based on a *threat of material injury*. While this assumption helps us to keep the results tractable, we also emphasize that it is in line with WTO ADA Article VI[4]. Its Article 1 reads: *The contracting parties recognize that dumping, by which products of one country are introduced into the commerce of another country at less than the normal value of the product, is to be condemned if it causes or* ***threatens material injury*** *to an established industry in the territory of a contracting party or materially retards the establishment of a domestic industry.* (emphasis added). Interestingly activating AD measures based on a threat of injury in not just a theoretical and legal possibility. In its 2016 Notice of initiation of and AD proceeding concerning imports of certain hot-rolled flat products of iron, non-alloy and other alloy steel originating in the People's Republic of China (2016/C 58/08), the European Commission took action precisely based on the threat of injury.[5]

To the best of our knowledge, this paper is the first to propose the idea that antidumping policy could be used as a signaling device to reveal information about the cost efficiency of a foreign firm. That being said, our methodology relies on and our results are related to several strands of the strategic trade literature.

Using a tariff or subsidy under incomplete information as a signaling device has already been studied extensively in the context of strategic trade policy by Collie and Hviid (1993, 1994, 1999a and 1999b). The first part of our paper is in particular close to Collie and Hviid (1999a) in which the domestic government can use a tariff to signal about the costs of the domestic firm, which are unknown to the foreign firm. They arrive at the counterintuitive result that the government sets a lower tariff than is optimal under complete information[6]. In our model the information asymmetry is reversed, but interestingly, we arrive at the more intuitive result that the government wants to signal that the foreign firm is relatively inefficient, implying a lower injury margin and hence calling for a lower AD tariff.[7][8] The second part of our paper goes beyond Collie and Hviid (1999a) by endogenizing the efficiency level of the foreign firm through R&D investment.

[4]The WTO ADA is available on www.wto.org.

[5]"*As regards the investigation launched on hot-rolled flat steel today, the Commission decided to take action on the basis of a "threat of injury", rather than waiting for such injury to materialize. This is an early preventive action which is in itself an exceptional step in trade defense proceedings. The European Commission decided to* ***activate*** *this instrument since the complaint presented by the industry contained sufficient evidence to meet the legal demands" (emphasis added).*

[6]As the authors explain, one may have expected that governments want to lower the tariff to signal that their import competing domestic firm is efficient and does not need to be protected that much.

[7]In addition, we provide an explicit solution for the separating AD-duty in the case of signaling.

[8]In addition we find that, in the case of full disclosure, the optimal tariff depends on the marginal cost of the foreign firm, while in the model Collie and Hviid (1999a), the optimal tariff in the case of full information does not depend on the level of efficiency of the home firm.

Kolev and Prusa (2002) or Collie and Vandenbussche (2004) have used the notion of the AD authority imposing a duty resulting from maximizing a social welfare function, but none have considered the home government having an information advantage over the home firm.

The analysis of a foreign firm signaling its level of technology has been covered by Miyagiwa and Ohno (2007), in which they provide a rational for dumping. They explore how an innovative foreign firm may need to export larger than normal quantities to signal its cost after adopting a new technology. Indeed, since the home firm does not have complete information about the level of R&D, the foreign firm may export larger than normal volumes to signal its efficiency. They also examine the effects of an AD policy, which reduces the cost of signaling but does not prevent dumping from occurring. This paper is different in at least two ways. First, it examines another channel through which the cost of the foreign firm is signaled to the home firm. Second, AD policy and the incentive for the foreign firm to invest in R&D are endogenized, which is not the case in Miyagiwa and Ohno (2007).

There is an extensive literature that studies the effects of AD policy on the incentive to engage in process improving R&D. Miyagiwa and Ohno (1995) have analyzed the link between permanent and temporary protection and the speed at which the protected firm adopts the new technology. Gao and Miyagiwa (2005) develop a model based on that of Anderson, Schmitt and Thisse (1995) and find that when a single government uses AD policy, then the protected firm decreases investment while the constrained firm invests more. When both governments engage in AD actions, then both firms invest more in R&D. Miyagiwa, Song and Vandenbussche (2016) extend the previous model to take into consideration country heterogeneity in intellectual property right (IPR) enforcements. They provide a more general result and demonstrate that AD policy used by countries with a strong IPR enforcement would be detrimental to R&D, however when a strong country uses AD against a country that violates IPRs, then it can spur R&D for its protected firm. Unfortunately, the present model only takes into consideration R&D by a foreign firm and in this respect does not conclude anything about the incentive of the home firm to invest in R&D. The scenario in our model joins the spirit of Miyagiwa and Ohno (1995) in which the foreign firm a leader in investing in R&D. This paper provides a new insight and provides an explanation as to why a relatively efficient foreign firm, endowed with a low R&D investment cost, will end-up investing less in R&D and conversely, an inefficient firm will invest more in R&D relative to the case of full disclosure.

The rest of the paper is organized as follows. Section 2 introduces the theoretical framework. Section 3 studies the AD game under non-disclosure and under full information and compares the equilibria of these two regimes. Section 4 analyzes the R&D investment decision of the foreign firm in both regimes. Section 5 concludes.

2 The theoretical framework

2.1 General structure

Consider a three period model with two countries, foreign (F) and home (H), each hosting one firm. In the first period the foreign firm has the opportunity to invest in cost reducing R&D. In the second period, Home's AD authority launches an AD investigation and decides on an AD tariff based on the knowledge that the foreign firm engaged in cost reducing R&D in period 1. In the third period, the firms produce a homogenous good and compete as Cournot duopolists in the domestic market. At the beginning of the game both firms have a marginal cost equal to $c > 0$. We now discuss these three periods in more detail.

2.1.1 Period 1: process improving R&D

Following the foreign firm's process-improving R&D investment, its marginal cost at the end of period 1 is given by $c - k \geqslant 0$, where we label k to be the level of technological efficiency. Importantly, the level k is known to the foreign firm but not to the home firm, so the foreign firm's marginal cost, $c-k$, is unknown to the home firm. Following d'Aspremont and Jacquemin (1988), Miyagiwa and Gao (2005) and Miyagiwa, Song and Vandenbussche (2016), the R&D cost takes the following quadratic form:

$$C(k) = \frac{\gamma}{2}k^2 \tag{1}$$

The home firm is not aware about the actual level of parameter γ, but knows that it is continuously distributed on the interval $[\gamma_L, \gamma_H]$. It is assumed that $\gamma > 0$ and is large enough so that $k \leqslant c$. As will be shown, the foreign firm will choose k to maximize its profit taking into consideration the cost of R&D as given by (1) . The optimal level of k thus depends entirely on γ, through a function $k(\gamma)$. Let $\underline{\gamma}$ be the critical value such that $\gamma \geqslant \underline{\gamma}$ implies $c - k \geqslant 0$.

2.1.2 Period 2: determination of AD duty

In the first period, the foreign firm is aware of the potential threat its R&D investment implies on the home market. It also understands the home government's rent extracting and profit shifting incentives for implementing an AD policy where lower cost firms are subject to higher AD duties as pointed out by the strategic trade policy literature (Brander and Spencer 1984). Since we abstract from modeling the local market of the foreign firm, the AD authority will follow the normal value approach[9] in order to determine injury and the AD-tariff. As explained in the introduction we assume that the home government launches an AD investigation solely based on the threat of injury. The ADA provides enough scope for the government to determine injury within the framework of this model[10]. Clearly, investments in a process improving R&D can constitute a real threat from the point of view of the WTO legislation. It is assumed that the normal value, denoted by p^* is exogenously fixed by the government and is sufficiently high to generate a positive dumping margin given by $p^* - p(Q)$ where $p(Q)$ is the home market price. The value p^* is common knowledge to all. When it launches an investigation the AD authority gathers confidential information, becomes perfectly informed about k and takes this into consideration when determining the duty.

[9] A product is considered to be sold at less than normal value if the price of the product exported from one country to another:

- *is less than the comparable price, in the ordinary course of trade, for the like product when destined for consumption in the exporting country, or,*
- *in the absence of such domestic price, is less than either*
  1. *the highest comparable price for the like product for export to any third country in the ordinary course of trade, or*
  2. *the cost of production of the product in the country of origin plus a reasonable addition for selling cost and profit.*

[10] Article 3.4 says: *The examination of the impact of the dumped imports on the domestic industry concerned shall include an evaluation of all relevant economic factors and indices having a bearing on the state of the industry, including actual and **potential** decline in sales, profits, output, market share, productivity, return on investments, utilization of capacity; factors affecting domestic prices; the magnitude of the margin of dumping; actual and **potential** negative effects on cash flow, inventories, employment, wages, growth, ability to raise capital or investments. This list is not exhaustive, nor can one or several of these factors necessarily give decisive guidance.* (emphasis added)

That being said, injury alone is not enough to administer AD protection. One also needs to show causality[11]. Following jurisprudence and an substantial part of the economics literature on AD we assume that causality always holds. The European Commission, for example, states on page 20 of its guide on how to draft an antidumping complaint[12] that *"Causality is usually shown by the coincidence in time of increasing imports at decreasing prices..."*

Since the normal value is high enough so that $p^* - p(Q) > 0$ and that R&D constitutes a real threat to the home firm, the government will administer protection. Indeed, since dumping always exists, an increase in R&D investment will at the same time increase import volumes and lower prices in the market, aggravating both dumping and injury simultaneously. This requires the government to make a prospective determination, requiring a forward-looking analysis. This is perfectly possible as mentioned in Article 9. which recognizes both retrospective and prospective assessments. Finally, bare in mind that the government is not forced to impose a duty equal to the dumping margin.[13] Our model follows Kolev and Prusa (2002) and Collie and Vandenbussche (2004) in which the government chooses a per-unit AD duty to maximize total welfare[14]. In a separating AD tariff equilibrium, the duty will be a function of the level of R&D investment of the foreign firm: $t(k)$.

2.1.3 Period 3: product market competition

In the third period, after the duty t has been observed and if the home firm correctly anticipates the equilibrium strategy of the government, $t(k)$, it will use this information to update its beliefs about the new marginal cost of the foreign firm, $c - k$. Then the two firms, independently and simultaneously, make their output decisions to maximize profits. The inverse demand in the home market is given by:

$$p(Q) = \alpha - Q, \tag{2}$$

where α is a strictly positive demand parameter with $\alpha > c$. $Q = q_H + q_F$ is the total output, where q_H and q_F are the home and foreign production levels respectively.

2.1.4 AD duties and government welfare

Following Kolev and Prusa (2002) and Collie and Vandenbussche (2004), the government will choose a per-unit AD duty, t to maximize its objective function given by the sum of the consumer surplus, the home firm's profit and the tariff revenue:

$$G(t) = \int_0^Q (\alpha - q)dq - p(Q)Q + \pi_H + t\, q_F, \tag{3}$$

where π_H denotes the profit of the home firm and $t\, q_F$ the revenue collected from the duty.

[11]Causality means that dumping be shown to have caused injury. Hindley (2009) with respect to the WTO ADA states that: *An antidumping authority that has proved to its own satisfaction that dumping has occurred, and that has demonstrated that the national industry competing with those imports displays symptoms of injury, may doubt the need for rigorous enquiry into the cause of the injury. Had the dumped product been sold at higher prices, the domestic industry would have been able to sell more, or sell at a higher price or both. IsnÕt it obvious that dumping injures the industry? Such thoughts may lead to lackadaisical cause-of-injury investigations.*

[12]The guide is available in all official languages of the European Community on the Commission's trade website: http://trade.ec.europa.eu/doclib/docs/2006/december/tradoc_112295.pdf

[13]Article 9.1 states that:*...the decision whether the amount of the anti dumping duty to be imposed shall be the full margin of dumping or less, are decisions to be made by the authorities of the importing Member.* In fact, countries may include WTO-plus provisions in their decision. For example, the European Union has two: the lesser duty and community interest. The former results in a duty below the dumping margin if it is adequate to remove injury and the latter recognizes the interests of consumers when imposing a duty.

[14]For the model to be consistent, we assume p^* is high enough to ensure that $t \leqslant p^* - p(Q)$.

We use backward induction to obtain a perfect Bayesian-Nash equilibrium. We first study our benchmark case in which AD policy is set under the current ADA non-disclosure regime. We show the existence and uniqueness of a separating equilibrium and study its properties. We also consider the alternative scenario in which there is full disclosure and compare both scenarios, focusing on the impact on welfare. We then study optimal technology adoption by the foreign firm under both complete and incomplete information. It will be shown that a relatively (in) efficient foreign firm, endowed with a low R&D investment cost, will end-up investing (more) less in R&D relative to the case of perfect information.

3 Antidumping Policy

In this section we establish the existence, uniqueness and characterization of a separating AD-tariff equilibrium, $t(k)$, both under non-disclosure of information and under full information.

3.1 Product competition equilibrium

We start by analyzing the product competition stage assuming that, after observing the antidumping duty t, the home firm perfectly anticipates k. The profits are given by

$$\pi_H = (\alpha - q_H - q_F - c)q_H; \tag{4}$$
$$\pi_F = (\alpha - q_H - q_F - c + k - t)q_F. \tag{5}$$

Profit maximization implies

$$\partial\pi_H/\partial q_H = \alpha - 2q_H - q_F - c = 0; \tag{6}$$
$$\partial\pi_F/\partial q_F = \alpha - q_H - 2q_F - c + k - t = 0. \tag{7}$$

Solving for q_H and q_F yields equilibrium outputs

$$q_H = \begin{cases} 0 & \text{if } t \leqslant k - (\alpha - c); \\ \frac{\alpha - c - k + t}{3} & \text{if } k - (\alpha - c) < t < t^p; \\ \frac{\alpha - c}{2} & \text{if } t \geqslant t^p, \end{cases} \tag{8}$$

and

$$q_F = \begin{cases} \frac{\alpha - c + k - t}{2} & \text{if } t \leqslant k - (\alpha - c); \\ \frac{\alpha - c + 2(k - t)}{3} & \text{if } k - (\alpha - c) < t < t^p; \\ 0 & \text{if } t \geqslant t^p, \end{cases} \tag{9}$$

where t^p is the prohibitive tariff beyond which the foreign firm is not active;

$$t^p = \frac{\alpha - c + 2k}{2}. \tag{10}$$

Starting from the top equations of (8) and (9) note that period 3 has three possible outcomes: (i) unconstrained foreign monopoly, (ii) Cournot duopoly and (iii) unconstrained home monopoly. The home firm becomes a monopolist if the foreign firm faces a prohibitive duty, i.e.

$t \geqslant t^p$. The foreign firm becomes a monopolist whenever $t \leqslant k - (\alpha - c)$. We consider that it is always possible that the foreign technology becomes so efficient that it drives the home firm out of the market.[15]

Using the equilibrium outputs (8) and (9) in the demand function given by (2) yields the market price

$$p(Q) = \begin{cases} \frac{\alpha+c+t-k}{2} & \text{iff } t \leqslant k-(\alpha-c); \\ \frac{\alpha+2c+t-k}{3} & \text{iff } k-(\alpha-c) < t < t^p; \\ \frac{\alpha+c}{2} & \text{iff } t \geqslant t^p. \end{cases} \tag{11}$$

Two effects are important to consider. First, note from equations (8) and (11) that although an AD duty increases the market share of firm H, the increase is not sufficient to benefit consumers, resulting in an increase in the market price. Second, R&D investments decrease the market price. So, even though R&D is considered a threat to firm H, it improves consumer surplus. This remains true even if the foreign firm monopolizes the market. Finally, profits are given by $\pi_F = (q_F)^2$ and $\pi_H = (q_H)^2$.

3.2 The signaling equilibrium

This section derives the optimal AD duty under incomplete information about k. In order to do so, we follow closely the method used in Collie and Hviid (1999a). Denote by $\hat{k(t)} = E\left[k \mid t\right]$ the home firm's belief about k when it observes t. Then the Bayesian Nash equilibrium outputs (see appendix A) are given by:

$$q_H = \frac{\alpha - c + t - \hat{k}(t)}{3}; \tag{12}$$

and

$$q_{F_2} = \frac{\alpha - c + 2(k-t)}{3} + \frac{\hat{k}(t) - k}{6}. \tag{13}$$

Note from that the prohibitive tariff, t^p, is equal to

$$t^p = \frac{\alpha - c + 2k}{2} + \frac{\hat{k}(t) - k}{4}, \tag{14}$$

and is equal to the prohibitive duty given by (10) when $\hat{k}(t) = k$. The government's objective function is obtained by substituting the Bayesian-Nash outputs and the home profit into (3). Thus the government surplus in case of non-disclosure ('ND'), labeled $G^{ND}(t)$, can be written as

$$G^{ND}(t) = \frac{1}{2}\left[\frac{4(\alpha-c)+3k-\hat{k}(t)-2t}{6}\right]^2 + \left(\frac{\alpha+t-c-\hat{k}(t)}{3}\right)^2 + t\left[\frac{\alpha-c+2(k-t)}{3} - \frac{k-\hat{k}(t)}{6}\right]. \tag{15}$$

[15]This assumption does not change the qualitative results of our paper. The only reason for insisting on this assumption is that it leads to an explicit solution of the separating equilibrium, which would otherwise be impossible to compute analytically. Bear in mind however, that even if an explicit solution cannot be found, one can easily perform a qualitative analysis as proposed by Collie and Hviid (1993, 1994, 1999a, 1999b) and appreciate that all the intuitions go through.

We now consider the existence of a unique separating equilibrium. Mailath (1987) has shown that there exists a unique signaling equilibrium in games of incomplete information with a continuum of types when the signaling agent's payoff function (i.e. the government's objective function) satisfies the regularity conditions *belief monotonicity*, *type monotonicity*, and the *single crossing*. These conditions are shown to hold in Appendix B.

To derive the separating equilibrium of this game with incomplete information, let the AD duty in the separating equilibrium be given by $t^* = \phi(k)$;

$$\phi(k) = \underset{t}{\text{argmax}} \; G^{ND}(t), \tag{16}$$

where $\phi(k)$ is a differentiable one to one function of the R&D process improving marginal cost k. In a separating equilibrium, incentive compatibly requires that the government maximizes G given beliefs consistency: $k = \hat{k}(t) = \phi^{-1}(t)$. As a result, maximizing the objective function (15) where the beliefs of the home firm are given $\hat{k}(t) = \phi(t)^{-1}$ with respect to the AD duty t, leads to the incentive compatibility condition

$$dG^{ND}(t)/dt = \partial G^{ND}(t)/\partial t + \left(\partial G^{ND}(t)/\partial \hat{k}(t)\right) d\phi^{-1}(t)/dt = 0. \tag{17}$$

The first term reflects the welfare effect under perfect information and the second effect is the signaling impact of the duty. If $\phi^{-1}(t)/dt > 0$, the home firm's belief, $\hat{k}(t)$, increases with t and the signaling effect is negative. For incentive compatibility to hold, it must be that $\partial G^{ND}(t)/\partial t > 0$, which means that the government will impose a lower duty than is optimal under perfect information. On the other hand, if $\phi^{-1}(t)/dt < 0$, $\hat{k}(t)$ decreases with t and the signaling effect becomes positive. Incentive compatibility implies that $\partial G^{ND}(t)/\partial t < 0$, leading to the imposition of a higher duty than under perfect information. Rearranging equation (17) and using $k = \hat{k}(t)$, the incentive compatibility condition that yields the separating equilibrium AD duty, $t^* = \phi(k)$, can be expressed as follows:

$$\begin{aligned} \frac{d\phi(k)}{dk} &= \frac{-\partial G^{ND}(t)/\partial \hat{k}(t)}{\partial G^{ND}(t)/\partial t} \\ &= \frac{4(\alpha - c) - 2k}{4(\alpha - c - 3t + k)}. \end{aligned} \tag{18}$$

It turns out that there is no explicit solution to the differential equation given in (18). To get a better sense of what the solution might look like we perform a geometrical analysis akin to the one of Collie and Hviid (1993, 1994, 1999a, 1999b). What is different, however, from Collie and Hviid's analysis is that we can derive an explicit solution from the graphical analysis (see appendix C):

$$t^*(k) = \begin{cases} \frac{(1+\sqrt{7})k - 2(\sqrt{7}-2)(\alpha - c)}{6} & \text{iff } k < 2(\alpha - c); \\ \frac{\alpha - c + k}{3} & \text{iff } k \geqslant 2(\alpha - c). \end{cases} \tag{19}$$

Note that the optimal duty $t^*(k)$ has a kink at $k = 2(\alpha - c)$.[16]

3.3 Optimal duty under full disclosure

We now study optimal AD tariff setting when the process improving R&D undertaken by the foreign firm is common knowledge. Thus, whenever, $k > 0$, the home firm is entitled to invoke

[16]Note that t^* is never prohibitive since $t^* \leqslant t^p$ is always satisfied. The prohibitive duty is given by equation (19), with $\hat{k}(t) = k$ at equilibrium.

AD action. The government determines the optimal AD duty to be imposed by maximizing its objective function. The objective function $G^D(t)$ of the government under a disclosure regime is obtained by substituting the optimal quantities and home profit into equation (3). Thus the government's maximization problem is given by:

$$\max_t G^D(t) = \begin{cases} G_1^D(t) = \frac{1}{2}\left(\frac{\alpha-c+k-t}{2}\right)^2 + t\frac{\alpha-c+k-t}{2} & \text{if } t \leqslant k-(\alpha-c); \\ G_2^D(t) = \frac{1}{2}\left[\frac{2(\alpha-c)+k-t}{3}\right]^2 + \left(\frac{\alpha-c+t-k}{3}\right)^2 & \\ \quad & \text{if } k-(\alpha-c) < t < t^p; \\ + \; t\frac{\alpha-c+2(k-t)}{3} & \\ G_3^D(t) = \frac{1}{2}\left(\frac{\alpha-c}{2}\right)^2 & \text{if } t \geqslant t^p. \end{cases} \tag{20}$$

As it turns out, the first order conditions of the top and middle equation, referred to as $G_1^D(t)$ and $G_2^D(t)$ respectively, are equal and given by:

$$\partial G_1^D(t)/\partial t = \partial G_2^D(t)/\partial t = \frac{\alpha-c+k-3t}{3} = 0. \tag{21}$$

Furthermore since $G_1^D(t)$ and $G_2^D(t)$ are both concave, solving for t leads to the optimal AD duty under complete information, t^o, is given by

$$t^o = \frac{\alpha-c+k}{3}, \tag{22}$$

which shows that the optimal AD duty is an increasing function of k. It remains to check however, that it is never optimal for the government to impose a prohibitive duty t^p. Indeed, it can easily be checked that $t^o < t^p$ is always satisfied.

Thus, using t^o in (8) and (9), the equilibrium outputs are given by

$$q_H = \begin{cases} 0 & \text{if } k \geqslant 2(\alpha-c); \\ \frac{4(\alpha-c)-2k}{9} & \text{if } k < 2(\alpha-c), \end{cases} \tag{23}$$

and

$$q_F = \begin{cases} \frac{\alpha-c+k}{3} & \text{if } k \geqslant 2(\alpha-c); \\ \frac{\alpha-c+4k}{9} & \text{if } k < 2(\alpha-c). \end{cases} \tag{24}$$

3.4 Non-disclosure vs disclosure

From the results of the previous two subsections it is immediate that the AD duty under the non-disclosure regime is (weakly) below the duty under the full information regime: $t^*(k) < t^o(k)$ for all $k \geqslant 2(\alpha-c)$ and $t^*(k) = t^o(k)$ for all $k < 2(\alpha-c)$. The home AD authority has an incentive to impose a lower AD duty than under complete information so that the home firm would believe the foreign firm is less efficient (has invested less in R&D). Our first take away is thus:

Proposition 1. *The WTO AD agreement stipulates the non disclosure of confidential information. Under such a rule, the home government cannot disclose the marginal cost of the foreign firm to the home industry, but it does so indirectly through signaling. In the separating equilibrium, the domestic government signals the "un"competitiveness of the foreign firm by setting a lower antidumping duty than is optimal under complete information.*

As can be seen from equation (19) the incentive to signal the 'un'competitiveness of the foreign firm decreases as k becomes larger. In fact, when k is large enough for F to monopolize the market, then the government has no incentive to signal, because once the home firm is out, then there is no a need for the government to use AD policy as a signaling device and thus imposes the same duty as under complete information.

Given that we were able to explicitly solve for the signaling equilibrium we can analyze the welfare effects of the non-disclosure of confidential information clause. It is well known from Spence (1973) that signaling leads to social waste, since its only purpose is to facilitate separation of types under incomplete information. Under full disclosure, the AD authority does not need to distort its AD tariffs in order to signal marginal cost information to is domestic import competing firm. If the domestic firm gains knowledge of k, whether this happens through full disclosure or through signaling, the optimal thing to do for the government is to impose a welfare maximizing duty equal to t^D. If in the signaling equilibrium t^* is lower than t^D, $\forall\ k < 2(\alpha - c)$, then this leads to lower welfare than under perfect information.[17] This reasoning leads our second take away:

Proposition 2. *The non-disclosure clause in the WTO antidumping agreement leads the home government to use antidumping as a signaling device inducing a welfare loss.*

4 Effects of antidumping policy on R&D

4.1 First period R&D investment

This section analyses the incentives to invest in R&D under full disclosure and non-disclosure of confidential information. Moving to the first period, the foreign firm engages in R&D investment to maximize:

$$\max_k \ \Pi_F = \pi_F - \frac{\gamma}{2}k^2 = \left[\frac{\alpha - c + 2(k-t)}{3}\right]^2 - \frac{\gamma}{2}k^2 \tag{25}$$

where $t \in \{t^o, t^*\}$ is the optimal AD duty, and (19) for the non-disclosure case and by (22) for the full information case.

From the FOC of the profit maximizing R&D problem we obtain:

$$\frac{\partial \Pi_F}{\partial k} = 0 \Leftrightarrow (\alpha - c - 2t)\left(1 - \frac{\partial t}{\partial k}\right) + \left[2\left(1 - \frac{\partial t}{\partial k}\right) - \gamma\right]k = 0. \tag{26}$$

Comparing the first order conditions for the signaling and full disclosure case reveals the different incentives at play when determining k. This boils down to studying the duty level (t)

[17]To appreciate this result, note that the AD duty under perfect information is welfare maximizing because:

$$t^D = argmax_t G(t) \Leftrightarrow \partial G(t)/\partial t\ |_{t=t^D} = 0.$$

In the signaling equilibrium, i.e. for any $t^*(k)$ *such that* $k < 2(\alpha - c)$, the welfare is strictly lower since:

$$t^* < t^D \Leftrightarrow \partial G(t)/\partial t\ |_{t=t^*} > 0$$

and its derivative given by $(\partial t/\partial k)$. We already established that $t^* < (=)\ t^o$ for all levels of $k < (\geqslant)\ 2(\alpha - c)$, leading the first term of expression (26) to be higher in the case of non-disclosure. *Ceteris paribus*, a lower duty under the signaling equilibrium leads the foreign firm to invest in more in R&D. On the other hand, the duty under incomplete information signals the uncompetitiveness of the foreign firm and all other things being equal, the foreign firm will invest less in R&D.

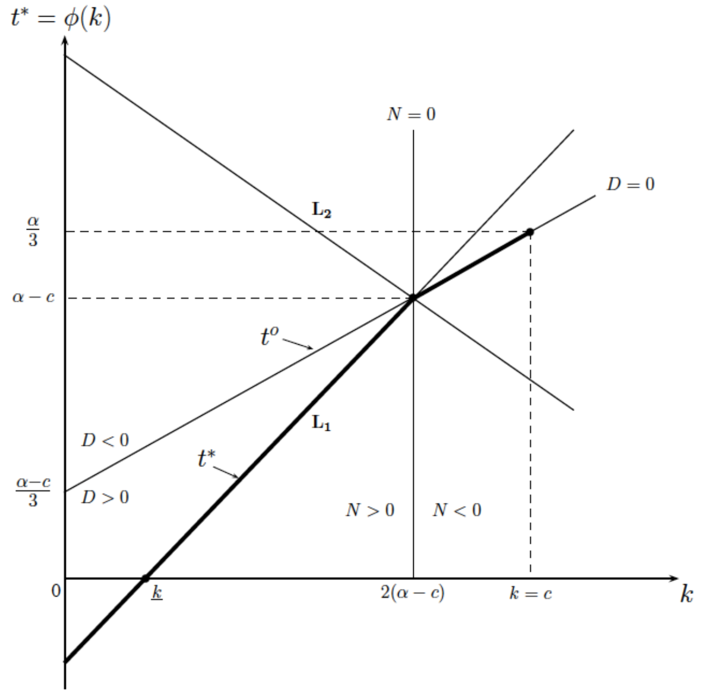

Figure 1: The separating equilibrium.

This can be appreciated by comparing the slopes of t^o and t^* in figure 1 and by noting from expression (26) that a higher slope leads the foreign firm to invest less in R&D.

4.2 R&D investment under non-disclosure clause vs full information.

Under antidumping policy and signaling, the maximization problem of the foreign firm is given by (25) with $t = t^*$. The equilibrium R&D level is given by (see Appendix D)

$$k^* = \begin{cases} \frac{2\left(11\sqrt{7}-19\right)(\alpha-c)}{81\gamma+4\left(5\sqrt{7}-16\right)} & \text{if } \gamma > \frac{5-\sqrt{7}}{9}; \\ 2(\alpha - c) & \text{if } \frac{1}{3} \leqslant \gamma \leqslant \frac{5-\sqrt{7}}{9}; \\ \frac{2(\alpha-c)}{9\gamma-2} & \text{if } \underline{\gamma} \leqslant \gamma < \frac{1}{3}, \end{cases} \tag{27}$$

where $\underline{\gamma} = \frac{2\alpha}{9c}$. Under antidumping policy and complete information, the maximization problem of the foreign firm is given by (25) with $t = t^o$. The equilibrium R&D level is given by (see

Appendix E)

$$k^o = \begin{cases} \frac{8(\alpha-c)}{81\gamma-32} & \text{if } \gamma > \frac{4}{9}; \\ 2(\alpha-c) & \text{if } \frac{1}{3} \leqslant \gamma \leqslant \frac{4}{9}; \\ \frac{2(\alpha-c)}{9\gamma-2} & \text{if } \underline{\gamma} \leqslant \gamma < \frac{1}{3}, \end{cases} \tag{28}$$

where $\underline{\gamma} = \frac{2\alpha}{9c}$ so that $k \leqslant c$.

Comparing the top equations of (27) and (28) leads to the following result: an efficient foreign firm, that is to say a firm with a relatively low R&D investment cost (γ), ends up investing less in the signaling equilibrium than in the full information case. A relatively inefficient firm (high γ) will invest more in R&D under the signaling equilibrium. This result is summarized in the following proposition:

Proposition 3. *When AD policy is used as a signaling device, for a relatively high R&D costs, namely*

$$\gamma > \frac{16\left(\sqrt{7}-2\right)}{3\left(11\sqrt{7}-23\right)},$$

the foreign firm invests more in R&D under the signaling equilibrium than perfect information, so that $k^* > k^D$. *For low levels of R&D costs,*

$$\gamma \leqslant \frac{16\left(\sqrt{7}-2\right)}{3\left(11\sqrt{7}-23\right)},$$

the foreign firm invests less in R&D relative to the full information case, so that $k^* \leqslant k^o$.

The incentives at play that drive the results can be understood from the FOC given by equation (26). A firm with a relatively high R&D investment cost gains more from receiving a lower AD duty in the signaling equilibrium. In other words, the positive effect from receiving a lower duty dominates the negative slope effect ($\partial t/\partial k$). This is not the case for an efficient firm which suffers more from the negative signaling effect than it benefits from receiving a lower duty.

5 Conclusion

The WTO non-disclosure clause prohibits antidumping authorities to disclose any confidential information they obtain during an investigation. Typically, during an antidumping investigation, the government gathers both confidential and non-confidential information when it imposes an antidumping duty, leading it to gain knowledge about the cost structure of a foreign firm. This leads the government to have an informational advantage over its home firm. This paper argues that AD tariffs can be used to signal confidential information, thereby circumventing, the ADA non-disclosure clause. To be specific, the government will use antidumping policy to signal the uncompetitiveness of the foreign firm by imposing a lower duty than is optimal under complete information.

The welfare implications of the non-disclosure clause are then examined and we find that using antidumping policy to signal the uncompetitiveness of the foreign firm leads to social waist due to the fact that the government imposes a lower duty than is optimal under complete information, i.e. the case where the government discloses all the information to the home firm.

The paper also analyzes how antidumping policy, when it is used as a signaling device, affects the behavior of the foreign firm when it comes to investing in a process-improving

R&D. It is demonstrated that a foreign firm with a relatively efficient R&D cost, will end up investing less, whereas a relatively inefficient invests more in R&D when antidumping is used as a signaling device. This is because an inefficient firm gains more from receiving a lower antidumping duty than the efficient firm who suffers more from the signaling effect, which signals its uncompetitiveness.

As we have chosen to keep the model as simple as possible it is important to highlight some of the limitations of the model. We assume that the foreign firm is perfectly aware about the home firm's cost parameters. Including two sided private information in our model would mean combining our set up and the one of Collie and Hviid (1999a). While such generalization would be very much welcomed, it is, at least to our knowledge, not obvious to characterize any equilibrium AD tariff schedule. Another interesting extension would be to assume that the AD authority cannot truthfully 'verify' the information provided by the foreign firm. One could then attempt to study the role of the AD authority as a revelation mechanism. We leave this question for future research.

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6 Appendix

A. The 3rd Period Bayesian-Nash Equilibrium Outputs

The expected profits of the home and the foreign firm are

$$\pi_H = E\Big[\big(\alpha - q_H - q_F - c\big)q_H \mid t\Big];$$

$$\pi_F = \Big[\alpha - q_H - q_F - (c-k) - t\Big]q_F,$$

where E is the expectation operator given the beliefs of the home firm about k. The firms choose their outputs to maximize their profits given the beliefs of the home firm about the amount k by which the foreign marginal cost has been reduced due to R&D. The first-order conditions for the Bayesian-Nash equilibrium are

$$\partial \pi_H / \partial q_H = \alpha - 2q_H - E(q_F \mid t) - c = 0;$$
$$\partial \pi_F / \partial q_F = \alpha - q_H - 2q_F - (c - k) - t = 0. \qquad \text{(A.1)}$$

To solve for the equilibrium quantities it is first necessary to solve for $E(q_F \mid t)$. This is done by taking the expectation of the first-order condition of the foreign firm and then using the firs-order condition of the home firm to obtain

$$E(q_F \mid t) = \frac{\alpha - c + 2(\hat{k}(t) - t)}{3}, \qquad \text{(A.2)}$$

where $\hat{k}(t) = E(k \mid t)$. Substituting (A.2) into (A.1) and solving yields the Bayesian-Nash equilibrium outputs

$$\begin{aligned} q_H &= \frac{\alpha + t - c - \hat{k}(t)}{3}; \\ q_F &= \frac{\alpha - c + 2(k - t)}{3} - \frac{k - \hat{k}(t)}{6}. \end{aligned}$$

□

B. Regularity conditions of $G^{ND}(t)$

Belief monotonicity is satisfied whenever $\partial G^{ND}(t)/\partial \hat{k}(t)$ is strictly positive or negative. From figure 1 we see that $\partial G^{ND}(t)/\partial \hat{k}(t) < 0$; hence, the domestic government would like the home firm to believe that the foreign firm has a low k, i.e. a high cost. *Type monotonicity* is satisfied whenever $\partial^2 G^{ND}(t)/\partial k \partial t$ is strictly positive or negative. Using (18), it can be shown that $\partial^2 G^{ND}(t)/\partial t \partial k = 1/2 > 0$. The interpretation of type monotonicity is that the marginal gain of the government objective from imposing an AD duty, i.e. $\partial G^{ND}(t)/\partial t$, is increasing in the R&D investment level k. Another way of thinking about type monotonicity is that for a high k, the gain from using a high AD duty becomes so large that it makes it costly for the government to use AD duty to signal the uncompetitiveness of the foreign firm to the home firm. *Single crossing* is a technical condition that requires $(\partial G^{ND}(t)/\partial k)/(\partial G^{ND}(t)/\partial \hat{k}(t))$ to be monotonic in the R&D investment level k. The single crossing condition is satisfied when $(\partial G^{ND}(t)/\partial k)/(\partial G^{ND}(t)/\partial \hat{k}(t))$ is monotonic in k. From equation (10) it can be shown that:

$$\frac{\partial G^{ND}(t)/\partial t}{\partial G^{ND}(t)/\partial \hat{k}(t)} = -\frac{4(\alpha - c + k - 3t)}{4(\alpha - c) + k - 3\hat{k}}.$$

By taking its derivative with respect to k;

$$\left(\frac{\partial G^{ND}(t)/\partial t}{\partial G^{ND}(t)/\partial \hat{k}(t)} \right)'_k = \frac{12(\alpha - c - \hat{k} + t)}{\left[4(\alpha - c) + k - 3\hat{k} \right]^2},$$

it can be seen that $(\partial G^{ND}(t)/\partial k)/(\partial G^{ND}(t)/\partial \hat{k}(t))$ is monotonic in k. The single crossing condition is hence satisfied.

□

C. Finding an explicit solution

The first step in analyzing the differential equation (18), as shown in figure 1, is to divide the (k, t^*) space into different regions where the numerator N is positive or negative, and the denominator D is positive or negative. This determines the sign of the differential equation in each region and allows to illustrate the solutions to be drawn in the figure.

Note that the $D = 0$ locus gives the optimal AD duty under complete information as given by equation (22). The numerator is positive (negative) below (above) the $N = 0$ locus and the denominator is positive (negative) below (above) the $D = 0$ locus. Therefore the sign of the derivative, $d\phi(k)/dk$ in (22) can be derived from any point in the (k, t^*) space. The two loci intersect at $k_0 = 2(\alpha - c)$ and $t_0 = \alpha - c$. This intersection is important because it is used to determine the two linear solutions of the differential equation (18), denoted by L_1 and L_2, which pass through this intersection[18]. The slopes of the linear solutions are obtained by positing a linear solution of form $t - t_0 = m(k - k_0)$. Then, noting that $d\phi(k)/dk = m$, the differential equation can be solved for m, yielding two solutions, one positive $m_1 = (1+\sqrt{7})/6$, and one negative $m_2 = (1 - \sqrt{7})/6$. These explicit solutions of the two linear equations of the differential equation that pass through the point $\Big(k_0 = 2(\alpha - c),\ t_0 = \alpha - c\Big)$ are obtained by positing a linear solution of the form $t - t_0 = m(k - k_0)$, where the slope m is set equal to the differential equation $d\phi(k)/dk$.

First, replace $(k_0 = 2(\alpha - c),\ t_0 = \alpha - c)$ and rearrange to obtain:

$$t = m\Big[k - 2(\alpha - c)\Big] + \alpha - c. \tag{C.1}$$

Then, set m equal to $d\phi(k)/dk$ to get

$$\begin{aligned} m &= \frac{d\phi(k)}{dk} \\ &= \frac{4(\alpha - c) - 2k}{4(\alpha - c - 3t + k)}; \end{aligned}$$

and solving for t:

$$t = \frac{2(\alpha - c + k)m - 2(\alpha - c) + k}{6m}. \tag{C.2}$$

Finally, set (C.1) equal to (C.2) and solve for m to obtain the two solutions of m:

$$m_1 = \frac{1+\sqrt{7}}{6} \approx 0.61,$$

and

$$m_2 = \frac{1-\sqrt{7}}{6} \approx -0.27.$$

Given the slopes m_1 and m_2 the linear equations are then given by $L_i \equiv t - t_0 = m_i(k - k_0)$, $i = 1, 2$.

The next step in the graphical analysis of the differential equation is to determine the initial condition that selects a particular solution to the differential equation. It will be shown here that the initial condition corresponds to the point where the $N = 0$ and $D = 0$ loci intersect,

[18] Note that we are able to derive an explicit solution by using this method only if we assume that the foreign firm can possibly monopolize the market (i.e. $k \geqslant 2(\alpha - c)$). We believe this assumption is realistic in our setting, as exporting firms are usually large and efficient enough to monopolize the domestic market.

i.e. point (k_0, t_0). To begin with, note from equations (23) and (24) that the home firm is driven out of the market when $k \geqslant 2(\alpha - c)$. Moreover, observe from figure 1 that for all values of $k > 2(\alpha - c)$, the numerator is negative ($N < 0$) which implies that $\partial G/\partial \hat{k}(t) > 0$. Belief monotonicity in this case states that the government wants the home firm to believe that the foreign firm has a high k, but since the home market is no longer active, there is no longer an incentive to signal, and the government imposes the optimal duty as given by equation (22). Thus, the only initial condition that can generate a solution is the point where $k = 2(\alpha - c)$ and $t = (\alpha - c)$. As shown above, starting from the initial condition, there are two possible linear solutions: L_1 and L_2. However, the second order condition of the government's objective function can be used to eliminated the linear solution L_2. According to Mailath (1987) or Collie and Hviid (1993, 1999a and 1999b), the second order condition can be expressed as:

$$\frac{d^2 G^{ND}(t)}{dt^2} = -\frac{d\phi^{-1}}{dt}\left[\frac{\partial^2 G^{ND}(t)}{\partial k \partial t} - \frac{\partial^2 G^{ND}(t)}{\partial k \partial \hat{k}(t)} \frac{(\partial G^{ND}(t)/\partial t)}{(\partial G^{ND}(t)/\partial \hat{k}(t))}\right] < 0.$$

The first term in the square brackets is positive, $\partial^2 G^{ND}(t)/\partial k \partial t > 0$ because of type monotonicity, whilst the second term tends to zero as $k \to c$, since $\partial G^{ND}(t)/\partial t \to 0$ and $\partial G^{ND}(t)/\partial \hat{k}(t) < 0$ because of belief monotonicity. Hence $d\phi^{-1}/dt > 0$ has to be strictly positive for the second order condition to hold, meaning that the linear solution L_2 can be ruled out because $D < 0$ and $N > 0$. The unique separating equilibrium is given by the positively sloped linear solution L_1 in figure 1, where $D > 0$ and $N > 0$. As a conclusion, the unique separating equilibrium for all values of $k \leqslant 2(\alpha - c)$ is given by line L_1 with equation:[19]

$$t = \frac{(1+\sqrt{7})k - 2(\sqrt{7}-2)(\alpha - c)}{6}.$$

The explicit solution of the optimal duty under incomplete information is then

$$t^* = \begin{cases} \frac{(1+\sqrt{7})k - 2(\sqrt{7}-2)(\alpha - c)}{6} & \text{iff } k < 2(\alpha - c); \\ t^o \equiv \frac{\alpha - c + k}{3} & \text{iff } k \geqslant 2(\alpha - c). \end{cases} \tag{29}$$

□

D. Proof of Equation (27)

Under the non-disclosure regime the maximization program for the foreign firm is given by (25) in which $t = t^*$ given by (19).

$$\max_k \ \Pi_F = \frac{1}{9}\left[\alpha - c + 2k - \frac{2(\sqrt{7}-2)(\alpha - c) + (1+\sqrt{7})k}{3}\right]^2 - \frac{\gamma}{2}k^2. \tag{D.1}$$

The FOC of the maximization of (D.1) with respect to k leads to

$$\begin{aligned} \frac{\partial \Pi_F}{\partial k} &= \frac{4}{9}\left(1 - \frac{1+\sqrt{7}}{6}\right)\left[\alpha - c + 2k \right. \\ &+ \left. \frac{2(\sqrt{7}-2)(\alpha - c) - (1+\sqrt{7})k}{3}\right] - \gamma k = 0. \end{aligned}$$

[19] The equation of line L_1 is derived by using slope $m_1 = (1+\sqrt{7})/6$ and point $k = 2(\alpha - c)$ and $t = (\alpha - c)$.

Taking the derivative reveals the second-order condition, which is satisfied if and only if $\gamma > 4\left(16 - 5\sqrt{7}\right)/81$. From the FOC the optimal level of R&D is given by

$$k^* = \frac{2\left(11\sqrt{7} - 19\right)(\alpha - c)}{81\gamma + 4(5\sqrt{7} - 16)}. \tag{D.2}$$

Note from equation (D.2) that $k \geqslant 2(\alpha - c)$ when $\gamma \leqslant \frac{5-\sqrt{7}}{9}$. Whenever, $\gamma \leqslant \frac{5-\sqrt{7}}{9}$, the foreign firm monopolizes the market. The computations are therefore the same as point 2 of appendix E. Consequently, putting (D.2) and (E.4) (see below) together leads to equation (27).

□

E. Proof of Equation 28

Under complete information the maximization program for the foreign firm is given by (25) in which $t = t^o$ given by (22)

$$\max_k \Pi_F = \left(\frac{\alpha - c + 4k}{9}\right)^2 - \frac{\gamma}{2}k^2. \tag{E.1}$$

1. The case of duopoly. The FOC of the maximization of (E.1) with respect to k leads to

$$\frac{\partial \Pi_F}{\partial k} = \frac{8(\alpha - c) + (32 - 81\gamma)k}{81} = 0.$$

Taking the derivative reveals the second-order condition, which is satisfied if and only if $\gamma > 32/81$. From the FOC the optimal level of R&D is given by

$$k^o = \frac{8(\alpha - c)}{81\gamma - 32}. \tag{E.2}$$

For $c - k^o \geqslant 0$ to be satisfied it follows that

$$\gamma \geqslant \frac{8\alpha + 24c}{81c}.$$

Finally, note that: $\underline{\gamma} > 32/81 \Leftrightarrow \alpha > c$, which is a required condition for the firms to be active in the market. So for k^o is an equilibrium whenever $\gamma \geqslant \underline{\gamma}$. Next, observe from (8) that $q_H = 0$ if $t^o \leqslant k - (\alpha - c)$. By replacing t^o, given by (25), and rearranging it follows that $q_H = 0 \Leftrightarrow k \geqslant 2(\alpha - c)$. From (E.2), $k \geqslant 2(\alpha - c)$ whenever $\gamma \leqslant 4/9$. This can only be an equilibrium if

$$\frac{4}{9} \geqslant \frac{8\alpha + 24c}{81c} \Rightarrow \alpha \leqslant \frac{3}{2}c.$$

Thus, for $\alpha > 3/2c$ monopolization is no longer possible.

2. The case of monopoly. Monopolization is possible when $\gamma < 4/9$. The monopoly quantity is given by equation of (9) and the optimal duty by (22). The maximization program is hence given by

$$\max_k \Pi_F = \left(\frac{\alpha - c + k - t^o}{2}\right)^2 - \frac{\gamma}{2}k^2, \tag{E.3}$$

where $t^o = (\alpha - c + k)/3$. The FOC of (E.3) leads to

$$\frac{\partial \Pi_F}{\partial k} = \frac{2(\alpha - c) + (2 - 9\gamma)k}{9} = 0.$$

Taking the derivative reveals the second-order condition, which is satisfied if and only if $\gamma > 2/9$. From the FOC the optimal level of R&D is given by

$$k^o = \frac{2(\alpha - c)}{9\gamma - 2}. \tag{E.4}$$

For $c - k^o \geqslant 0$ to be satisfied it follows that

$$\gamma \geqslant \underline{\gamma} \equiv \frac{2\alpha}{9c}.$$

It can be seen that $k^o > 2(\alpha - c) \Leftrightarrow \gamma < 1/3$. Moreover, note that $\underline{\gamma} < 1/3 \Leftrightarrow \alpha < 3c/2$. Finally putting (E.2) and (E.3) together reveals equation (28).