Strategic Interactions in Markets with Innovative Activity: The Cases of Strategic Trade Policy and Market Leadership

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Contents

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Introduction

The common denominator of this monograph is the application of dynamic oligopoly theory in analyzing the underlying strategic effects in particular microeconomics issues (positive analysis) and ensuing policy implications of these issues (normative analysis). More specifically, I focus on strategic interactions and policy implications in markets in which innovative activity prevails and has a strategic dimension. In particular, I study i) international trade competition in which strategic behavior occurs and ii) the issue of market leadership in which there is free or endogenous entry. As already mentioned investments in R&D are assumed to be important and chosen strategically in both setups. Thus, part I deals with strategic trade and accompanied strategic policy and part II is devoted to the positive and normative issues of market leadership under endogenous entry.

We start with a survey of Part I. It is important to stress at the outset that the theory of strategic trade policy posted a challenge to the prevailing concept of free trade and advanced a possible new paradigm in international trade. The key claim of the theory is that a significant share of international trade takes place in an imperfectly competitive environment, so that strategic interaction among participating firms becomes relevant. Consequently, the proper description of this strategic interaction requires the use of oligopoly theory as an underlying concept. Moreover, the government is viewed as an important actor in this context which possesses the ability to alter the above strategic interactions in favor of the domestic firm, and possibly in favor of domestic consumers and the domestic treasury. In other words, it is socially beneficial for a government to intervene with tariffs, subsidies, quotas, etc. in order to secure higher domestic social welfare (through improving domestic terms of trade, profits shifting to domestic firm, increased tariff revenue, increased consumer surplus, etc.).

In the first article, entitled "Intellectual Property Rights Violations and Spillovers in the North-South Trade", (1998), we analyze the role of technological spillovers when Northern and Southern firms compete in quantity on the common world market and also when only the Northern firm is supposed to conduct innovative activity. The intensity of spillovers is interpreted as an indicator of the strength of intellectual property rights (IPR) protection. In this light, we reconsidered the questions commonly raised in the economic analysis of IPR protection in North-South relations: when and whether the Southern countries benefit, in welfare terms, from protecting IPR; how the North fares in this story; how large the conflict is between the North and South; and what the optimal level of IPR protection is at the world level. We showed that the common belief that the South generally benefits from relaxing IPR protection, while the North is worse off, may not carry over in the applied duopoly model with spillovers. In this respect, the congruence of interests between North and South, with respect to Southern IPR protection regime, should not be regarded as an exceptional or even impossible state of affairs.

Finally, note that the policy variable here is the level of IPR protection that affects strategic relations rather than standard trade policy instruments like tariffs or export subsidies. Thus, that kind of policy can be viewed as a strategic IPR protection policy rather than as a strategic trade policy in the narrow sense of this concept.

In the next article, "Strategic Trade Policy, Intellectual Property Rights Protection, and North-South Trade", (2000), we explicitly include trade policy in the above North-South trade framework. In addition, we introduce the standard assumption of segmented markets. More specifically, we focus on the optimal trade policy of the domestic country ("North") in an environment in which its trade with the foreign country ("South") is accompanied by a leakage of technological information (spillovers). In this set up, we examine the interaction between the Northern strategic trade policy (in the form of tariff) and the Southern government's incentives to set the level of IPR protection and the corresponding social welfare implications. Much like in the first paper, we also examine the issue of optimal IPR protection from the global welfare point of view, but in a new context where markets are segmented.

We show that optimal Northern tariffs have some additional functions beyond their traditional role as a device to shift foreign profit to the domestic treasury and to domestic profit. Tariffs also act as an instrument which may reduce IPR violations and, therefore, drive a domestic firm to invest in socially beneficial R&D that, in turn, leads to better exploitation of scale economies. In this setup, optimal tariffs are higher than in the standard duopoly model without R&D investment and IPR violations.

The Southern government sets the IPR policy strategically by anticipating the Northern firm's R&D decision and Northern government's decision on tariffs. The Southern government would prefer to set a maximal slack in IPR protection, but it cannot do this (unless the R&D efficiency is "very low") since such an IPR violation triggers a prohibitive tariff. Since the appropriation of R&D output by the South is a form of informal technology transfer, it is not a priori clear that the world planner should discourage it.

The world planner would have to weigh the benefits of innovation diffusion carefully and the costs of diminished incentives and decreased R&D investment in the North. Such considerations will urge a zero or low tariff if R&D efficiency is low, but will require a prohibitive tariff if R&D efficiency is high.

A few testable predictions also arise from the above-described analysis: first, given that the Southern government sets the IPR for all industries under the same conditions, we should observe higher tariff levels on products for which the production process (or the product) is subject to higher spillovers. Second, the Northern innovating firm (firms where scale economies are important) faced with spillovers but without tariff support (or any other effective IPR protection) will operate at a lower scale in comparison to Northern firms where there is effective IPR protection.

In the third related article, "Tariffs, Market Conduct, and Government Commitment: Policy Implications for Developing Countries", (2010a), we change sides and analyze Southern tariffs. This means that now the Southern country and the Southern firm become the "domestic" ones. The Southern firm invests in technological upgrades, since it lags behind the Northern firm which has advanced technology; this investment is of an imitative nature rather than a true investment in technological improvement. In a sense, we relax the assumptions made in Žigić, (1998) and Žigić, (2000) that the imitations or spillovers are costless. In this setup, we analyze different domestic policy options that occur due to the mode of the oligopoly conduct and due to the (in)ability of the domestic (Southern) government to commit to its policy. We consider three policy options: government commitment regime, government non-commitment regime, and free trade. We find that regardless of the market conduct and the ability of the domestic government to commit in advance to the level of its policy, the optimal tariff protection improves not only domestic social welfare, but also the effort to imitate of the domestic firm. However, free trade, as a policy option per se, has its virtues since the information requirement for its implementation is virtually zero. Thus we introduce policy criteria beyond generated social welfare (including information requirement, time consistency, and the threat of agency and manipulative behavior) in order to evaluate the policy options under consideration. We show that the most robust policy choice is the government "non-commitment" regime, in which there is a low information requirement, the optimal tariff is time consistent and there is no fear of manipulation by the domestic firm. In addition, we show that the social welfare loss vis-a-vis the government commitment regime is negligible.

In the last paper of the Part I, entitled "Free trade versus strategic trade as a choice between two "second-best" polices: a symmetric versus asymmetric information analysis", (2005), we switch to the most common and the simplest setup used in studying strategic trade known as "third market" model. Unlike the previous three articles, in which competition takes place on the domestic (either Northern or Southern) market, in the "third market" setup, a domestic firm competes on some "third" market so consumer surplus does not enter the social welfare function. Thus, social welfare equals the firm's profit (net of potential export and R&D subsidy). Apparently, tariffs are not feasible instruments in this setup.

We focus on the situation where the domestic government is bound to intervene only after the domestic firm's strategic variable, in the form of R&D investment, is chosen. That is, we assume the government to be a "non-commitment" regime. In addition we allow for a particular case of information asymmetry on the side of the domestic government.

In such a setup, we study the policy dilemma of strategic trade policy versus free trade. The novel feature here is that the information asymmetry stems from the assumption that the government may not, a priori, know the true mode of competition. Unlike the above-described home market setup, the inability of a domestic government to commit to its policy instrument (export subsidy in this case) allows a domestic firm to manipulate the government through the chosen level of R&D and results in a socially inefficient choice of the strategic variable. However, a commitment to free trade results in the forgoing of profit-shifting benefits. Yet, from the social point of view, free trade may be optimal even under the assumption of symmetric information. Due to costly signaling, this result is reinforced in the case of asymmetric information.

I omit from the selected collection a large body of research which is in pre-publication form yet is related to the above topic. Most notably, in Žigić, (2010b), I introduce an intra-industry setup in order to reconsider the consequences of government (in)ability to pre-commit to its policies when it is constrained to only one policy instrument (second-best policies). This setup nests the above-discussed standard frameworks of strategic trade policy-the "third-market" and the "home-market" frameworks. I also analyze how robust the signs of particular policy instruments (R&D subsidies) are when passing from the "second-best" to the "first-best" policy and show that, in the considered setup, this issue is closely related to the issue of the government commitment. The policy instruments under consideration are import tariffs and export and R&D subsidies, and there are R&D spillovers from the domestic firm to the foreign firm.

Another related project of my colleagues and I deals with normative and positive issues of strategic trade and is based on the concept of vertical product differentiation. The whole analysis of the strategic interactions which we reviewed above is based on the assumption of either homogenous goods (as in articles one and two) or the assumption of horizontal product differentiation (as in papers three and four). Vertical intra-industry trade is, however, an important pattern in trade between North and South. In other words, this trade is characterized by the differences in qualities of products that they offer in the same market. The papers that address the international trade issues in the context of vertical product differentiation are Kunin and Žigić, (2004) and Kovać and Žigić, (2007).

In Part II of this collection, there are two articles that make contributions to the recent theory of market leadership under endogenous entry. This theory was introduced by F. Etro in series of articles and a book (see Etro, 2004, 2006, 2007 and 2008). Etro focuses not only on the positive features that market leaders exhibit on market structure but also investigates a great deal the normative aspects that such behavior entails on social welfare in general and consumer welfare in particular.

One major new insight is that the market leader under the threat of entry always behaves more aggressively in a sense that it invests more in R&D than its competitors, produces more and charges a lower price compared to the situation of no entry. Thus, strategic effects that are present with exogenous number of competitors that might soften competition disappear in the presence of endogenous entry. Such aggressive behavior of the leader may result in leader being the only firm in the market, yet it behaves much more competitively than the standard monopolist would do. In this sense, high market concentration may in fact be an outcome of tough (both price and non-price) competition rather than an indicator of market power and lack of competitive forces when conditions of free (or more generally, endogenous) entry prevail.

As for the normative aspect, the theory of market leadership under endogenous entry sheds a completely new light on antitrust issues like predatory pricing, bundling, vertical restraints, price discrimination, mergers and the like, and it shows that these phenomena may not be necessarily anticompetitive per se. An intriguing finding, which offers a strong policy signal, is that the allocation of resources is improved in the presence of a leader faced with endogenous entry. Hence, shifting market structure and related market conduct away from market leadership may soften competition and, consequently have undesirable social welfare effects. This is especially likely in dynamic markets (like, for example, the software market) characterized by innovative activity (and high investment in R&D) and free entry. One way the government can engineer such a shift is to deprive the leading firm of its patented product, or of its superior technology, by forcing it to reveal secret pieces of information to its competitors.

In the first article of Part II, entitled "Competition Policy and Market Leaders", (2011), we study positive and normative aspects of a particular situation in which the dominant firm is deprived of its leading position by means of competition policy. In the first scenario, we closely follow the above-described setup of market leadership with endogenous entry assuming competition in quantities and Stackelberg leader concept adding to this a novel feature that both the leader and all the followers undertake process innovation. So the strategic variable is, again, investment in R&D. We then compare two setups - one without a leader and other with it. In each setup, there are a potentially infinite number of identical firms (or followers in the setup with leader!) which opt whether to enter the market (at a certain setup cost) and how much to produce and invest in R&D. The products that each firm produces are imperfect substitutes, that is, they are not equal, but the availability of one reduces the demand for the other. R&D lowers the marginal cost of production, but is itself costly. Due to entry costs and finite demand, there will be only a limited number of firms in equilibrium. When we compare the markets with and without a leader, we find that the aggregate output and R&D are identical. However, when a leader is present, there are fewer firms in the market and therefore less is wasted on entry costs. The industry profit is higher with a leader than without it and, finally, the market with a leader generates a higher consumer surplus due to the leader's aggressive conduct (pricing lower than followers). So the total social welfare is larger with leadership.

In our second scenario, we depart from the theory of market leadership under endogenous entry to check the robustness of its conclusions under alternative plausible scenario. Thus, unlike in the first scenario, we assume price competition and, in addition, assume that there are repeated interactions among firms. Moreover, unlike in the first scenario where the market leadership is exogenously given, here we allow that one firm might be more technologically advanced than the others and thus acts as the technological leader. Much like in the first scenario, R&D serves to lower production costs. When all firms are identical (there is no leader) they would tacitly collude to set a monopoly price in equilibrium. The presence of a technological leader may preclude this situation. If technological advantage is large enough, it would be optimal for the leader to price all other firms out of the market. The leader behaves aggressively, charges a lower price, generates larger social welfare, and (under plausible conditions) invests more in R&D than would be the case in a similar setup without the technological and market leader.

To conclude, the first article provides two scenarios that seek to offer a plausible description of markets in the new economy (e.g., software markets). The mechanical removal of the leader in such market is likely to be harmful from the both the consumer surplus and the social welfare points of view. As stated in "Economic Focus" section of The Economist sometime ago " antitrust authorities should be especially careful when trying to stamp out monopoly power in markets that are marked by technical innovation. It could still be that firms like Microsoft are capable of using their girth to squish their rivals; the point is that continued monopoly is not cast-iron evidence of bad behavior [...]. The fact that a dominant firm remains on top might actually be strong evidence of vigorous competition. The very ease of entry, and the aggressiveness of the competitive environment, are what spur monopolists to innovate so fiercely." (" Slackers or Pacesetters," The Economist, May, 2004)

In the second paper, "Technological Leadership and Persistence of Monopoly under Endogenous Entry: Static versus Dynamic Analysis", (2010c), we, much like in the second scenario of the first paper, assume the technological, (rather than market) leadership as given. We study the situation in which a technological leader, being faced with free (or endogenous) entry of other firms, may undertake preemptive R&D investment (strategic predation strategy) that eventually leads to rival firms' exit. If this strategy is optimal, then the technological leadership is converted into the market leadership: that is, the technological leader becomes a monopolist. Next, we contrast strategic predation outcomes with those of accommodation behavior, when it would be optimal for the technological leader to accommodate a certain number of followers. This comparison enables us to study the positive aspects of the two main strategies of the leader - accommodation and strategic predation - as well as the social welfare implications of the two resulting market structures, namely, oligopoly and (constrained or unconstrained) monopoly.

Applying a full-fledged infinite horizon dynamic model with endogenous entry at every instance in time enables us to study the conditions under which technological leadership transfers into market dominance (monopoly). More specifically, we analyze how such factors as technological efficiency, speed of the adoption of new technology, and the (relative) size of the market contributes to this market dominance.

The main findings of our analysis are summarized below:

(1) The technological leader adopts the accommodation strategy only when its R&D efficiency is "low" or/and the size of the market is relatively large (more precisely, when fixed costs are small relative to the size of the market). In all other cases, the leader opts for strategic predation aiming to achieve a monopoly position after certain time T.

(2) During the predation period (up to certain time T), the leader might even be willing to incur losses in order to enjoy monopoly profit from time T onward. Thus, unlike in a static model, in a fully dynamic model, the costs of predation last for a certain period of time and have to be contrasted against the infinite stream of monopoly profit earned afterwards. As these costs depend on the speed of adoption of new technology, strategic predation becomes the more attractive strategy to pursue when the adoption of new technology accelerates. In the limited case, when adoption is instantaneous, the dynamic model essentially reduces to the static one.

(3) Once all rivals are eliminated, the leader may continue to further increasing its R&D investment and become a so-called unconstrained monopolist. Alternatively, the leader may behave as a constrained monopolist that keeps its investment at a low level, just high enough to prevent rivals from re-entering the market. Nevertheless, such investment levels are still higher than those observed in the case of accommodation.

(4) Regarding social welfare considerations, we show that the social planner, choosing the flow of R&D investment to maximize the sum of profit and consumer surplus while keeping the market structure unchanged, also prefers strategic predation to accommodation when its R&D efficiency is "large" or/and the size of the setup costs relative to the size of the market is large. Moreover, the social planner would prefer a longer predation time than the profit-maximizing leader, provided the combination of R&D efficiency and the relative size of fixed costs are below a certain threshold curve. On the other hand, the social planner can be more aggressive than the leader in the sense that the planner prefers shorter predation times if another threshold curve is surpassed (this threshold corresponds to the situation when both R&D efficiency and the relative size of fixed costs are large).

As a final point, it is important to stress that the two surveyed applications of oligopoly theory - strategic trade and market leadership - are by no means mutually exclusive concepts. On the contrary, the theory of market leadership under endogenous entry can be also applied in the case of strategic trade when a particular international market fits the assumption of the theory (see for instance, Etro, 2011 for pioneering work in this area). I expect that a sensible combination of the two concepts represents a promising venue for future research in the field of applied oligopoly theory.

Part I

Intellectual Property Rights Violations and Spillovers in North-South Trade

The article examines the role of technological spillovers when Northern and Southern firms compete in quantities on the common world market and when only the Northern firm is supposed to conduct innovative activity. The intensity of spillovers is interpreted as an indicator of the strength of intellectual property rights (IPR) protection. In this light, the paper reconsiders the questions raised in the recent economic analysis of IPR protection in North-South relations: when and whether the Southern countries benefit, in welfare terms, from protecting IPR; how the North fares in this story; how large is the conflict between the North and South; and what is the optimal level of IPR protection at the world level. The paper shows that the common belief that the South generally benefits from relaxing IPR protection while the North is worse o does not carry over in the applied duopoly model with spillovers. In this respect, the congruence of interests between North and South, with respect to Southern IPR protection regime, should not be an exceptional or even impossible state of affairs.

1 Introduction

The perplexity of North-South economic relations seems to be a long lasting inspiration for both empirical and theoretical economic analyses. The Uruguay GATT round from the late 1980s contributed to this perplexity. The issue at stake in the Uruguay negotiations was the problem of trade-related intellectual property rights (IPR). Predictably, the views on this issue were polarized: the North (highly developed countries) led by the US took an aggressive position, arguing that the infringement of property rights by the South (developing countries) has inflicted losses in the range of billions of dollars. Such a decisive stance taken by the North has its roots in the fact that the developed countries have become more R&D intensive and the ongoing high-tech and scientific revolution has significantly contributed to both cheap and fast dissemination of expensive knowledge and increased economic globalization. As a result, the output of other innovative efforts could be captured more easily than before.

On the academic side, the importance of IPR protection in the North-South relationship reached such a level that the topic has already become a part of the economic encyclopedia. The third volume of he Handbook of International Economics contains, in the chapter on 'Technology and Trade', a separate section entitled 'Intellectual Property Rights and North-South Trade'. (Helpman and Grossman, 1995).

There are several formal models devoted to North-South IPR protection issues. The first contribution seems to be that of Chin and Grossman (1990).[1] The authors used a simple duopoly model with one firm from the South and the other from the North. One of their major issues was a comparison between the welfare effects of two IPR regimes. One of these regimes has full patent protection, and the other has no patent protection whatsoever so that the South can costlessly copy the process innovations coming

[1] A couple of elegant dynamic models dealing with the North-South trade, technology transfer and imitation emerged somewhat earlier without explicit reference to the IPR problem. See, for instance, Krugman (1979), Jensen and Thursby (1986) and Dollar (1986).

from the North. In this framework, the South generally benefits in social welfare terms through this lack of protection of IPR. The model developed by Diwan and Rodrik (1991) stresses the impact of different preferences for technology or products between North and South. This may lead to the South benefitting from protection of IPR if the differences in preferences are substantial. Deardorff (1992), using the North-South framework and product innovation, examines the welfare effects of the geographical scope of patent coverage. Like Chin and Grossman, he showed that the North always benefits from enforcing property rights, whereas the South fares generally worse due to monopoly pricing after such an enforcement taking place. Taylor (1993) shows that Southern IPR violation induces Northern firms to act strategically and make imitation deliberately more di- cult through so-called 'masquing'. Under certain conditions, this response by Northern firms can completely prevent the losses from the increased IPR violations. Helpman (1993) investigates the North-South economic relationship issue using a general equilibrium framework and the theory of endogenous growth. The general equilibrium approach enabled the author to identify several channels through which a change in the degree of IPR protection could affect welfare of both parties (terms of trade, interregional allocation of manufacturing, R&D pattern, and availability of products). He also examines the impact of the speed of imitation on social welfare, showing that a tightening of the property rights regime by the South could harm both North and South if the rate of imitation is initially low. Vishwasrao (1994) analyzes the incentives for the North to engage in transfers of technology (different types of licensing contracts) depending on expectations concerning the Southern IPR protection regimes.

This paper extends and complements Chin and Grossman's model of intellectual property rights in North-South trade when licensing is not feasible.[2]

Unlike Chin and Grossman (1990) who consider two polar cases (complete IPR protection versus complete violation), we have started from the empirical observation (see Mansfield, 1994) that the strength of IPR protection can attain many dierent levels. To take this feature into account, we introduce the 'R&D with spillovers'[3] type of model and reconsider the welfare effects of IPR protection in the North-South trade relationship. R&D spillovers are defined as the leakage of important pieces of technical information which can be used by the recipient at zero or small marginal costs.[4] The basic idea is that the intensity of spillovers may be interpreted to reflect the strength of IPR protection.

The major insights provided by this 'spillover approach' can be summarized as follows:

(a) The nature of North-South market interaction is dependent not only on R&D efficiency, as was the case in Chin and Grossman (1990), but also on the level of spillovers (e.g., the degree of patent protection). Given the R&D efficiency, the equilibrium market structure depends on the level of IPR protection.

[2] The licensing option could be easily introduced into the model in a manner similar to that of Chin and Grossman (1990). It could then be shown that licensing can take place if both the incentive compatibility of the North and the participation constraint of the South are satisfied.

[3] For the examples of 'R&D with spillovers' models [games], see, e.g., Spence (1986), Katz (1986), D'Aspremont and Jacquemin (1988), Kamien et al. (1992), Suzumura (1992) and De Bondt et al. (1992).

[4] There is a basic difference between R&D spillovers and imitation; unlike R&D spillovers imitation implies an active and costly process in order to disentangle the original innovation.

(b) Using this approach the result that the South generally fares better in terms of social welfare by not protecting property rights is no longer robust.

(c) Similarly, the finding that the North is always worse off from increased IPR violations by the South does not carry over in the 'spillover' framework.

(d) Finally, when the level of R&D efficiency approaches a 'medium to high' level, the situation of convergence of interests between North and South becomes a rule rather than an exception.

The remainder of the paper is organized as follows: Section 2 states and discusses the assumptions of the analyzed game between the North and South, examines the conditions under which particular market forms (duopoly, constrained monopoly, and monopoly) emerge in equilibrium, and briefly discusses the impact of a change in spillovers on the R&D expenditures of the Northern firm. Section 3 deals with the effect of spillovers on the social welfare of the North and the South. Section 4 analyzes the issue of the optimal level of intellectual property rights protection at the world level. Section 5 is devoted to concluding statements and qualifications.

2 The Model

2.1 Assumptions

For the sake of simplicity, let us assume that there are only two countries, 'North' and 'South'. In each country there is only one firm. These firms encounter each other on the integrated world market (which consists of Northern and Southern parts) and compete in quantities. The Northern firm is the only one supposed to conduct R&D. The effects of R&D are captured by an 'R&D production function' which displays 'diminishing returns'.[5] Following Chin and Grossman, we further assume that initially both Northern and Southern firm have access to an 'old' technology to produce a good demanded in both countries. By the very definition of spillovers, part of the generated knowledge which leaks out is assumed to have a public-good character and it can be appropriated by Southern firm at zero marginal cost.[6]

In order to focus on the effects of change in the IPR regime, we assume that the Northern firm does not engage in 'masquing activities' (as in Taylor, 1993). We also neglect the possibility of any strategic action by the Northern government which could impose punitive tariff due to IPR infringement (see Žigić, 1996b).

[5] This specification reflects empirical observations and was listed as a 'stylized fact' in Dasgupta (1986), p. 523, for instance.

[6] The more general model may allow for both types of non-formal technology transfers, i.e., for both costless leakage of technological information (spillovers) and active and costly imitation. However, none of the results under consideration here would qualitatively change in this more general setting. The extended version of the model which takes these features into account is available upon request from the author.

2.2 The game

The model to be examined is a two-stage game. In the first stage, the Northern firm chooses its R&D expenditure, x. In the second stage, the firms compete in quantities. The Northern firm has unit costs of production (C):

$$C = \alpha - (gx)^{1/2}, \qquad x \leqslant \alpha^2/g \tag{1}$$

where the parameters g and α describe the efficiency of the R&D process and pre-innovative unit costs, respectively. The expression $(gx)^{1/2}$ is an 'R&D production function' as in Chin and Grossman (1990).

The Southern firm benefits through spillovers from the R&D activity carried out by the Northern firm. Its unit cost function is

$$c = \alpha - \beta(gx)^{1/2}, \qquad \beta \in [0, 1] \tag{2}$$

where β denotes the level of spillover assumed to reflect the strength of IPR protection.

The above structure generalizes the Chin and Grossman (1990) model, which only allows extreme cases when $\beta = 1$ (violation of the property rights regime) and $\beta = 0$ (full property rights protection regime), respectively.

Consumers in the two countries are identical,[7] with $1/\theta$ of market demand made up of Southern consumers, where θ ranges from one to infinity. We assume a single world market with the linear inverse demand function: $P = A - Q$. $A > \alpha$ captures the size of the market, q_s and q_n denote the quantities of the South and North, respectively, and $Q = q_s + q_n$.

Social welfare (W) is defined as the sum of consumer surplus (S) and the firm's profit (π). In the case of a linear demand function and a fraction of $1/\theta$ of total demand coming from the South, the respective expressions for consumer surplus in the North and South become

$$S_n = \frac{({q_s}^* + {q_n}^*)^2(\theta - 1)}{2\theta}, \qquad S_s = \frac{({q_s}^* + {q_n}^*)^2}{2\theta} \tag{3}$$

2.3 Duopoly and equilibrium R&D expenditures

In the second stage, given the Northern firm's R&D investment, the two firms engage in Cournot-Nash competition.

The North maximizes profit net of the R&D expenditures. The first-order condition for a maximum yields $A - 2q_n - q_s - C = 0$. The optimization problem for the Southern firm is similar yielding the analogous first-order condition: $A - 2q_s - q_n - c = 0$. Solving the 'reaction functions' yields the Cournot outputs and price as functions of R&D investment:

[7] The impact on the preferred strength of IPR protection that arises because of the difference in consumer preferences between the North and South was the keystone of Diwan and Rodrik's model (Diwan and Rodrik, 1991). The authors proved that the difference in preferences could play a distinctive role with respect the desirability of strengthening the IPR in the South.

$$
\begin{aligned}
q_n(x) &= \frac{1}{3}(A+c-2C), \qquad q_s(x) = \frac{1}{3}(A-2c+C), \\
P(x) &= \frac{1}{3}(A+c+C).
\end{aligned} \tag{4}
$$

Substituting Eq. (4) into the profit function yields the Northern profit function expressed in terms of R&D investment:

$$\pi_n(x) = \frac{(A+c-2C)^2}{9} - x. \tag{5}$$

In the first stage of the game, the Northern firm selects x to maximize its profit. By substituting Eqs. (1) and (2) for C and c into Eq. (5) and maximizing with respect to R&D investment,[8] we obtain

$$x^* = \frac{(A-\alpha)^2(2-\beta)^2 g}{[(2-\beta)^2 g - 9]^2} \tag{6}$$

It is straightforward to check that the Northern R&D effort decreases with an increase in spillovers, i.e., $dx^*/db < 0$.

2.4 Strategic predation and R&D expenditures

Since spillovers are in general imperfect ($\beta < 1$), there is a critical value of R&D efficiency, g_d (leading to critical unit cost asymmetry between two firms), defined by

$$g_d \equiv \frac{3}{(1-\beta)(2-\beta)} \equiv g_d(\beta) \tag{7}$$

such that for $g > g_d$ duopoly ceases to exist (see Fig. 1). Equivalently, for any given g, there exists a critical value β_d below which duopoly is not viable. This critical value is simply obtained by inverting Eq. (7).

When R&D efficiency exceeds g_d two possibilities may occur; unconstrained monopoly and monopoly constrained by the credible threat of entry by the Southern firm (or shortened 'constrained monopoly'). To see this, let us look first at the optimal quantity, R&D expenditures and price if unconstrained monopoly emerges. The North, which is now assumed to be a monopolist, maximizes

$$Max[\pi_m] = (A - q_m)q_m - Cq_m - x. \tag{8}$$

The first-order condition for a maximum yields $A - 2q_m - C = 0$. Solving for q. and substituting in Eq. (8) yields $\pi_m(x)$. Substituting the expression for C, Eq. (1), into the $\pi_m(x)$ and maximizing with respect to the R&D investment (x), we obtain

[8] We assume that a is sufficiently large in all cases so that the non-negativity constraint on C does not bind. The second-order condition is satisfied for all permissible values of parameters, and the optimal R&D expenditure, x^*, is always positive.

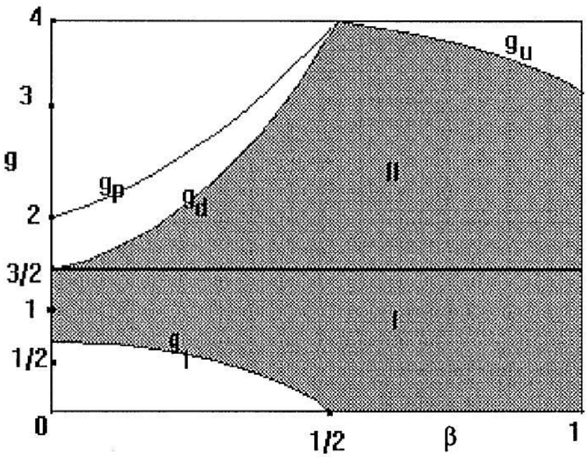

Figure 1: Region of parameters g and β in which $dS_s^*/d\beta < 0$ and $d\pi_s^*/d\beta > 0$.

$$x_m = \frac{g(A-\alpha)^2}{(4-g)^2} \tag{9}$$

with the corresponding price as

$$p_m = \frac{A(2-g)+2\alpha}{(4-g)} \tag{10}$$

(note that spillovers play no role in the case of monopoly).

Chin and Grossman (1990) showed that when the efficiency parameter, g, is greater than 2, the Northern firm becomes a monopoly. In our framework, however, the border line beyond which the Northern firm acquires a monopoly position also depends on the degree of spillovers. As can be seen from Eq. (7), higher spillovers require a higher critical level of g for both constrained and unconstrained monopolies to arise.

To find the parameter values which allow for a pure monopoly to exist, we have to evaluate the reduced profit function of the Southern firm, i.e., $\pi_s^*(x)$, at the Northern optimal R&D investment level expressed in terms of parameters and determining the region of parameters that leads to $\pi_s^*(x_m) \leq 0$. Equivalently, for the Northern firm to acquire an unconstrained monopoly position, it is necessary that $p_m \leq \alpha - \beta(gx_m)^{1/2}$. Such a post-innovative situation is that in which 'drastic innovation' takes place (see Tirole, 1991, p. 391). By substituting for p_m and x_m in the above expression we obtain the critical efficiency, g_p, defined as

$$g_p \equiv \frac{2}{(1-\beta)} \equiv g_p(\beta) \tag{11}$$

such that for $g > g_p$ the equilibrium market form is unconstrained monopoly. The critical spillovers level below which the Northern firm gains unconstrained monopoly position is labeled as β_p.

However, if we compare this critical condition with the one required to sustain an asymmetric duopoly (see Eq. (7)), we see that there is a region of parameters β and g where there is neither pure monopoly nor sustainable duopoly. (See area between g_p and g_d in Fig. 1.)

If the degree of spillovers and the efficiency of cost reductions happen to be in this region, the Northern firm exhibits 'strategic predation', (i.e., it chooses R&D expenditures in such a way as to cause $q_s^* = 0$ in equilibrium and thus induces its exit).[9] Note that the efficiency parameter g in this situation is in the range of

$$\frac{3}{(1-\beta)(2-\beta)} \leq g \leq \frac{2}{(1-\beta)} \tag{12}$$

whereas β stays below $\frac{1}{2}$.

Suppose now that the Northern firm chooses q. (i.e., the quantity a profit maximizing monopoly would select) when parameters g and β are in the region defined by Eq. (12). Such behavior would then induce a price which would invite competition by the Southern firm, and some sort of 'unsustainable duopoly' would arise. The monopoly price would now be in the range $p_m > \alpha - \beta(gx_m)^{1/2} \geq p_p$ (where subscript p stands for 'predatory'). This duopoly is, however, not a Nash equilibrium. The Northern firm could unilaterally increase its R&D investment (and, consequently, the equilibrium quantity) to achieve a higher profit by reducing the Southern firm's profit to zero.

There are two useful corollaries resulting from the above discussion: the Northern firm can enjoy the position of the unfettered monopolist only if spillovers are 'small' ($\beta < \frac{1}{2}$) and the R&D efficiency is rather high, more specifically, $g \geq g_p(\beta)$ has to hold. Second, since strategic predation is an option always available to the Northern firm, it is optimal only if spillovers and the R&D efficiency are in the region described by Eq. (12).

2.5 Spillovers, equilibrium R&D and profit in constrained monopoly

Although in the case of strategic predation only one firm survives in equilibrium, the degree of spillovers does affect the optimal values of such a constrained monopoly. As discussed above, in the first stage the North as a 'constrained' monopolist selects the predatory level of R&D expenditures so that $\pi_s^*(x_p) \leq 0$. (In fact, x_p is set to make $\pi_s^*(x_p) = 0$. This is assumed to be enough to induce exit or to block entry). The solution to the above equation gives the optimal level of R&D

$$x_p^* = \frac{(A-\alpha)^2}{(1-2\beta)^2 g} \tag{13}$$

[9]As a referee observed, if there were more than one Northern firm in the market, predation might be collectively optimal but then the well known temptation to cheat arises. Achieving a predatory level of R&D in this situation would require deliberate government action (e.g. an R&D subsidy).

Lemma 1 $\frac{dx_p^*}{d\beta} > 0$, if if predation is the optimal strategy of the Northern firm, i.e., if $\beta < \frac{1}{2}$and g is in range defined by Eq. (12).

Proof

$$Sign[\frac{dx_p^*}{d\beta}] = Sign\left[\frac{-4(A-\alpha)^2}{(-1+2\beta)^3 g}\right] = -Sign[(-1+2\beta)g] = 1$$

(recall that, for predation to take place, β has to be lower than $\frac{1}{2}$).[10]

As already indicated above, the intuition for such a seemingly perverse result (since $dx^*/d\beta < 0$ in duopoly) is the following: when predation is the optimal strategy, it requires that the competitor should be forced to exit the market. The higher the spillovers, the smaller the gap between Northern and Southern firm unit costs and therefore a higher R&D effort has to be undertaken in order to induce the exit.

The equilibrium quantity, q_p^* , also increases with the spillovers causing the predatory price to fall. That, in turn, increases both the Northern and Southern consumer surpluses. However, as a corollary of Lemma 1, the respective change in the Northern firm's profit is negative since the R&D level in a predatory regime is set above the myopic profit-maximization point and, as we see, an induced increase in R&D expenditures due to an increase in spillovers leads to a lower equilibrium 'predatory' profit.[11]

3 The effect of spillovers on social welfare

3.1 Duopoly

We concentrate here on the Southern welfare considerations.[12] To analyze the welfare effects of change in IPR protection, we break up welfare change ($dW_s^*/d\beta$) into its constitutive parts - change in consumer surplus and change in profit. Thus, $dW_s^*/d\beta \equiv dS_s^*/d\beta + d\pi_s^*/d\beta$. (See Appendix A for a formula for W_s^*.)

As noted in the previous section, duopoly is viable only if $g < g_d(\beta)$. We focus here on the largest (the shaded area in Fig. 1) duopoly subregion.[13] Without additional information, it is not possible to say how the change in IPR protection would affect

[10] Following a suggestion of the referee, we prove now that Lemma 1 holds for a general R&D 'production function', $f(x)$ with $f^{'(x)>0}$. It is straightforward to show that $\frac{dx_p^*}{d\beta} = \frac{2f(x)}{[f'(x)-2\beta f'(x)]>0}$ for $\beta < \frac{1}{2}$.

[11] In terms of mathematics, it means that 'the strategic effect' $\partial\pi_n^*/\partial x_p \;\; dx_p/d\beta < 0$ at x_p^* and not zero as it was in the case of duopoly. Since the 'direct effect' is zero now, it unambiguously leads to $d\pi_n^*/d\beta < 0$.

[12] As far as the change in spillovers of Northern welfare is concerned, the Grossman and Chin finding carries over fully here, i.e., the North is always worse off by increases in IPR violation.

[13] As is seen from Fig. 1, there are two extreme duopoly subregions in which there is no trade off caused by a change in spillovers. In the lower left corner, there is a segment of the duopoly region delineated by the line g_1 in which $dS_s^*/d\beta > 0$ and $d\pi_s^*/d\beta > 0$ implying $dW_s^*/d\beta > 0$. At the opposite side of the duopoly region, there is the upper right part delineated by the line g_u and characterized by $dS_s^*/d\beta < 0$ and $d\pi_s^*/d\beta < 0$ implying $dW_s^*/d\beta < 0$. (See Žigić, 1996a, for formal derivations and discussions of these two extreme duopoly regions.)

social welfare within this region since $dW_s^*/d\beta$ could, in general, be either negative, zero or positive. Thus, this region seems to be the one in which the welfare maximizing Southern government would face the usual trade off; relaxing IPR would result in higher spillovers and stronger dissemination of innovation at zero additional cost and this will make the Southern firm more competitive (hence $d\pi_s^*/d\beta > 0$). Unfortunately, relaxing IPR protection comes at a cost for the Southern consumers. It generates disincentives for the Northern firm to invest in R&D due to the famous inapropriability argument. There is a consequent fall in Northern equilibrium output which more than offsets the increase in the Southern firm's output which results in a lowering of both the total and Southern consumer surplus ($dS_s^*/d\beta < 0$). Thus, it seems that the only thing we can say a priori is that the Southern government should balance these two opposing forces in order to find the welfare maximizing level of IPR (denoted by β_{opt}) for given g.

The share parameter, however, plays a crucial role for the existence and resolution of the above trade-off by determining whether $dS_s^*/d\beta$ or $d\pi_s^*/d\beta$ will dominate welfare change. If, for instance, the Southern share in world consumption is 'high enough' (θ is low), then consumer surplus is a large part of Southern welfare and consequently, the change in consumer surplus, $dS_s^*/d\beta < 0$, is the dominating part of $dW_s^*/d\beta$ (see Eq. (3)).

To make the analysis more transparent, we further divide our largest region in Fig. 1 into two parts; area I being the Chin-Grossman case (characterized by $g < \frac{3}{2}$) and the area II with $g > \frac{3}{2}$. As far as the first area is concerned, it turns out that Chin-Grossman results hold in an even more extreme form; the South is in general better off by substantially relaxing IPR unless its share in consumption is well above 90% and at the same time R&D efficiency is very near to $\frac{3}{2}$.

However, the analysis becomes more interesting once we pass to the second area. As we saw before, for any given g bigger than $\frac{3}{2}$ with the IPR protection at β_d or lower, going back to β_p, the optimal behavior of the Northern firm would be strategic predation. As shown in the previous section, the Northern innovative activity increases monotonically with β in this region. This implies that (a) the maximum investment in R&D (for a given g) will be at a value of β_d , and (b) R&D investments increase monotonically in g along the $g_d(\beta)$ curve. Furthermore, this means that maximum total output and maximum (total and Southern) consumer surplus are reached along this curve as well. (Recall that R&D, total output as well as the Southern and total consumer surplus decrease as the IPR protection level goes beyond β_d.) Thus, the β_d is a priori a very attractive candidate for an optimal IPR protection level.[14] Technically speaking, $W_s^*(\beta_d) = S_s^*(\beta_d)$ represents a so-called 'corner solution'. (It is easy to demonstrate that the left-hand side derivative, $dW_s^{*-}(\beta_d)/d\beta < 0$, see Appendix B.)

However, what is not a priori clear, is whether $W_s^*(\beta_d)$ is necessarily a global maximum since, as already noted, both its value and the value of its change (i.e., the absolute value of $dW_s^*(\beta_d;\theta)/d\beta$) monotonically falls with a decrease in the share of consumption. In other words, if the Southern consumption share is 'big enough', then $W_s^*(\beta_d)$ would be the only 'extreme point' since the marginal profit effect would be too small to offset the fall in the consumer surplus. Problems arise when the Southern consumption share is

[14]Note that at the point β_d conditions for both strategic predation and duopoly are simultaneously satisfied (with optimal duopoly output for South $q_s^* = 0$). Therefore, we consider this point to be a duopoly border case.

'not so big' where it is quite possible that at some level of IPR violation marginal profit ($d\pi_s^*/d\beta$) starts to 'catch up' and welfare starts to increase, which eventually yields at least the local maximum, denoted as $W_s^*(\beta^*)$. For a 'not so big' consumption share, determining whether rather strict or very loose IPR protection maximizes welfare, requires the comparison of the two extreme points, i.e., $W_s^*(\beta_d;\theta)$ and$W_s^*(\beta^*;\theta)$. That is, for given $g \in [\frac{3}{2}, 4)$, it is necessary to find θ_c after which $W_s^*(\beta^*;\theta)$ starts to exceed $W_s^*(\beta_d;\theta)$. We also know that the higher R&D efficiency along the g_d line, the higher R&D investment will be and consequently the higher $W_s^*(\beta_d)$. Thus, the critical level, θ_c has to increase with g. Solving the equation $W_s^*(\beta_d;\theta) = W_s^*(\beta^*;\theta)$ for θ gives us the value of θ_c and enables us to state the first proposition. (See Appendix A for technical details.)

Proposition 1 *When the R&D efficiency of the Northern firm is such that $g > \frac{3}{2}$,the initial value of β happens to be in the interval $(\beta_d, 1]$ and $\theta < \theta_c$, then the South benefits from more rigorous enforcement of property rights, i.e.,$W_s^*(\beta_d) > W_s^*(\beta^*)$.*

To illustrate the actual importance of the above proposition, we proceed with several examples. When, for instance, $g = 2$, then β_d is the welfare maximizing level if the Southern consumption share is equal to or higher than 42% ($\theta_c = 2.38$). For $g = 2.5$ this critical share falls to 20.2% whereas for $g = 3$ it only amounts to 8.6% ($\theta_c = 11.6$). (See Table 1 in Appendix A.)

As the above examples indicate, β_d is a strong candidate for an optimum IPR level which is not confined only to extreme values of parameters. This should not be surprising since total consumer surplus is maximized at β_d. With the higher Northern R&D efficiency, disincentives to relax the IPR regime in the South are stronger. Losses in consumer surplus in this case outweigh the benefits from increased prot even with fairly small shares of the consumption coming to the South. Finally, when the Southern share in consumption becomes low enough ($\theta > \theta_c$), the welfare maximizing Southern government faces the trade off between increased competition for its firm and a decreased consumer surplus. The welfare maximizing spillovers level then is an interior optimum, β^*.

3.2 Strategic predation

When strategic predation happens to be an actual strategy, it is the Northern welfare that needs to be discussed.[15] The 'predatory' welfare for the North (denote it as W_n^{*p}) can be written as

$$W_n^{*p} = \frac{(A-\alpha)^2(-2\theta - g + 2\beta g - \beta^2 g + 3\theta g - 6\beta\theta g + 3\beta^2\theta g)}{2(1-2\beta)^2\theta g}$$

W_n^{*p} is defined for the parameter region between g_p and g_d (see Fig. 1) with a corresponding level of spillovers $\beta \in [\beta_p, \beta_d]$.

[15] The Southern firm is not in the market in the case of strategic predation. Thus, $dW_s^{*p}/d\beta = dS_s^{*p}/d\beta > 0$ (the superscript 'p' denotes the case of 'predation').

The impact of spillovers on Northern welfare depends now on the share of Northern consumption and is, in general, ambiguous. Thus,$dW_n^{*p}/d\beta(\theta)$ could be positive, negative, or zero. Obviously, if all consumption goes to the South (implying $\theta = 1$) we are left with $dW_n^{*p}/d\beta(1) = d\pi_n^{*p}/d\beta < 0$. However, the appearance of Northern consumption ($\theta > 1$), introduces an 'opposing force' and we clearly have $dW_n^{*p}/d\beta(\infty) > 0$ at the other extreme. More specifically, for $dW_n^{*p}/d\beta(\theta) > 0$, the share parameter h has to be bigger than the critical value defined as

$$\theta^p \equiv \frac{(1-\beta)g}{3g(1-\beta)-4} \equiv \theta^P(\beta) \tag{14}$$

To make the above expression more informative, we evaluate $\theta^p(\beta)$ at the lower bound, i.e., at β_p. We start with the case when $g \geq 2$. The importance of this evaluation comes from the fact that monopoly welfare[16] (denote it W^{*m}.) and the Northern 'predatory' welfare evaluated at β_p are the same, i.e.,$W^{*m} = W_n^{*p}(\beta_p)$. Straightforward calculation shows that $\theta_p(\beta_p) = 1$ which implies that the North is always better off (unless all consumption takes place in the South) with a certain degree of spillovers coming to the South (or with a lax Southern IPR protection). The degree of these desirable spillovers are at least β_p.[17]

Thus, whenever $g > 2$, there is a range of spillovers which goes at least from 0 to β_p, where there is no conflict between Northern and Southern interests considering the desirable direction of change in spillovers. As will be shown, this range of congruency of interest could easily go beyond β_p, towards β_d provided that the share of the North is 'big enough'.

Intuitively, in this case ($g > 2$), the Northern government does not, in general, prefer perfect IPR protection ($\beta = 0$), since perfect protection would permit its firm to achieve an unconstrained monopoly position, which would be very harmful to domestic consumers. On the other hand, to constrain such monopoly power through competition from the Southern firm is also not the best policy due to economies of scale, caused by fixed R&D cost. Thus, the 'second best' policy (if somehow possible) would be to allow a certain amount of spillovers. It would constrain monopoly power through the credible threat of the Southern firm that would in turn result in a price equal to Southern average costs. The possibility that both North and South simultaneously benefit from relaxing IPR in the South within a certain range of the strength of IPR protection does not exist in related partial equilibrium models (see, for instance, Chin and Grossman, 1990; Deardorff, 1992). Helpman (1993), however, obtained a similar result in a rather different general equilibrium framework. In his approach, a small increase in spillovers (the 'rate of imitation' in his terminology) from zero to some positive level initiates production in the South and trade between the South and the North begins. 'As a result, the

[16]Monopoly welfare is $W^{*m} = (a-\alpha)^2(-2+6\theta-\theta g)/(g-4)^2$. Note that it does not depend on spillovers.

[17]The importance of the share in consumption in determining whether desirable spillovers are positive or not, is only confined to the region of g between $\frac{3}{2}$ and 2. In this region strategic predation is an optimal strategy even without spillovers. The simple substitution shows that $\theta^p(0) = \frac{g}{3g-4}$, implying that the share of consumption is important at the lower bound of g (two-thirds of consumption has to be in the North if spillovers are to be desirable), but as g approaches 2, the critical value, $\theta_p(0)$ is rapidly yielding $\theta_p(0) = 1$.

North can exploit its monopoly power (which it could not, to begin with) and also enjoy some gains from trade. As the deterioration of the terms of trade has only a negligible effect under these circumstances (i.e., non-zero spillovers, K.Ž.), these benefits dominate the welfare calculus' (Helpman, 1993, p. 1256). The increased Northern welfare due to increased spillovers in our partial equilibrium model stems from the fact that the Northern firm, faced with the threat of entry, charges a lower price, invests more in R&D and produces more the higher the level of spillovers. Provided that the Northern share in world consumption is not zero, the increase in consumer surplus is higher than the profit decrease, which lead to a net gain in Northern welfare. Southern welfare in this case is equal to its consumer surplus, which naturally increases with a lower price and a higher level of output.

Finally, when the Northern share of consumption exceeds a certain threshold, β_d appears as the optimal level of spillovers for the North. To find the corresponding critical value of θ, we have to solve the inequality: $dW_n^{*p}/d\beta(\beta_d) \geq 0$. This is equivalent with evaluating $\theta^p(\beta)$ at β_d:

$$\theta^p(\beta_d) = \frac{g - \sqrt{g(12+g)}}{8 + 3g - 3\sqrt{g(12+g)}} \equiv \theta^d.$$

A corollary of that result is that W_n^{*p} reaches an interior maximum if h happens to be in an interval such that $\theta^p < \theta < \theta^d$ with the accompanying optimal level of spillovers of β_n^* such that$\beta_p < \beta_n^* < \beta_d$. (It is easy to show that $d^2W_n^{*p}/d\beta^2 < 0$ for $\theta^p < \theta < \theta^d$.) The size of θ^d is what is relevant. That is, when should we expect β_d to be the optimal spillovers level for the North? To illustrate the actual relevance of θ^d, here are some concrete cases: at the R&D efficiency value of $g = 2$, $\theta^d = 1.76$ requiring that Northern consumption be higher than 43% if β_d is to be a Northern welfare maximizing level of spillovers. At a value of $g = 3$, the corresponding $\theta = 1.186$ and the critical consumption share is only 15.74% for β_d to be an optimal IRP level.

We close the above discussion by summing up some of the most interesting findings in Proposition 2.

Proposition 2 *Both North and South are better off, or at least not worse off, from increased spillovers (relaxing of the Southern IPR regime) if $g > 2$, and if initial β happens to be in an interval $\beta[0, \beta_n^*)$ provided that not all consumption takes place in the South. If the critical share of Northern consumption exceeds θ^d, then the optimal spillovers level for the North is β_d.*

4 World welfare, spillovers, and the conflict

4.1 The optimal IPR protection at the world level

A good prelude to determine the optimal IPR protection level for the world would be to look first at the level of IPR preferred by the South. This always seems to be the most problematic piece in the tale of the appropriate strength of world IPR protection. Mansfield (1989), while recognizing that it is not 'always socially beneficial for the South to strengthen IPR', emphasized that 'a reasonable amount of respect for IPR' is crucial for fostering R&D and innovation worldwide. Any lax in IPR protection in the South should be judged not only in terms of its implication for Southern innovative activity but also in terms of its impact on R&D and innovation in developed countries. Mansfield conjectures that there is reason to believe that worldwide R&D investments are below their socially optimal level. What is not clear, however, is 'whether this is a major or a minor aggravation from the point of view of the developing countries, the developed countries and the world as a whole'.

Our previous analysis of Northern and Southern welfare effects due to changes in β is of major assistance in finding the desirable world level of IPR protection. It should be clear that whenever $g > \frac{3}{2}$, the optimal β will be a corner solution (β_d) lying on the curve defined by $g_d(\beta)$, and the constrained monopoly will be the optimal market form. This follows from two facts: first, the world marginal welfare is always non-negative ($dW_w^*/d\beta \geq 0$) in both the monopoly region and the region of predation,[18] and second, the Northern firm has a natural monopoly position, which is the reason the corresponding welfare in constrained monopoly is higher than in duopoly.

Duopoly is sustainable when $g < \frac{3}{2}$ and the optimal level of IPR violation can a priori reach any value from zero to one since the world planner (e.g., WTO) has to weigh the benefits from increased spillovers (a higher dissemination of knowledge and technology) against the cost of dampened R&D incentives. It turns out that $dW_w^*/d\beta \leq 0$ as soon as the efficiency parameter slightly exceeds a unit (see Appendix C). This indicates that the world planner will prefer a tight IPR regime under these circumstances and will set β equal to zero. There will be an interior maximum only if $g < 1$.

4.2 How big is the conflict?

The controversial issue in the North-South debate on IPR protection is whether the conflict of interests characterizes their relationship as a rule. Chin and Grossman (1990), (p. 97) state that 'the conflict of interest between the North and the South in regard to the system of intellectual property rights is the rule rather than exception in our model'. In his concluding remarks, Helpman (1993) also leaves no doubt about the issue by stating 'Who benefits from tight intellectual property rights in less developed countries? My analysis suggests that if anyone benefits, it is not South'.

As far as our analysis is concerned, the shortest answer to the question concerning this conflict would be that it depends. Roughly speaking, when the R&D efficiency parameter is low ($g < 2$), one could, generally, expect to find a conflict between the North and South in regard to IPR protection. If, e.g., $g = 0.5$, then the North prefers complete protection by the South whereas the South prefers very loose IPR protection, or even no IPR protection if its share in world consumption does not exceed 71.4%. For bigger g (around 2 or larger), however, it is quite possible that both sides would prefer tight IPR regimes. If $g = 2$, then the optimal choice for both the North and the South (and correspondingly for the world planner) will be β_d, provided that both the Northern and the Southern shares are bigger than 42%. In this setting, both sides prefer β_d as the optimal level. As g approaches its highest value (g approaches 4), β_d tends to be the optimal level for both sides. In other words, if the distribution of consumption between

[18] Note that the share parameter has no meaning for the world planner since she has no interest in where the welfare is generated, thus $dW_w^*/d\beta(\theta) = dW_w^*/d\beta(\infty) > 0$.

North and South is approximately equal, then there will be no conflict between them in regard to the intensity of the IPR regime. As g increases, the potential for conflict over the optimal level of β is reduced only to the situations in which the share of consumption of either the Northern or the Southern side is rather small.

Despite the fact that the desirable level of β is the same under these circumstances, in a more realistic setting there may be, however, a qualitative difference between the North and the South in preferred market structure. One could argue that whenever the constrained monopoly and duopoly yield the same or similar level of welfare for the South, duopoly will be preferred due to other considerations (e.g., the social cost of unemployment) not captured by our model. On the other hand, the welfare-maximizing Northern government will strictly prefer constrained monopoly; i.e., it will tolerate a positive level of spillovers which will discipline its firm by forcing it to charge a limit instead of a monopoly price in a situation in which both the share and the efficiency parameters of the Northern firm are high enough. Increased competition via the presence of the Southern firm is not optimal for the North because of the scale economies of the Northern firm and its corresponding natural monopoly position. Clearly, as we have already argued, the 'second best' outcome is in this case a sort of a contestable market equilibrium, in which only one firm serves the market and its price equals the average costs of the Southern firm.

5 Conclusion

The 'R&D with spillovers' model has been applied to the problem of IPR in the North-South trade relationship context. The level of spillovers has been interpreted to reflect the strength of IPR protection. The 'spillovers' approach turned out to have several virtues. The first is the finding that the resulting market structure (duopoly, pure monopoly, or constrained monopoly) depends not only on R&D efficiency but also on the level of IPR protection. The second, and even more important one, is that the usual results in which the North generally loses and the South generally benefits by relaxing IPR protection are not the conclusions here. As we have observed, if R&D efficiency is moderate (g is around 2), and the distribution of consumption is roughly even, both countries would prefer the same level of IPR violation ($\beta = \beta_d > 0$). As R&D efficiency increases, so does the likelihood of congruency concerning the optimal (welfare maximizing) level of IPR protection and both governments would generally prefer a lax in Southern IPR protection around β_d. The reason why the Northern government would prefer a certain lax in IPR protection is the disciplinary device of spillovers to its firm which would otherwise behave as pure monopoly substantially harming its consumer surplus.

The above considerations point to the fact that the constrained world planner would also pick up the above critical level of spillovers if g is 'high enough'. Since the world planner does not have any interest from where the consumption comes, she would prefer β_d even more often than the two governments. Therefore, as soon as $g \geq \frac{3}{2}$, the welfare maximizing world planner would set spillovers at β_d. That is, the world planner would have to weigh the benefits from increased spillovers (a higher dissemination of knowledge and technology) against the cost of dampened R&D incentives only if the R&D efficiency of the North is low ($g < \frac{3}{2}$).

To summarize our discussion, the theoretical analysis of North-South intellectual property rights relations and how it affects welfare appears to be complex even in our simple model, since it is influenced not only by the three parameters (R&D efficiency, level of spillovers and share of consumption), but also by its intensity and cross-relationships. In this light, it is not difficult to agree with Helpman when he points out that the question 'Are tight intellectual property rights desirable?' cannot be answered by theoretical arguments alone. The theoretical analysis is most helpful in identifying channels through which regions are affected by such policy changes and circumstances under which the answer goes one way or the other (see Helpman, 1993, p. 1275).

***Appendix A*: Determining the critical share of Southern consumption below which strong enforcement of IPR is desirable for the South**

Determination of the critical share of Southern consumption below which stronger enforcement of IPR is desirable for South implies solving the equation $W_s^*(\beta_d;\theta) = W_s^*(\beta^*,\theta)$ for θ_c. Substituting

$$\beta_d = \frac{3}{2} - \frac{\sqrt{g(12+g)}}{2g} \tag{15}$$

into the following equation:

$$W_s^* = \frac{(A-\alpha)^2[(-6+(2-\beta)(1-\beta)g)^2 + 2\theta(-3+(2-\beta)(1-\beta)g)^2]}{2\theta(9-(2-\beta)^2 g)^2} \tag{16}$$

yields

$$W_s^*(\beta_d;\theta) = \frac{18(A-\alpha)^2}{\theta(12-g-\sqrt{g(12+g)})^2}$$

Similarly, to get $W_s^*(\beta^*;\theta)$ it is necessary to solve $dW_s^*(\beta_d;\theta)/d\beta = 0$ for β^*. Since the explicit expression for β^* in terms of g and θ is rather messy, we keep the symbol β^* instead. Thus, solving $W_s^*(\beta^*;\theta) - W_s^*(\beta_d;\theta) = 0$ for θ_c and denoting the arg. maximum as β^*, we get

$$\begin{aligned}\theta_c = {} & \frac{(207 + (-2+\beta^*)g(60 - 78\beta^* - 8g + 28\beta^* g - 26\beta^{*2} g + 7\beta^{*3} g))}{4(-3+2g-3\beta^* g+\beta^{*2} g)^2(12+5g-4\sqrt{g(12+g)})} \\ & \times \frac{\sqrt{g(12+g)} + (-378 - 135g - 432\beta^* g + 180\beta^{*2} g + 168 g^2}{4(-3+2g-3\beta^* g+\beta^{*2} g)^2(12+5g-4\sqrt{g(12+g)})} \\ & - \frac{192\beta^* g^2 - 66\beta^{*2} g^2 + 96\beta^{*3} g^2 - 18\beta^{*4} g^2 - 24 g^3}{4(-3+2g-3\beta^* g+\beta^{*2} g)^2(12+5g-4\sqrt{g(12+g)})} \\ & + \frac{88\beta^* g^3 - 106\beta^{*2} g^3 + 52\beta^{*3} g^3 - 9\beta^{*4} g^3)}{4(-3+2g-3\beta^* g+\beta^{*2} g)^2(12+5g-4\sqrt{g(12+g)})}.\end{aligned}$$

Table 1:

g	θ^c	Critic.cons.share
1.6	1.28	78.13%
2.0	2.38	41.95%
2.5	4.94	20.23%
3.0	11.6	8.62%
3.5	44	2.27%

To see the actual implications of the critical share below which it pays to have rather strict IPR protection, we calculate the particular values of θ^c for a given g in Table 1.

Appendix B: $W_s^*(\beta_d;\theta)$ as a point of the maximum for given g and θ

To show that $W_s^*(\beta_d;\theta)$ is a point of the maximum, we evaluate $dW_s^*(\beta;\theta)$ at β_d. Taking the derivative of $W_s^*(\beta;\theta)$ with respect to β and evaluating the derivative at β_d yields the expression

$$\frac{dW_s^*}{d\beta}(\beta_d) = \frac{12(A-\alpha)^2(18g^2+g-6\sqrt{g(12+g)}+g\sqrt{g(12+g)})}{\theta(-12+g+\sqrt{g(12+g)})^3}.$$

The sign of (B.1) is equal to the $(-12+g+\sqrt{g(12+g)})$. Since $g \in (0,4)$, this expression is always negative. This implies $dW_s^*(\beta_d;\theta) < 0$ for all permissible values of g and θ.

Appendix C: World's optimal level of spillovers

The world welfare function for the case in which duopoly is an equilibrium market form is given by

$$W_w^* = \frac{(A-\alpha^2)^2(72-56g+80\beta g-26\beta^2 g+12g^2)}{2(-9+4g-4\beta g+\beta^2 g)^2} - \frac{36\beta g^2+39\beta^2 g^2-18\beta^3 g^2+3\beta^4 g^2}{2(-9+4g-4\beta g+\beta^2 g)^2} \tag{17}$$

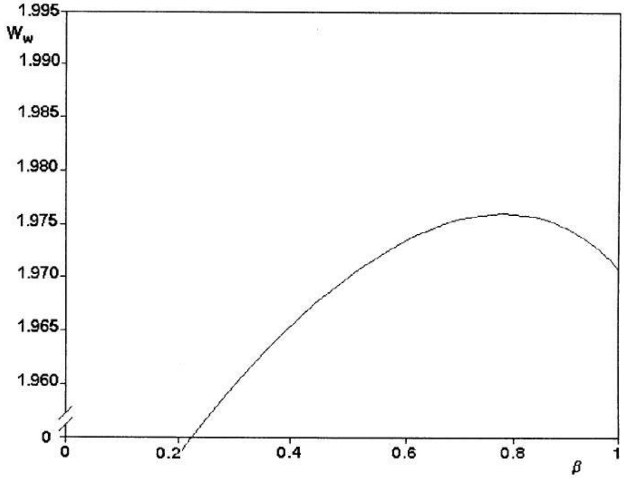

Figure 2: The world welfare function when R&D efficiency is small ($A = 10, \alpha = 8, g = 0.5$)**; the optimal IPR level is** $\beta* = 0.688$**.**

When Northern R&D efficiency is small ($g < 1.02$), the optimal world level of IPR protection is somewhere between the Northern desirable level ($\beta = 0$) and the Southern desirable level (which is $\beta = 1$, or very near to one, in the case that the Southern share of consumption is rather large). Thus, e.g., the typical shape of W_w^* for this range of g is shown in Fig. 2. For larger values of $g(g > 1.02)$, the world welfare is maximized at $\beta^* = \beta_d$.

Strategic Trade Policy, Intellectual Property Rights Protection, and North-South Trade

In this paper, we analyze the issue of optimal tariffs when the Northern and Southern firms compete in quantities in an imperfectly competitive Northern market and there are potentially varying degrees of intellectual property rights (IPR). violation by the South. IPR violation is reflected through the leakage of technological knowledge ('spillovers'). from the Northern to the Southern firm creating unit cost reduction. It is shown that optimal tariffs in this framework are always higher than in the simple duopoly model since they serve here not only as profit shifting devices but also as instruments that influence domestic innovative activity, generate scale economies and countervail the IPR violation of the South. The other notable difference from the standard duopoly model is that positive tariffs may be desirable from the world welfare point of view.

1 Introduction

The appearance of strategic trade theory represented a challenge to the prevailing concept of free trade and suggested a possible new paradigm in international trade. One of its main messages was that it is, in general, socially beneficial for a government to intervene by tariff, subsidy, quotas, etc. in order to secure higher profits for its domestic firms. Despite its theoretical attractiveness and tempting conclusion, 'strategic trade policy' arguments have not convinced the majority of trade economists that the profession's traditional support for free trade should be abandoned. To a large extent, this reaction reflected the a priori bias of trade economists against trade activism, rather than being the implication of rigorous analysis (see, for instance, Krugman, 1987; Bhagwatti, 1989; Grossman and Maggi, 1998). Their intuition may have been right in general, since some results, based on 'calibration' models, indicate that indeed the gains are at best modest when strategic trade policies are applied as profit shifting or facilitating devices (see Venables, 1994). However, in the particular case where free trade leads to the unilateral violations of intellectual property rights (IPR), losses may be large due to the well known appropriability problem.[1] Moreover, lack of appropriability may result in lower output that does not fully utilize scale economies (see Krugman, 1984 for a discussion of scale economies in the international trade context).

The Uruguay round of the GATT negotiations and several recent cases where trade sanctions have been imposed suggest that the issue of (trade-related) IPR violation and its prevention is especially critical in NorthSouth trade. For instance, the European Community suspended Generalized System of Preferences benefits for Korean products in 1987 as a response to Korean violations of IPR. A year later, the United States imposed a 100% (punitive) tariff against some Brazilian goods (see Braga, 1990). In 1995, the US

[1] See Levin et al. (1987) for a comprehensive empirical analysis of the causes, forms and aspects of attenuated appropriability due to inability to capture the induced benefits of innovating activity and intellectual property. Vishwasrao (1994), for example, refers to the documents of the United States International Trade Commission (1988) reporting the aggregate losses for US firms amounting to US$23.8 billion due to inadequate IPR protection.

threatened China with a similar 100% (punitive) tariff on exports to the US in response to IPR violations.

From the academic point of view, the importance of IPR protection in the NorthSouth relationship has already made its way into economic encyclopedias. [2] The theoretical literature in this area focuses mainly on the social welfare consequences of different levels of IPR protection, including, for example, conditions under which the South benefits in welfare terms from protecting IPR, the welfare consequences for the North if the South fails to protect IPR, optimal IPR protection from a world welfare point of view, and the level of conflict between North and South (Chin and Grossman, 1990; Diwan and Rodrik, 1991; Deardorff, 1992; Helpman, 1993; Vishwasrao, 1994; Žigić, 1996a, 1998a). The empirical literature, on the other hand, has concentrated mostly on measurable considerations such as the impact of IPR protection on the type, structure and volume of Northern foreign direct investment in the South (Ferrantino, 1993; Mansfield, 1994), the role of IPR protection as a part of the international policy mix (Ferrantino, 1993), and the impact of IPR protection on economic growth (Gould and Gruben, 1996).

This paper aims to show that the distinctive role of strategic trade policy in the specific case when IPR violation prevails is not as a profit shifting or facilitating device but rather as a specific policy instrument that may help overcome appropriability problems. More specifically, we combine the strategic trade approach with the issue of IPR protection in order to explore the role of tariffs as instruments influencing IPR protection, innovative activity and trade patterns. In other words, by demonstrating that tariffs can promote innovation and attenuate or eliminate the illegal appropriation of research and development (R&D) output, this paper provides an alternative rationale for the policy recommendations put forward in the strategic trade literature.

IPR violations are assumed to be closely related to 'R&D spillovers', defined as the leakage of important pieces of technical information, which can be used by the recipient at zero or small marginal costs. The channels through which spillovers take place have been well documented (see, for instance, Mansfield, 1985; Mansfield et al., 1981; Levin et al., 1987; Neven and Siotis, 1996). This information may come from common suppliers of inputs and customers, reverse engineering, hiring of employees from innovating firms, informal communications networks among engineers and scientists, industrial espionage and technological sourcing, publications and technical meetings, patent disclosure, conversations with the employees of innovating firms, etc. As Mansfield (1985) pointed out, this intelligence-gathering process varies considerably from industry to industry. Bayoumi et al. (1996) stress the importance of international trade as a major transmission mechanism by means of which spillovers take place. They refer to 'mutual interdependence across countries' manifested in the usage of common intermediate goods, consumer and capital goods, technology transfer and learning as a source of important technical information.

R&D spillovers in general (and in the context of international trade in particular) have two components or, in other words, are subject to two restrictions: technological and IPR restrictions. Thus, even when it is rather easy to gain relevant information about new products and processes (that is, when technological restriction is 'not binding'),

[2] The third volume of The Handbook of International Economics contains, in the chapter 'Technology and Trade', a separate section entitled 'Intellectual Property Rights and NorthSouth Trade.' See Grossman and Helpman (1995).

there is the question of whether these pieces of information could be legally exploited by recipients. This is where the issue of IPR comes into play. Namely, the government has the discretion to determine how easy it will be 'to invent around a patent', just what the scope of a patent will be, how easy it will be to copy trademarks, whether the country complies with the Berne and Paris conventions, or not, etc.

The interaction of tariffs and IPR protection in the NorthSouth trade relationship is modeled by relying on the concept of strategic interaction. The market of interest is the Northern market since the real world examples of trade sanctions such as those presented above indicate the existence of products which the South exports to the Northern market where violations of IPR by the South have taken place. [3] Moreover, numerous US firms have cited huge losses in sales incurred in their domestic (that is, the US) market due to the inadequate foreign protection of intellectual property. [4] The 'Northern' market is assumed to be important for the Southern exporter either because it is big, or because the North has enough power to seriously constrain or even prevent the Southern firm selling the goods in question on the world market (or some 'third market'). [5] Finally, we assume that the IPR in the Northern market is strict so that other domestic firms are not allowed to imitate the innovating firm, which is therefore fully protected by its patent.

We consider a sequential (four-stage) game. In the first stage, the Southern government selects a level of IPR protection taking into account the impact on the subsequent choice of tariff (and the choice of all other strategic variables). In the second stage, the Northern government selects the tariff, taking into account the ensuing R&D investment choice by its firm and subsequent competition in quantities. In the third stage, the Northern firm chooses its R&D investment taking into account the spillovers and following competition in quantities. Finally, in the fourth stage, the firms select quantities, and consequently, profits and welfare are realized.

Analytically, the model is related to the 'R&D with spillovers' types of models. [6] The underlying idea is that the 'spillovers parameter', β, measures the strength of IPR protection. Thus, we assume that by setting a loose IPR regime the Southern government stimulates imitation and thus enhances spillovers and vice versa. Looser IPR would imply higher spillovers so that the intensity of spillovers is then interpreted as reflecting the strength of IPR protection. An alternative interpretation not exploited here is that the technological restrictions are always non-binding so that relevant information can be obtained relatively easily but the available information can be used legally by the Southern firm only up to the level of the strength of IPR protection.

[3] Another NorthSouth issue relevant to IPR emerges when Northern firms (usually multinational corporations) are, or consider becoming, located in the South (see, for instance, Mansfield, 1985, 1994; Ferrantino, 1993; Vishwasrao, 1994).

[4] See the International Trade Commission (1988) survey devoted to IPR protection where 64 US corporations reported losses in sales totalling US$1.80 billion in the domestic market due to foreign IPR violations.

[5] The example of this is the recent ChinaUS case when the US threatened China with the sanctions due to the IPR infringement on CDs. The US had the power to effectively prevent China redirecting sales of the CDs to, for instance, the European Union or Latin America.

[6] For the examples of 'R&D with spillovers' models [games], see, for example, Katz (1986), Spence (19860, D'Aspremont-Jacquemin (1988), De Bondt et al. (1992), Kamien et al. (1992), and Suzumura (1992).

The new insights the analysis provides can be summarized as follows.

(a) The impact of tariffs on the innovative activity of the Northern firm hinges crucially on the prevailing market form. If, for instance, duopoly is the outcome of the game, then the tariff serves as a technological policy instrument to restore the incentive for investing in socially desirable R&D.

(b) Depending on the prevailing market structure, tariffs reduce or completely eliminate illegally appropriated research output and thus thwart IPR violations by the South.

(c) Despite the fact that the level of IPR protection is assumed to be under the full control of the Southern government, duopoly is a viable market form only if the efficiency of innovative activity is sufficiently 'small'. That is, beyond a given innovative efficiency threshold, a welfare maximizing Northern government will prefer to impose a prohibitive tariff that forces the Southern firm to leave the market regardless of the level of IPR protection.

(d) Due to its impact on innovative activity, a positive tariff may be optimal even from the world welfare point of view.

A few testable predictions also arise from the model: First, given that the Southern government sets the IPR for all industries under the same conditions, we should observe higher tariff levels on products for which the production process (or the product) is subject to higher spillovers. [7] Second, the innovating firm (firms where scale economies are important) faced with spillovers but without tariff (or any other effective IPR) protection will operate at a lower scale in comparison to firms where there is effective IPR protection.

The remainder of the paper proceeds as follows. Section 2 states and discusses the assumptions of the game between the Northern and the Southern firms, develops the core duopoly model, and discusses the role of tariffs in it. Section 3 is devoted to the solution of the third and fourth stages of the game and to comparative statics concerning the impact of tariffs on the relevant economic variables in both the duopoly and constrained monopoly outcomes. This analysis is a prerequisite for the subsequent analysis of optimal tariffs and the optimal IPR protection level examined in Sections 4 and 5, respectively. Section 6 is devoted to world welfare considerations while Section 7 contains concluding remarks.

2 The model

2.1 Assumptions

Two firms, each from one of the two types of 'countries' North and South engage in international trade. A more concrete definition of 'North' can be found in the cluster analysis of countries' international IPRs and other international policies performed by Ferrantino (1993). He came up with several stylized facts, the first one being that

[7] I am grateful to a referee for pointing this out.

‘ ...the intranational economic polices of developed countries are markedly different than those of developing countries.’ An examination of his Table 1 shows that this is valid for IPR policy in particular. On the other hand, the ‘South’ as a group of countries with rather weak IPR protection can be, for instance, represented by the ‘Asian New Industrial Countries’, which have a rather low value describing the degree of IPR protection (see Table 1 in Ferrantino, 1993). As Helpman (1993) pointed out, most technological imitation takes place in newly industrialized countries, while the majority of less developed countries engage in this activity only marginally. Thus, the former group is relevant in the model developed in this paper and is referred to as the ‘South’.

As was already indicated, the market of interest is the Northern market. By assumption, the Northern firm produces only for the domestic market while the Southern firm exports all of its production to the Northern country.Alternatively, and, more generally, one could introduce the ‘segmented market’ hypothesis in which the Southern firm produces for both markets but it perceives the two markets to be different (e.g., the Southern firm considers the Northern market to be different from its domestic market and, consequently, its optimization problem for the Southern market is independent of its optimization decision for the Northern market). In other words, arbitrage is not important (because it may be too costly) and it is not allowed for in the analysis (see, for instance, Brander and Krugman, 1983; Spencer and Brander, 1983; Brander and Spencer, 1984). In addition, we assume that the export to the Northern market is essential for the Southern firm. [8] This assumption is needed to prevent the uninteresting and trivial outcome in which IPR violation is complete and the Southern firm produces only for its domestic market or for some ‘third markets’.

We further assume that initially both the Northern and the Southern firms have access to an ‘old’ technology to produce a demanded good. However, the Northern firm is the only one assumed to conduct R&D. Again, this assumption is taken almost for granted in the related literature. The assumption is, however, not so restrictive if we recall that the world patent statistics show that developing countries hold only 1% of existing patents (see Braga, 1990 and Appendix C concerning the R&D expenditures statistics of the ‘North’ and ‘South’).

The Southern firm does not perform R&D but benefits through lax IPR protection reflected in costless spillovers from the R&D activity of the Northern firm. The focus is on what is known as ‘process innovations. [9] An ‘R&D production function’ captures the effects of R&D on unit costs. The function displays ‘diminishing returns’, that is, every additional dollar invested in decreasing unit costs results in less and less of a reduction in unit costs. [10]

Much like in Žigić (1998b), the core model in this paper is a model of duopolistic competition between the Northern (or ‘domestic’) and the Southern (or ‘foreign’) firm.

The domestic firm has unit costs of production $C = \alpha - f(x)$ where x stands for the R&D expenditures and $f(x)$ can be viewed as an ‘R&D production function’ with

[8] The reason for this may be a too small Southern market or balance of payment considerations. Furthermore, the Northern market may be the only relevant market for the good under consideration, or its presence on the Northern market may enhance spillovers, etc.

[9] As Spence (1986) shows, the difference between the concept of process innovation vis-a-vis product innovation is semantic rather than fundamental.

[10] This specification reflects empirical observations and was listed, for instance, as a ‘stylized fact’ in Dasgupta (1986), p. 523.

classical properties, $f(x) \neq \alpha, f(0) = 0, f'(x) > 0$ and $f''(x) < 0$. α is a parameter that can be thought of as pre-innovative unit costs describing the old technology initially accessible to both the Northern and the Southern firms.

The foreign firm benefits through spillovers from the R&D activity carried out by the domestic firm. If it exports its products, the foreign firm also pays a specific tariff t per unit of production. Its unit (pre-tariff) cost function is $c = \alpha - \beta f(x)$ and β denotes the level of spillovers (or, equivalently, level of the strength of IPR protection). The value of β can take values from zero to one.

The inverse demand function of the domestic market (assumed to be linear with units chosen such that the slope of the inverse demand function is equal to one) is $P = A - Q$ where $Q = q_s + q_n$ and $A > \alpha$. Parameter A captures the size of the market, whereas q_s and q_n denote the choice variables, that is, the corresponding quantities of the domestic and the foreign firms.

Social welfare (W) is defined as the sum of consumer surplus (S) and the domestic firm's profit (P) and the revenue from tariffs (R). In the case of a linear demand, consumer surplus is defined as $S = (1/2)(q_s + q_n)^2$.

2.2 The role of tariff

The optimal policy mix when foreign and domestic firm compete on the home market is well-known tariff-cum-subsidy scheme where a tariff is imposed on imports while domestic output is subsidized. The 'division of labor' between these two instruments is such that the subsidy is aimed at eliminating the domestic oligopoly distortion [11] whereas the tariff is used to transfer some foreign income to the domestic treasury (see for instance, Cheng, 1988; Dixit, 1988; Levy and Nolan, 1992). However, as noted by Dixit (1988), subsidies are likely to be an infeasible instrument. Moreover, Bhattacharjea (1995) demonstrated that implementing a subsidy might be troublesome for numerous reasons arising from the high information content required to implement the optimal subsidy to the distorting effects of taxes necessary to finance the subsidy. Similar considerations are valid for the subsidizing R&D investment. Thus, following these authors, we also confine our analysis to tariffs as only feasible instruments. [12]

Tariffs change the nature of the 'game' among foreign and domestic firms by altering the strategic interactions among them. What is crucial to this result is that the government has the credibility to commit to its policy choice (e.g., tariff) before the firms make their choices.

Another important feature of a tariff is that it is a device by means of which the government can influence the market structure. Confining our analysis, for instance, to the simplest case of two firms, there are three possible market patterns which could arise

[11] Oligopoly distortion comes from the fact that the equilibrium price exceeds marginal costs. The optimal subsidy eliminates completely this distortion. See Neary (1994) and Leahy and Neary (1997) for the thorough analysis of the optimal subsidy in the oligopoly with spillovers setup and Hinloopen (1997) for the discussion of the R&D subsidy.

[12] As referee pointed out, subsidy as an instrument might be used when domestic firm compete on the 'third market' since tariff is not available in this case. As an implication of this argument, it might be reasonable to expect that the Southern government supports its firm by an export subsidy. However, allowing for this export subsidy will change the analysis in no qualitative way. The only consequence will be the higher optimal tariff since tariff will act then as a 'countervailing duty' (see Dixit, 1984).

in equilibrium as a consequence of the erected tariff: duopoly, constrained monopoly, and unconstrained monopoly. Thus, duopoly will be the viable market form unless the tariff reaches a certain critical value (labelled 't_p') at, and beyond, which the constrained monopoly arises. The optimal strategy for the domestic firm is to commit to the level of R&D for which the rival firm's optimal production (as well as profit) is zero. By increasing the tariff beyond t_p the difference in the marginal costs becomes so large that at (and beyond) the value of the tariff (denoted by t_m), the domestic firm gains an unconstrained monopoly position. [13]

3 The game – the last two stages

3.1 The case of duopoly

Duopoly is assumed to be a viable market form before the tariff is set. We now start to solve the game backwards. In the last (fourth) stage, the firms choose the equilibrium quantities. The domestic firm maximizes

$$\max_{q_n}[\pi_n] = (A - Q)q_n - Cq_n - x \tag{1a}$$

given q_s.

The first-order condition for a maximum is $\partial\pi/\partial q_n = 0$ and yields $A-2q_n-q_s-C = 0$.

The optimizing problem for the foreign firm yields [14]

$$\max_{q_s}[\pi_s] = (A - Q)q_s - cq_s - tq_s \tag{1b}$$

given q_n and t. The first-order condition is: $A - 2q_s - q_n - c - t = 0$. Solving the reaction functions yields the Cournot outputs as a function of R&D investment:

$$q_n(x) = \frac{(A + c - 2C + t)}{3} \tag{2a}$$

$$q_s(x) = \frac{(A - 2c + C - 2t)}{3} \tag{2b}$$

Substituting Eqs. (2a) and (2b) into Eq. (1a) yields the domestic firm profit function expressed in terms of R&D investment and tariff:

$$\pi_n(x) = \frac{(A + c - 2C + t)^2}{9} - x \tag{3}$$

In the third stage of the game, the domestic firm selects x in order to maximize its profit. Note that the set of R&D action is given by X where $x \in X = [0, x^*]$ and x^* is

[13]We assume away the possibility of negative tariff (subsidizing imports) since it is most likely infeasible.

[14]We neglect the profit which the Southern firm earns on its home market if we adopt segmented market hypotheses since it is irrelevant to the maximization problem under considerations.

the solution of the equation $\alpha - f(x) = 0$.[15] Substituting expressions for C and c into Eq. (3) and maximizing with respect to R&D investment gives the first order condition and (implicitly) x_c^*:

$$\frac{2(2-\beta)(A-\alpha+t+(2-\beta)f(x_c^*))f'(x_c^*)}{9} = 1 \tag{4}$$

The second order conditions requires

$$\frac{2(2-\beta)[(2-\beta)f'(x_c^*)^2+(A-\alpha+t+(2-\beta)f(x_c^*))f''(x_c^*)]}{9} \leq 0 \tag{5}$$

3.2 The impact of tariffs on R&D, profit and consumer surplus in duopoly

We first start with the R&D expenditures.

Lemma 1 *An increase in tariff increases the R&D expenditures if duopoly is the equilibrium market form in the post-tariff situation.*

Proof Differentiating Eq. (4) with respect to t gives

$$\frac{dx_c^*}{dt} = \frac{f'(x_c^*)}{-[(2-\beta)f'(x_c^*)^2+(A-\alpha+t+(2-\beta)f(x_c^*))f''(x_c^*)]} > 0 \tag{6}$$

$f'(x^*)$ is positive by definition while the denominator of Eq. (6) is also positive, as can be seen from comparing it with the second order condition (5).

The intuition for this result lies in a specific 'feedback' mechanism: an increase in the tariff increases the unit costs of the competitor and leads to a higher output of the domestic firm in the new equilibrium. The higher the output, the more it pays to reduce unit costs and, therefore, the higher R&D investments will be. Higher R&D investments enhance the firm's cost advantage that results in higher equilibrium output and so on.

Since an increase in tariff has a positive both direct and indirect (via increased R&D expenditures) impact on the output of the Northern firm, the corollary of Lemma 1 is that tariff in duopoly may help better exploit the scale economies of the firm. [16] Thus, the testable prediction that arises at this point is that, ceteris paribus, the firms faced by IPR violation but protected by tariff operate at higher scale than the firms of comparable sizes where there is IPR violation but no tariff protection.

Lemma 2 *An increase in the tariff brings about higher profit if duopoly is the equilibrium market form in a post-tariff situation.*

[15] We assume that α is big enough that the optimal R&D is always in the interior of the set X.

[16] It can be shown that average costs of the Northern firm are monotonically declining as tariff increase from zero on. The discussion on the scale economies generated by the imposition of tariff within analyzed model can be obtained from the author upon request.

Proof First note that $d\pi^*(x_c^*, t)/dt = \partial\pi^*(x_c^*, t)/\partial x \;\; dx_c^*/dt + \partial\pi^*(t)/\partial t = \partial\pi^*(t)/\partial t$ since the first part is zero according to the first order condition. Finally,

$$\begin{aligned} \frac{d\pi^*(x_c^*, t)}{dt} &= \frac{\partial\pi^*(t)}{\partial t} \\ &= \frac{2[A - \alpha + t + (2 - \beta)f(x_c^*)]}{9} > 0 \quad \text{for} \quad t \in [0, t_p] \end{aligned} \tag{7}$$

holds.

Lemma 3 *The impact of a tariff on consumer surplus is ambiguous a priori.*

Proof $dS^*(x_c^*, t)/dt = \partial S^*(x_c^*, t)/\partial x \;\; dx_c^*/dt + \partial\S^*(x_c^*, t)/\partial t$ where $\partial S^*(x_c^*, t)/\partial x \;\; dx_c^*/dt > 0$ and $\partial\S^*(x_c^*, t)/\partial t < 0$.

To see this, note that

$$S^*(x_c^*, t) = 1/2(q_s^* + q_n^*)^2 = \frac{[2(A - \alpha) - t + (1 + \beta)f(x_c^*)]^2}{18} \tag{8}$$

The sign of $\partial S^*(t)/\partial t$ is then

$$\frac{\partial S^*(t)}{\partial t} = \frac{2(\alpha - A) + t - (1 + \beta)f(x_c^*)}{9} < 0 \;\; \text{for} \;\; t \in [0, t_p]$$

and

$$\begin{aligned} \frac{\partial S^*(x_c^*, t)}{\partial x} &= \frac{(1 + \beta)[2(A - \alpha) - t + (1 + \beta)f(x_c^*)]f'(x_c^*)}{9} > 0 \\ &\Rightarrow \frac{\partial S^*(x_c^*, t)}{\partial x}\frac{dx_0^*}{dt} > 0 \quad \text{for} \quad t \in [0, t_p] \end{aligned}$$

As is well known, the direct effect of a tariff on consumer surplus is always negative, since price is higher in the new equilibrium. The indirect effect of the tariff on consumer surplus is, however, always positive in duopoly, since increases in the tariff stimulate investment in R&D (see Lemma 1), which, in turn, increases output and consumer surplus. Thus, the sign of $dS^*(x_c^*, t)/dt$ is a priori ambiguous.

3.3 The constrained monopoly and strategic predation

Strategic predation (or limit pricing) behavior is the optimal strategy for the domestic firm in the situation in which, for a given t, predatory profit is equal to or bigger than the profit in duopoly. Equivalently, this strategy becomes optimal if the imposed tariff reaches or exceeds a certain critical level (t_p). The timing of the game remains the same as before. We refer here only to the last two stages: in the second to last stage, the domestic firm commits to an R&D level which forces the foreign firm to choose zero output in the last stage of the game. In the last stage, two firms are supposed to compete in quantities, but the best that the foreign rival can do under the given circumstances is to produce zero quantity and thus exit the market. The domestic firm, which remains in the market, then chooses the monopoly output. However, this output (and correspondingly, this price) is generally different than the output which would result were the domestic firm to select the unconstrained monopoly R&D expenditures. [17]

The corresponding predatory level of R&D (labelled x_p^*) is implicitly obtained by substituting the expressions for C and c into Eq. (2b) and equating this expression to zero:

$$\frac{A + \alpha - 2t - f(x_p^*) - 2(\alpha - \beta f(x_p^*))}{3} = 0 \tag{9}$$

where t is now from the interval $t \in [t_p, t_m]$. Equating Eq. (2b) to zero when $x = x_c^*$ and solving for tariff yields 't_p':

$$t_p = \frac{A - \alpha - (1 - 2\beta) f(x_c^*)}{2} \tag{10}$$

Tariff t just suffices to eliminate the competitor from the market and we refer to it as a 'predatory tariff'.[18] Differentiation of Eq. (9) with respect to t provides us with two important additional lemmas:

Lemma 4 *An increase in tariff decreases R&D expenditures if spillovers are small* ($\beta < 1/2$) *provided that strategic predation is the optimal strategy for given* t.

Proof

$$\frac{dx_p^*}{dt} = \frac{-2}{(1 - 2\beta) f'(x_p^*)} < 0 \qquad \text{if} \;\; \beta < 1/2.$$

The question is, however, what caused such a reverse reaction of the domestic firm here in comparison with its behavior in the duopoly case. (Recall that in duopoly the optimal R&D increases as a response to an increase in the tariff).

The answer is not difficult once we understand the logic of 'predatory' behavior. When the domestic firm preys, and there are small spillovers, it spends more resources on innovative activity than it would if it followed myopic (unconstrained monopoly) profit maximization (see Appendix A for formal proof). In other words, the firm commits to higher R&D to induce the exit (or prevent the entry) of the rival. An increased tariff has the same effect. In fact, the government, by increasing the tariff (assumed to be initially in the predation interval $t \in [t_p, t_m]$), preys somewhat for its firm, and it pays for the firm to decrease its R&D expenditure towards the (monopoly) profit maximizing level of R&D investment after the tariff has been increased. These considerations, however, bear an important policy implication: a tariff set too high will decrease R&D spending, decrease output and, as a result, may have a counterproductive implication for social welfare. This particular situation is consistent with the stylized fact reported in Braga

[17] For an excellent and comprehensive review of the entry deterrence and predation, see Martin (1993).

[18] Note that $t_m = [A - \alpha - (1 - 2\beta) f(x_m^*)]/2$ where x_m^* stands for the R&D investment which an unconstrained monopoly would select. Further, note that $t_m \geq t_p$ (see Appendix B).

and Willmore (1991), where technological innovativeness is negatively related with the degree of trade protection. Here, this is the case when $\beta < 1/2$ and when high trade protection expressed in tariff $t \in [t_p, t_m]$ induces domestic firm to undertake the strategic predation strategy.

The policy conclusions are exactly reversed in the situation characterized by high spillovers ($\beta > 1/2$).

Lemma 5 *An increase in tariff increases R&D expenditures if spillovers are large ($\beta > 1/2$) and predation is an optimal strategy for given t.*

Proof Analogous to Lemma 2.

Note that here, the actual level of R&D is lower than the corresponding monopoly R&D (see Appendix A) due to the high disincentives caused by spillovers. An increase in tariff lessens potential competition from the foreign firm and reduces disincentives to invest in R&D. Thus, the optimal response of the profit-seeking firm is to increase the R&D level and move towards the monopoly (or myopic) profit maximizing point. The policy concern now is not to put the tariff too low.

Furthermore, observe that, at the level of spillovers of one-half ($\beta = 1/2$), the optimal level of R&D coincides with the 'decision theoretical' solution (see Appendix A). That is, the selected level of R&D to induce the exit of the foreign firm is the same as if the domestic firm were an unconstrained monopoly, ($t_p = t_m$ at $\beta = 1/2$).

What remains to be discussed is the impact of the tariff on predatory profit and consumer surplus which arises in these circumstances. The domestic firm selects the R&D investment, x_p^*, in such a way as to exclude the foreign firm. Given x_p^*, the last stage payoff is given by:

$$\max[\pi^p] - (a - q_p)q_p - Cq_p - x_p^*. \tag{11}$$

The first-order conditions for a maximum yields,

$$\frac{d\pi^p}{dq_p} = 0 \Rightarrow A - 2q_p - C(x_p^*) = 0 \Rightarrow q = \frac{A - C(x_p^*)}{2} \tag{12}$$

Substituting Eq. (12) into Eq. (11) gives the predatory profit function $\pi^p(x_p^*)$ as a function of predatory R&D expenditures:

$$\pi^p(x) = \frac{(A - \alpha + f(x_p^*))^2}{4} - x_p^*. \tag{13}$$

Lemma 6 *An increase in tariff induces higher profit if constrained monopoly is the equilibrium market form in a post-tariff situation.*

Proof Differentiating Eq. (13) with respect to t reveals only the existence of the indirect effect, $\partial\pi^p/\partial x \; dx_p^*/dt$ since the tariff now influences profit only via its impact on R&D expenditures. Note that $\partial\pi^p/\partial x < 0$ if $\beta < 1/2$ due to overinvestment in

R&D implying $x_p^* > x_m^*$. If, however, $\beta > 1/2$, then $\partial\pi^p/\partial x > 0$ since large spillovers produces large disincentive to invest in R&D and, as a consequence, $x_p^* < x_m^*$ holds (see Appendix A). Combining these results with Lemmas 4 and 5 yields unambiguously $d\pi^p/dt = \partial\pi^p/\partial x \; dx_p/dt > 0$

Thus, a tariff, irrespective of the level of spillovers, improves the profit of the domestic firm, since it dampens the strength of the potential competition from the foreign firm and brings the domestic firm closer to the unconstrained monopoly position. As far as consumer surplus in the 'predation region' is concerned, here also only an indirect effect of tariff exists and its sign is entirely determined by the level of spillovers.

Lemma 7 *An increase in tariff generates an increase in consumer surplus if spillovers are large* ($\beta > 1/2$) *whereas the opposite holds for small spillovers* ($\beta < 1/2$).

Proof Note that now consumer surplus, $S^{p*} = (A-\alpha+f(x_p^*))^2/8$ whereas its derivative is:

$$\frac{dS^{p*}}{dt} = \frac{\partial S^{p*}}{\partial x}\frac{dx_p^*}{dt} = \frac{(A-\alpha+f(x_p^*))f'(x_p^*)}{4}\frac{dx_p^*}{dt}.$$

Since $\partial S^p/\partial x > 0$ always and $dx_p^*/dt > 0$ for $\beta > 1/2$, this implies that $ds^{*p}/dt > 0$ for $\beta > 1/2$. Thus, $dS^p/dt = \partial S^p/\partial x \;\; dx_p/dt > 0$ if $\beta > 1/2$. By the same token, note that $dS^{*P}/dt < 0$ for $\beta < 1/2$.

An increase in R&D expenditures has always a beneficial effect on consumer surplus. When coupled with large spillovers the overall effect of tariff is unambiguously positive since an increase in tariffs boosts R&D expenditures. When spillovers are small, however, the optimal reply to an increase in tariffs requires cutting R&D expenditures, thus, lowering the consumer surplus.

3.4 Impact of tariff on the appropriated research output by the South

The total research output appropriated by the South through IPR violations is defined as $F[x_c^*(t), t] \equiv \beta f(x_c^*)q_s^* =$

$$F[x_c^*(t), t] \equiv \frac{\beta f(x_c^*)(A-\alpha-2t-(1-2\beta)f(x_c^*))}{3}$$

whereas the impact of tariff's change is given as $dF(t)/dt = \partial F(t)/\partial x \;\; dx_c^*/dt + \partial F(t)/\partial t =$

$$\frac{dF(t)}{dt} = \frac{-2\beta f(x_c^*)}{3} + \frac{\beta(A-\alpha-2t-(1-2\beta)f(x_c^*))f'(x_c^*)}{3}\frac{dx_c^*}{dt}. \quad (14)$$

To illustrate intuition that $dF(t)/dt < 0$, we use here a specific R&D production function $f(x^*) = (gx^*)^{1/2}$ evaluated at the optimal R&D investment, x^* (see expression (19) for the value of x^*). Substituting $(gx^*)^{1/2}$ and its derivative for $f(x_c^*)$ and $f'(x_c^*)$ in Eq. (14), respectively, and evaluating the expression at zero tariff, [19] we obtain

[19]Note from Eq. (14) that dF/dt monotonically declines in t, thus, $dF/dt(0) < 0$ is sufficient condition for $dF/dt(t) < 0$.

$$\frac{dF(0)}{dt} = \frac{(A-\alpha)(-2+\beta)\beta g(3-2\beta g+\beta g)}{(9-(2-\beta)^2 g)^2}.$$

Taking into account the values of g and β consistent with duopoly (see Section 4.2 and Fig. 1), $Sign[dF/dt(t)] = Sign[-2+\beta] = -1$. Thus, an increase in tariffs reduces illegally appropriated research output and thwarts IPR violations. As we will see later, such an increase in tariffs can be caused by an increase in IPR violation. Obviously, if tariffs are at or above t value, then $F(t) = 0$ and the IPR violation is completely eliminated.

4 The second stage the optimal tariff in duopoly

4.1 The welfare improving R&D expenditures and tariff

Before we move to the determination of the optimal tariff, it is important to note that the role of the tariff in duopoly is not only to be a strategic tool to capture the foreign firm's producer surplus, but also to help increase R&D expenditures towards the socially optimal level[20] (see Lemma 1).

Lemma 8 *An increase in the R&D expenditures enhances the social welfare.*

Proof We define social welfare as $W^*[x_c^*(t), t] = \pi^*(x_c^*) + S^*(x_c^*) + R^*(x_c^*)$ where $R^*(x^*) = tq_s^*$ is revenue from tariffs. First, note that $d\pi^*(x_c^*)/dx = 0$ by the first order condition of profit maximizing. This requires that the joint impact of R&D on consumer surplus and tariff revenue at point (x_c^*) has to be positive, that is, $dS^*(x_c^*)/dx + dR^*(x_c^*)/dx > 0$ to have $dW^*(x_c^*)/dx > 0$. It is, however, straightforward to see that the impact of R&D investment on consumer surplus in duopoly is always positive (not only in point (x_c^*)), that is, deriving $S(x)$ with respect to x gives always $dS(x)/dx > 0$. The tariff revenue as a function of x is, after appropriate substitution given by Eq. (15):

$$R(x) = \frac{t(A+\alpha-2t-f(x)-2(\alpha-\beta f(x)))}{3} \tag{15}$$

and $dR(x)/dx = -[(1-2\beta)tf'(x)]/3$. Interestingly enough, $dR(x)/dx > 0$ for $\beta > 1/2$ but $dR(x)/dx < 0$ for $\beta < 1/2$. Thus, the only thing we have to prove is that 'net sum' is positive when spillovers are small (that is, $dS(x)/dx + dR(x)/dx > 0$ for $\beta < 1/2$). The 'net sum' is given by:

$$\frac{dR(x)}{dx} + \frac{dS(x)}{dx} = \frac{5\beta t - 4t + (1+\beta)[2(A-\alpha)+(1+\beta)f(x)]f'(x)}{9}. \tag{16}$$

Since Eq. (16) is monotonically decreasing in t, we substitute the highest permissable value of tariff, t_p , to get,

[20] Note that tariff has this role also when the Northern firm is constrained monopoly (strategic predation) and spillovers are large (see Lemma 5).

$$\frac{[3\beta(A-\alpha)+(2-3\beta+4\beta^2)f(x)]f'(x)}{6}>0$$

for all $\beta < 1/2$ (and, therefore, for all $\beta \in [0,1]$).

4.2 The optimal tariff

So far, tariffs have been considered as though they were arbitrarily set. However, a benevolent domestic government should desire to set tariffs at the optimal welfare maximizing level. Determining the optimal tariff requires selection of the optimal (welfare maximizing) market structure. Remember that we assumed duopoly to be a viable market form in the pre-tariff situation. Thus, the government has three options: (a) to maintain duopoly by charging a 'low' tariff, (b) to constrain its firm through potential competition from abroad by imposing a tariff which forces the foreign firm to exit the domestic market, but does not enable the domestic firm to charge the full monopoly price and (c) to set the tariff so high that it allows the domestic firm to obtain an unfettered monopoly position. However, in order to ensure the existence of the first stage of the game (in which the Southern government picks the IPR level), we must establish the conditions under which duopoly is the welfare maximizing market structure and the 'duopoly' tariff dominates the other options.

Recalling that the social welfare function is represented as the sum of consumer surplus, domestic firm profit and tariff revenue, marginal social welfare is given by:

$$\frac{dW^*(t)}{dt}=\frac{\partial S^*(t)}{\partial x}\frac{dx_c^*}{dt}+\frac{\partial S^*(t)}{\partial t}+\frac{\partial \pi(t)}{\partial t}+t\left(\frac{\partial q_s^*}{\partial x}\frac{dx_c^*}{dt}+\frac{\partial q_s^*}{\partial t}\right)+q_s^* \tag{17}$$

The first thing to note is that the optimal tariff is positive[21] which, in turn, requires $dW^*(0)/dt > 0$. To see this, it is only necessary to compare marginal profit with the direct effect of tariff on consumer surplus. Summing these two effects gives $\partial\pi^*/\partial t + \partial S^*/\partial t = (f(x^*)(1-\beta)+t)/3 > 0$. Since the indirect consumer surplus effect, $\partial S^*/\partial x \ dx_c^*/dt$, and q_s are always non-negative, marginal social welfare is unambiguously positive at $t = 0$ implying that the positive tariff is welfare improving.

This result is related to the standard conclusion in strategic trade theory which claims that, given duopoly Cournot competition between the foreign and the domestic firm, imposing a 'low' tariff is beneficial in terms of social welfare under fairly general conditions (see Helpman and Krugman, 1989). A sufficient (but not necessary) condition for this result to hold is that there be a 'positive terms of trade effect', which, in this context, means that the new equilibrium price rises by less than the increase in tariff. This is surely the case with a linear demand function.

The specific context of the problem, however, suggests that positive social welfare effects may not be limited to situations where tariffs are low, but may also be present at a level of tariff high enough that duopoly is not a viable market form. In other words,

[21] A sufficient condition to have optimal positive tariff is a not 'too convex' demand function. A linear demand function surely satisfies this requirement. For a full discussion of the sign of an optimal tariff, see Brander and Spencer (1984).

the optimal tariff may be so high that it induces the foreign firm leaving the market. Such 'non-standard' result is the consequence of the distinctive feature of our model that the domestic firm is a type of 'natural monopoly' due to scale economies caused by tariff. Namely, tariff in duopoly boosts domestic output both directly by shifting the reaction curve of the competitor inwards and indirectly through increase in R&D investment. An increase in R&D, in turn, reduces marginal costs, C, and all these effects reduce the average costs, $C[x(t)] + x(t)/(q_n[x(t), t])$, of the Northern firm despite the increase in n x 16. Thus, it makes sense to increase the tariff more than it would otherwise be increased. The only opposing force, which may preserve duopoly as the optimal market form, is tariff revenue. This occurs only if the benefits from tariff revenue are higher than the losses from lower R&D, higher appropriation of the R&D output and, finally, losses of having more than one firm (with natural monopoly characteristics) in the market. Clearly, such a situation arises only if the R&D efficiency is in some sense 'low'. [22] Nevertheless, even in this situation, the optimal tariff is, as illustrated in Section 4.3, still higher than in the standard duopoly model in which there is no innovative activity and IPR violation.

Technically, the Northern government's optimization problem is defined as $\max W^*(t)$ s.t. $q_s^* \geq 0$. However, only an interior maximum is consistent with duopoly. Thus, we assume that there is an interior solution so that the optimal tariff can be obtained by solving the equation $dW(t)/dt = 0$ for t. Denote this solution as t^* where

$$t^* = \frac{3\beta f(x^*) + (1-\beta)^2 f(x^*) x^{*\prime} f'(x^*) + (A-\alpha)(3 + 2(1+\beta)x^{*\prime} f'(x^*))}{9 + (4-5\beta)x^{*\prime} f'(x^*)} \tag{18}$$

and $x^{*\prime}$ stands for dx_c^*/dt. As already discussed, this assumption requires that the implicit R&D efficiency is 'low', implying that the marginal welfare loss net of tariff revenue is equal to the marginal benefit of the additional tariff revenue at some $t^* < t_p$. It further implies that the constraint on the R&D production function has to be such that $f(x^*)$ is lower than a certain threshold value, $B(P)$, obtained by solving the equation $q_s^*[x^*(t^*)] = 0$. Thus, $f(x_c^*) \leq B[x_c^*(\beta), \beta]$ has to hold where $B(\cdot)$ is given as

$$B[x_c^*(\beta), \beta] \equiv \frac{(A-\alpha)(1 - 3\beta x_c^{*\prime} f'(x_c^*))}{3 - 4\beta + (2 - 3\beta^2 + 4\beta)x_c^{*\prime} f'(x_c^*)}.$$

Note that t is the upper bound of the optimal tariff in duopoly. Similarly, we are able to characterize the lower bound of tU^*. It is easy to show that the tariff revenue is maximized at the tariff level of $t_p/2$. Since the welfare net of tariff revenue requires optimal tariff to be at least t_p, it is clear that the interior solution will be in the interval $t^* \in (t_p/2, t_p]$. However, this is only a necessary but not a sufficient condition for t^* to be a global (rather than local) maximum. Namely, even if $t^* \in (t_p/2, t_p]$, it may easily happen that welfare from the unconstrained monopoly exceeds the welfare from duopoly if spillovers are large. Thus, for $t*$ to be a global optimum, there is an additional condition that $W^*(t) \geq W_m^*$ where W_m^* stands for the welfare generated in an unfettered monopoly ('monopoly welfare' henceforth). The discussion above is summarized in the first proposition.

[22] The R&D efficiency is implicitly captured by the function $f(x)$ and its underlying parameters (and its first and second derivatives).

Proposition 1 *Duopoly is the optimal, welfare maximizing market form in the post-tariff situation if the R&D efficiency is 'low', that is if* $f(x) \leq B[x_c^*(\beta), \beta]$ *and* $W^*(t) \geq W_m^*$*. In addition, the optimal tariff* $t_{opt} = t^*$ *and* $t^* \in (t_p/2, t_p]$*.*

The above proposition as stated is rather abstract. What does, for example, 'low' R&D efficiency mean? In order to illustrate more concretely the situation where duopoly turns to be the optimal market structure, we again use the explicit R&D production function introduced in Section 3.4 (that is, $f(x) = (gx)^1/2$) where the parameter g explicitly captures R&D efficiency (see, for instance, Chin and Grossman, 1990 or Žigić, 1998a, for use of this functional form). In addition, we restrict g to be such that $g \in (0, 4)$.[23] Thus, substituting $(gx)^1/2$ into Eq. (4) enables us to get an explicit expression for x_c^*, which we label by x^*, where x^* is

$$x^* = \frac{(A - \alpha + t)^2(2 - \beta)^2 g}{(9 - (2 - \beta)^2 g)^2}. \tag{19}$$

Substituting further $(gx^*)^1/2$ into the welfare function, and taking the derivative with respect to t gives us an analogue to Eq. (17). The solution of this equation yields an explicit expression for the interior optimum tariff denoted as t^{**} such that:

$$t^{**} = \frac{(A - \alpha)(27 + (-2 + \beta)g(10 - 2g - \beta(11 - 5g + 4\beta g + \beta^2 g)))}{81 + (-2 + \beta)g(32 - 6g - \beta(10 - 7g + 2\beta g))}. \tag{20}$$

Substituting $(gx^*)^1/2$ and t^{**} into Eq. (2b) gives $q_s^{**}(\cdot)$. in terms of g and β. Solving the equation $q_s^{**}(\cdot) = 0$ for the threshold level of R&D efficiency (denoted g_{cr}) gives the expression (21), which is an analogue to the B function (see Fig. 1).

$$g_{cr} = \frac{9}{[(2 - \beta)(-2(-2 + \beta)) + (7 - 7\beta + 4\beta^2)^{1/2}]} \tag{21}$$

Finally, comparison of $W^*(t^*)$ with W_m^* gives the other critical value g (Appendix C with the derivation of g_{cc} can be found in Žigić, 1996b or obtained upon request from the author). The line $g_c c$ is relevant only if $\beta > 1/2$ since it is easy to demonstrate that monopoly welfare is never higher then welfare in duopoly if $\beta < 1/2$.

The set of parameters consistent with post-tariff duopoly as the welfare maximizing market structure is represented by the shaded area in Fig. 1. Thus, for $g = g_1$, the highest value of β consistent with duopoly is β_1 (see Fig. 1). Interpreting the Proposition 1 in the light of the above gives Proposition 2:

Proposition 2 *Duopoly is the optimal, welfare maximizing market form in the post-tariff situation if* $\beta < 1/2$ *and* $g < g_{cr}(\beta)$*. If, on the other hand,* $\beta > 1/2$ *then in addition to* $g < g_{cr}(\beta)$*,*$g < g_{cc}(\beta)$ *must also hold.*

[23]This follows Chin and Grossman (1990). For $g = 4$ monopoly profit is not defined.

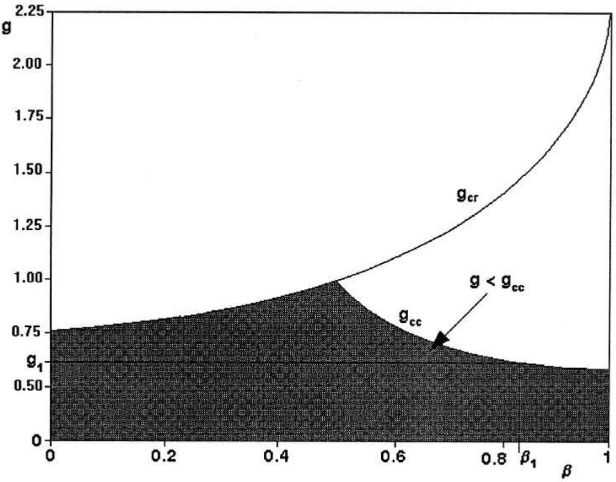

Figure 1: The region of parameters ($g < g_{cr}$ and $g < g_{cc}$) consistent with the duopolistic competition.

Although the shaded area in Fig. 1 is our main concern, it is important to note that the unconstrained monopoly yields higher welfare than duopoly and con- strained monopoly[24] as long as $\beta > 1/2$ and g is not 'too low' (i.e., $g > g_{cc}$). The reason for this is that the R&D expenditures in duopoly and constrained monopoly are suppressed when $\beta > 1/2$ so that the unconstrained monopolist (for whom spillovers do not matter), invests more in R&D than the duopolist or constrained monopolist[25] and since R&D efficiency is not too low, the welfare costs of the lost R&D output (net of tariff revenues) in duopoly exceeds the monopoly distortion. Moreover, the unconstrained monopoly is, in fact, a natural monopoly (despite the fact that the tariff has no influence on R&D expenditures here) since the average costs are always falling in the point of the optimal R&D, x_m^* (the proof is straightforward and can be obtained upon request from the author). However, the policy implication here is not that unfettered monopoly is unconditionally the best solution. Obviously, the government may try to use other instruments (e.g., price caps) to regulate the monopoly, provided that this intervention does not adversely affect R&D.

4.3 The three roles of the optimal tariff

Before discussing the first stage of the game, we will briefly examine the different roles of tariffs in our setup. As already mentioned, in our specific context tariffs may act not only

[24]Note that the constrained monopoly cannot be the optimal market form here because when $\beta > 1/2$ a further increase in tariff beyond t_p up to t_m would increase both the Northern firm's profit and Northern consumer surplus.

[25]See Appendix A for the proof that $x_m^* > x_p^*$ and therefore $x_m^* > x_c^*$ when $\beta > 1/2$.

as a device for profit shifting, but also as an instrument that boosts socially beneficial R&D investments (see Lemma 8), generates economies of scale and finally serves as a buffer that dampens the extent of IPR violation.[26]

In a standard duopoly case when there are neither innovative activities of the domestic firm nor IPR violations by the foreign firm, the optimal tariff[27] is $t^* = (A - c)/3$. This can be easily seen by evaluating t^* at $\beta = 0$ and $f(x) = 0$ (or t^{**} at $\beta =$ and $g = 0$. and by recalling that in this case $c = \alpha$. To account for the second, technological function of tariff, let us for the moment assume that the Northern firm invest in the innovative activity but there is no IPR violation by the Southern firm. The optimal tariff in this case is the special case of t^* with $\beta = 0$. In order to get graphical representation of the problem, we use here t^{**} when $\beta = 0$. Thus,

$$t^{**} = \frac{(A - \alpha)(27 - 20g^2 + 4g)}{81 - 64g + 12g^2}.$$

It is easily seen that the optimal tariff increases with the increase in R&D efficiency. The higher is R&D efficiency, the more it pays to stimulate investment in R&D and the higher is the optimal tariff (see Fig. 2).

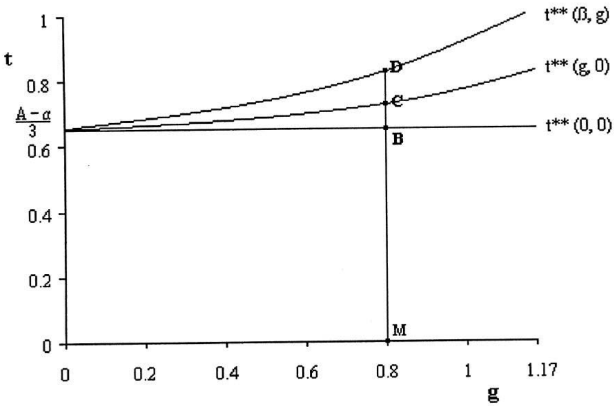

Figure 2: The decomposition of the optimal tariff on its three roles; $A = 10$, $\alpha = 8$**.**

Finally, allowing for a violation of IPR ($\beta > 0$), the optimal tariff increases even more. As seen from Fig. 2, for a given R&D efficiency, g, the total optimal tariff (MD), can be decomposed into three parts. MB is the part of the optimal tariff due to its

[26]It can easily be shown that $dt^*/d\beta > 0$.

[27]As Bhattacharjea (1995) nicely demonstrated, the optimal tariff $t^* = (A - c)/3$ is rather robust concept independent from the things like the degree of product differentiation, or the slope of the demand curves. More importantly, this optimal tariff has far less demanding information content than subsidy, since it, among other things, does not depend on the domestic unit costs, and the strategic manipulation by the domestic firm (e.g., costly signalling) is avoided.

profit shifting role, BC is due to its technological function, and CD stems from its role in counteracting IPR violation.

Proposition 3 *If duopoly is the equilibrium market form then the optimal tariff can be broken up into the three parts: profit shifting, technological and, IPR violation offsetting. Due to latter two roles, optimal tariff is higher then in the standard duopoly case.*

5 First stage-optimal IPR protection.

5.1 The Cournot - Nash equilibrium

In the first stage of the game, the Southern government has to decide the level of IPR protection by, for example, adopting patent protection legislature of a particular degree of stringency.[28] For the sake of simplicity, we assumed that the complex phenomenon of the level of IPR protection (or violation) can be condensed into a single parameter, β, scaled from zero to one.[29]

The underlying assumption is that the Southern government can commit to its choice of IPR strength and that the degree of IPR violation is selected strategically, taking into account its impact on the subsequent choice of the optimal tariff by the Northern government. Nonetheless, let us for the time being assume that the Southern government ignores the impact of its choice variable on the subsequent tariff. In the technical sense, this is equivalent to the situation in which two governments choose their strategic variables simultaneously. The rationale for modelling behavior in this way might be that the two governments interfere more than once, in which case a pure Nash equilibrium may be the appropriate technical description of the situation. In this case, the welfare function for the South reduces to its firms profit function, thus:

$$W_s^* = \pi_s^*[x(\beta), \beta] = \frac{[A - \alpha - 2t^* - (1 - 2\beta)f(x)]^2}{9} \tag{22}$$

Given t^*, the optimal level of IPR, protection, β^*, is determined by maximizing π_s^* with respect to β, subject to $\beta \leq 1$ and $W^*(t^*) > W_m^*$. The necessary condition requires $d\pi_s^*/d\beta \geq 0$ where $d\pi_s^*/d\beta$ is given by the expression below:

$$\frac{d\pi_s^*}{d\beta} = \frac{\partial \pi_s^*}{\partial x}\frac{dx_s^*}{d\beta} + \frac{\partial \pi_s^*}{\partial \beta} = \frac{2(A - \alpha - 2t - (1 - 2\beta)f(x_c^*)(2f(x) - (1 - 2\beta)(x_c^*)' f'(x_c^*)))}{9}$$

[28] In practice, the Southern governments could manipulate the level of IPR violation not only by adopting, say the appropriate patent law but also through the lax enforcement of the law. In addition, as the evidence in some developing countries shows (see Braga, 1990), governments enable the direct procurement of the important foreign technological pieces of information to its nationals. The government usually acquires these important pieces of information through patent disclosure. Furthermore, the government could by its policy influence the absorption capacity for adopting innovations and, thus, in ultima linea, the level of spillovers.

[29] Some authors (e.g., Rapp and Rozek, 1990) have compared the patent laws of the South and the others and attached a scalar ranging from zero to five, depending how far the particular country's IPR legislature is from conforming with the American one.

Thus, in choosing the optimal level of IPR protection, the Southern government takes into account its impact on the Northern firm's R&D expenditures but, by assumption, not its impact on optimal tariff imposed by the Northern government. It is easy to see that in the case of large spillovers, the Southern firm's profit also increases with R&D investments, thus, $\partial\pi_s^*/\partial x > 0$ for $\beta > 1/2$ (and vice versa). Also, it is straightforward to prove that $dx_c^*/d\beta < 0$. Thus, the 'strategic effect' above is negative if $\beta > 1/2$. Yet, the total effect is always positive since the direct effect $\partial\pi_s^*/\partial\beta > 0$ always dominates.

Lemma 9 *Relaxing IPR protection is always beneficial for the Southern welfare if duopoly is viable market form in the post-tariff situation.*

Proof Substituting the value of t_p into the expression above (recall that t_p is the maximal possible 'duopoly' optimal tariff leading to $q_s^* = 0$), gives us $d\pi_s^*/d\beta(t_p) = 0$. Since the function $d\pi_s^*/d\beta(t)$ is monotonically declining in t, $t^* \in [0, t_p]$, it implies that $d\pi_s^*/d\beta > 0$ for all values of t^* such that $t^* \in [0, t_p]$.[30]

Applying this conclusion to the specific case when $f(x^*) = (gx^*)^1/2$, the Southern government has a dominant strategy. It should select the highest level of β that is consistent with duopolistic competition, independent of the erected tariff by the North. That is, by choosing β, it should not induce the Northern government to set $t_p(\beta)$ or $t_m(\beta)$ as its best response, because this will lead to $W_s^*(\beta, t) \equiv \pi_s^*(\beta, t) = 0$, which is surely not desirable for the South.

If, say, the actual R&D efficiency is $g = g_1$, then (see Fig. 1) the optimal level of IPR violation from the point of view of the Southern government is $\beta = \beta_1$ (to be rigorous, it should be slightly less than β since $W^*(t^*) > W_m^*$ has to hold).[31]

5.2 The Stackelberg - Nash game between the governments

Our full-fledged, four-stage game requires, however, that the Southern government takes into account the impact of the selected IPR violation on the optimal tariff chosen by the Northern government. In other words, the Southern government acts as a Stackelberg leader in the policy game and its optimization problem looks now as

$$\max_{\beta}[W_s^*] = \pi_s^*(x[t(\beta), \beta], t(\beta), \beta)$$

s.t

$$t = t^*(\beta), \beta \leq 1 \text{ and } W^*(t^*) > W_m^*.$$

Substituting $t^*(\beta)$ for t into the above objective function and taking the derivative with respect to β gives now

[30] Alternatively, note that $\pi_s^*(\beta) = q_s^{2*}$. Thus, $d\pi_s^*/d\beta = 2q_s^* dq_s^*/d\beta \geq 0$ since it is straight forward to show that $dq_s^*/d\beta > 0$.

[31] The highest permissible value of g, consistent with the duopoly competition, is $g = 1.17$, with the corresponding optimal value $\beta^{**} = 1/2$ (see Fig. 1). On the other hand, for a value of g smaller than 0.385 the optimal value will be $\beta^{**} = 1$. For all other values of the parameter g between these two values, the optimal β will be in the interval $\beta^{**} \in (1/2, 1)$.

$$\frac{d\pi_s^*}{d\beta} = \frac{\partial\pi_s^*}{\partial x}\frac{\partial x}{\partial t}\frac{dt^*}{d\beta} + \frac{\partial\pi_s^*}{\partial x}\frac{dx_c^*}{d\beta} + \frac{\partial\pi_s^*}{\partial t}\frac{dt^*}{d\beta} + \frac{\partial\pi_s^*}{\partial\beta}$$

The difference from the analysis in Section 5.1 is the additional term:

$$\left(\frac{\partial\pi_s^*}{\partial x}\frac{\partial x}{\partial t} + \frac{\partial\pi_s^*}{\partial t}\right)\frac{dt^*}{d\beta} \tag{23}$$

that is apparently negative since Southern government takes now into account the fact that increase in IPR violation leads to the higher tariff, that is $dt^*/d\beta) > 0$ (see Section 4.3). This, in turn, suggests that we might expect to see a lower level of IPR violation than in the case of the simultaneous choice of tariff and IPR. To gain a more intuitive understanding of the problem, we again look at our example using the specific R&D production function $f(x) = (gx)^{1/2}$.

The problem can now be written as:

$$\max_{\beta}[\pi_s^*(\beta)]$$

s.t

$$\beta \leq 1, g < g_{cc}(\beta) \text{ and } t = t^{**}(\beta)$$

where $\pi_s^*(\beta)$ is obtained by the appropriate substitution of $(gx^*)^{1/2}$ for $f(x^*)$:

$$\pi_s^*(\beta, t) = \frac{((1-\alpha)^2(3 + (1-\beta)(-2+\beta)g) - (6 - (2-\beta)g)t)^2}{(9 - (2-\beta)g)^2} \tag{24}$$

Substituting $t^{**}(\beta)$ for t in Eq. (24), we get $\pi_s^{**}(\beta)$. Taking the derivative with respect to β gives the value of $d\pi^{**}(\beta)/d\beta$. It is straightforward, but a bit messy, to show that $d\pi^*(\beta)/d\beta > 0$[32] for all permissable values of g and β. Thus, the optimal level of IPR, denoted as β^{**}, turns out to be the same as in the case when the Northern and the Southern governments simultaneously choose the level of IPR protection and optimal tariff. That is, although in the Stackelberg case the Southern government takes into account the negative impact of increased b on subsequent tariff, within the particular model this additional effect (see expression 23) is not too strong to lead us to the interior solution[33].

Finally, before we state Proposition 4, it is important to note that β^* (or β^{**}) reflects only the IPR restriction and ignores the technological restriction that some industries

[32] Similarly to footnote [31], we can again write $\pi_s^*(\beta, t^*(\beta)) = q_s^{2*}$ but now, $d\pi_s^*(\beta)/d\beta = 2q_s^*(dq_s^*/dtdt_s^*/d\beta + dq_s^*/d\beta)$ and $Sign[d\pi_s^*(\beta)/d\beta] = Sign[dq_s^*/dtdt_s^*/d\beta + dq_s^*/d\beta]$. When $f(x^*) = (gx^*)^{1/2}$ then it can be shown that $dq_s^*/d\beta$ exceeds $dq_s^*/dtdt_s^*/d\beta$ in absolute values for all permissible value of β. Obviously, an interior optimum would require that the negative impact of the tariff on the Southern firm's output exceeds the corresponding positive effect of spillovers at some possibly large values of β.

are more susceptible to spillovers than others. Thus, β^* represents in some sense the upper bound of the permissible spillover level ($\beta \leq \beta^*$). What matters for the Northern government in imposing a tariff is the actual level of spillovers in particular Southern exporting industries (see expressions 18 and 20. rather than the overall strength of IPR protection that is set for all industries and measured by β^*. This observation yields the empirical prediction that the exported products which are subject to higher spillovers will also be subject to higher tariffs.

Proposition 4 *The Southern government strategically chooses the level of spillovers (that is, the degree of the IPR enforcement) in such way as to keep its firm always (if possible) in a duopoly competition with the Northern firm. In the specific case in which* $f(x) = (gx)^{1/2}$ *the CournotNash and the Stackelberg level of preferred IPR coincide.*

This particular result, is however, the consequence that there is no consumption of the good z on Southern market and therefore, there is no negative implications of IPR violation on Southern consumer surplus. If, however, the consumption of the Southern market is big enough and in addition, the R&D efficiency exceeds certain critical level, then Southern government would prefer rather strict IPR protection (see Žigić, 1998a).

6 World welfare and the optimal tariff

As well known, the standard tariff game is a negative sum game where one country's welfare gain is lower than the other's loss and the change in net total (world) welfare is negative if tariff is imposed. However, in the context in which tariffs have not only a strategic, profit shifting, function but also act as instruments of the technological policy, this conclusion need not hold.[33] To illustrate this point, let us assume that North and South together represent the relevant world market of the good under considerations. Let WTO act as a world central planer and has the power to pick the tariff taking into account the total world welfare. That is, it maximizes the function $W_w^*(t) = W^*(t) + W_s^*(t) = W^*(t) + \pi_s^*(t)$. For the sake of simplicity, we take β as given. Clearly, the level of the optimal tariff will depend now on the importance of its two roles: strategic and technological. If the strategic role dominates, the WTO would prefer to eliminate the tariff and opt for the free trade, while if the technological role is the dominant one, a positive tariff might be desirable outcome. To investigate whether there is a place for such positive tariff, we look at the marginal world welfare evaluated at the zero tariff. Thus, with $t = 0$, we have now:

$$\frac{dW_w^*(0)}{dt} = \frac{\partial S^*(t)}{\partial x}\frac{dx_c^*}{dt} + \frac{\partial S^*(t)}{\partial t} + \frac{\partial \pi^*(t)}{\partial t} + q_s^* + \frac{\partial \pi_s^*(t)}{\partial x}\frac{dx_c^*}{dt} + \frac{\partial \pi_s^*(t)}{\partial t}. \tag{25}$$

Note that this corresponds to Eq. (17) when $t = 0$ with the additional component, $\frac{\partial \pi_s^*(t)}{\partial x}\frac{dx}{dt} + \frac{\partial \pi_s^*(t)}{\partial t}$, that captures the total effect of the tariff on the Southern firm's profit. Since this total effect, $d\pi^*(t)/dt$, is negative (at least when$\beta < 1/2$), the sign of $dW^*(0)/dt$ is ambiguous. However, recalling the intuition above regarding the Northern

[33] I am grateful to both referees for pointing to this important issue.

government's choice of the optimal tariff, we expect here again that in case of 'high' R&D efficiency, the technological role of tariff may be so important as to overcome its negative impact on the Southern firm's profit, so that the optimal tariff is positive. In the same light, 'low' R&D efficiency may easily require zero tariff since the distortional effect of tariffs dominates. Also note that, unlike the Northern government, the World planner does not necessarily consider the appropriation of the R&D output by the South as something bad since it helps the diffusion of innovation worldwide. If the benefits of the diffusion of technology exceed the costs in terms of dampened incentives to conduct R&D, then the tariff will be put to zero (Region I in Fig. 3) or rather low level like $t^0 < t^*$(Region II in Fig. 3).

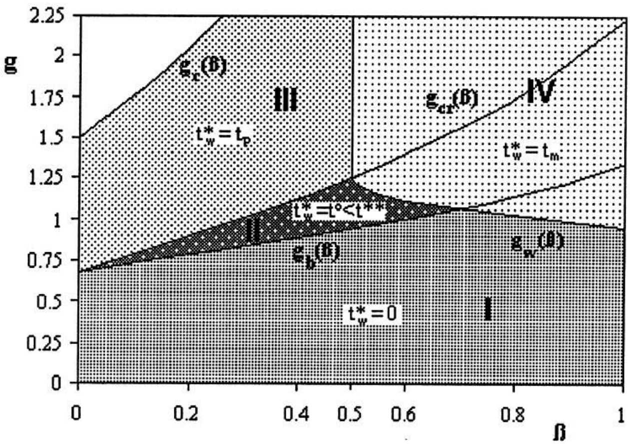

Figure 3: The optimal tariff from the world welfare point of view as a function of g and IPR violation.

Since, unlike in Eq. (17), we cannot tell anything a priori on the bases of the general expression (25), we now turn to the example in which $f(x) = (gx)^1/2$. Evaluating $W_s^*(t)$ for $f(x^*) = (gx^*)^1/2$, taking the derivative with respect to t, and evaluating it at the zero tariff gives:

$$\frac{dW_w^*(0)}{dt} = \frac{(A-\alpha)(-9+(-2+\beta)g(-8+\beta+2g-\beta g-2\beta^2 g+\beta^3 g))}{(9-(-2+\beta)^2 g)^2} \tag{26}$$

It is easy to prove that whenever $g > g_b(\beta)$, $dW_w^*/dt(0) > 0$. Thus, $g_b(\beta)$ represents the border line between 'low' and 'high' R&D efficiency in this context (see Fig. 3). Another interesting question is when $dW_w^*/dt(t_p) > 0$. If this is the case, the optimal world tariff will (depending whether β is bigger or lower than 1/2) be t_p or t_m.[34] In other words, the importance of R&D efficiency will be so large that it would require t_p or t_m

[34]Recall from Lemma 4 that for $\beta < 1/2$ an increase in tariff above t_p reduces socially beneficially R&D investment and thus harms welfare despite its positive impact on profit. Thus, the optimal tariff

as the optimal choice despite its obvious negative implications for the Southern firm's profit. Interestingly enough, $dW_w^*/dt(t_p) > 0$ requires that $g > g_{cr}(\beta)$ (see Fig. 3). Thus, for $g > g_{cr}(\beta)$, the optimal tariff will be t_p or even t_m. In this case, the choice of tariff by the Northern government coincides with that of the world planner. Finally, since welfare in unfettered monopoly can easily exceed the welfare in duopoly when spillovers are large, we have to work out the border line similar to $g_{cc}(\beta)$ line by identifying the parameter space for which $W_m^* > W_w^*(t)$. This gives the $g_w(\beta)$ line (see Fig. 3).

To summarize, there are four distinct regions relating the impact of tariffs on world welfare. In Region I, R&D efficiency is not high enough to justify a positive tariff. Note, however, that unlike the world planner, a 'rent shifting' Northern government would impose a positive tariff even in this region. In Region II, both the world planner and Northern government will impose positive tariff, however, the World planer takes into account the Southern firm's profit and its optimal tariff is lower than the one chosen by the Northern government. In Region III, the world planner selects $t_w^* = t_p$ and, finally, in Region IV, $t_w^* = t_m$. In these last two cases, both the world planner and the Northern government choose the same optimal tariff.[35]

7 Concluding remarks

In this paper, we have examined the functions of tariffs in the situation when there are IPR violations. Besides their traditional role as a device to shift foreign profit to the domestic treasury and domestic profit, tariffs in these circumstances have an additional role as an instrument that reduces IPR violations and, therefore, stimulates the domestic firm to invest in socially beneficial R&D that in turn leads to better exploitation of the scale economies. In this setup, optimal tariffs are higher than in the standard duopoly model without R&D investment and IPR violations.[36]

Since the appropriation of R&D output by the South is a form of informal technology transfer, it is not a priori clear that the world planner should discourage it. The world planner would have to weigh carefully the benefits of innovation diffusion and the costs of diminished incentives and decreased R&D investment in the North. Such considerations will urge a zero or low tariff if R&D efficiency is low (see Fig. 3), but it will require a prohibitive (t_p or t_m) tariff if R&D efficiency is high.

As is well known, the optimal design of strategic trade policy is sensitive to the type of market competition (see Spencer, 1986). Bertrand competition will not be so useful

will be t_p. If, on the other hand, spillovers are large ($\beta < 1/2$), an increase in tariff beyond t_p boosts the R&D spending, hence, the optimal tariff will be t_m. The formal proof can be found in Žigić, 1996b or obtained upon request form the author.

[35] All of the above analysis assumes that β was given exogenously. If the WTO simultaneously chooses both β and the tariff, things become more complicated. It can be shown that depending on the R&D efficiency, both optimal IPR, β_w^*, and optimal tariff, t_w^* , can be positive.

[36] It is important to stress that all our results have been derived assuming no export of the domestic firm to the South and therefore passive Southern government's policy. However, our analysis will not change in a fundamental way if the domestic firm also exports to the foreign market and the Southern government imposes a tariff on its export. The Southern government will solve the analogous problem like Eq. (17) and the set of optimal tariffs will be determined in this interactions as a Nash equilibrium. Thus, as Brander (1995) noted, the erection of the tariff by the foreign government does not offset the incentives of the domestic government to impose a tariff.

here since we concentrated on duopoly as the core model. A moment of reflection tells us that in our setup the domestic market will be completely covered by a domestic producer who charges a price equal to the unit cost of the foreign firm, that is, $p^* = \alpha - \beta(gx) + t$, provided that $p_m \geq p^*$ where p_m stands for the monopoly price. Thus, the resulting market form will be a constrained monopoly (or the unconstrained one if $p_m \leq p^*$). As shown in Žigić, 1998b, the crucial comparative static result the impact of tariff on the R&D expenditures is qualitatively the same under either quantity or price competition in the case of a constrained monopoly. The optimal tariff is however, lower in the Bertrand case since the competition is tougher and there are, in general, fewer distortions to correct.

An interesting extension of our model would allow for the announcement of a strategic trade policy to precede the actual intervention. This would imply changes in the moves in the game and as a consequence the government would leave itself open to strategic manipulation by its own firm (see, for instance, Grossman and Maggi, 1998). The domestic firm may want to engage in costly and possibly welfare reducing signalling in order to seek rents from the government. For instance, it may be profitable for the domestic firm with low R&D efficiency to pretend that it is of the high R&D efficiency type. The welfare implications of these issues, in particular whether free trade may reemerge as the optimal solution for a certain range of parameters in this setup, seem to be an interesting topic for future research.

***Appendix A*:**

Monopoly profit is given by Eq. (A.1.1)

$$\pi^m(x) = \frac{(A - \alpha + f(x))^2}{4} - x \qquad (A.1.1)$$

and is maximized at the value of x_m^*. Thus, the derivative of Eq. (A.1.1) with respect to x is

$$\frac{\partial \pi}{\partial x} = \frac{(A - \alpha + f(x))f'(x)}{2} - 1 \qquad (A.1.2)$$

with

$$\frac{(A - \alpha + f(x_m^*))f'(x_m^*)}{2} - 1 = 0 \qquad (A.1.3)$$

However, when predation is an optimal strategy, x_m^* is not feasible and the level of R&D expenditures x_p^* is in general different than x_m^*. To show this, note that the 'predatory price' has to be such that $p = \alpha - \beta f(x) + t$ holds. Taking this into account, the predatory profit can be written as:

$$\pi^p(x_p) = \frac{(A - \alpha + f(x_p))(t + (1 - \beta)f(x_p))}{2} - x_p \qquad (A.1.4)$$

with $t \in [t_p, t_m]$. Differentiating Eq. (A.1.4) with respect to x_p and evaluating the derivative at t_s where $t_s \in [t_p, t_m]$ gives the following expression:

$$\left.\frac{\partial \pi}{\partial x}\right|_{t=t_s} = \frac{(A-\alpha+f(x_p))f'(x_p)}{4} + \frac{(1-\beta)(A-\alpha+f(x_p)f'(x_p)}{2} - 1 \quad (A.1.5)$$

Note (by comparing Eq. (A.1.5) with Eq. (A.1.3). that the value of Eq. (A.1.5) is lower than zero for $\beta < 1/2$ implying $x_p^* > x_m^*$ and that the opposite is true for $\beta > 1/2$. For $\beta = 1/2$, the two values coincide, implying $x_p^* = x_m^*$.

***Appendix B*:**

Here we compare t_s with t_m for both small and large spillovers effect where:

$$t_s = \frac{A-\alpha-(1-2\beta)f(x_p^*)}{2}$$

and

$$t_m = \frac{A-\alpha-(1-2\beta)f(x_m^*)}{2}$$

and $t_s \in [t_p, t_m]$.

If $\beta < 1/2 \Rightarrow x_m^* < x_p^* \Rightarrow f(x_m^*) < f(x_p^*) \Rightarrow t_m > t_s$ because the last number in the above expression, $-(1-2\beta)f(x) < 0$.

If $\beta > 1/2 \Rightarrow x_m^* > x_p^* \Rightarrow f(x_m^*) > f(x_p^*) \Rightarrow t_m < t_s$ because now, $-(1-2\beta)f(x) > 0$.

Finally, when $\beta > 1/2 \Rightarrow t_m = t_s = (A-\alpha)/2$.

Tariffs, Market Conduct and Government Commitment

Policy Implications for Developing Countries

We analyse a simple 'tariffs cum foreign competition' policy targeted at enhancing the competitive position of a domestic, developing country firm that competes with its developed country counter part on the domestic market and that carries out an innovative (or imitative) effort. We evaluate this policy with respect to social welfare, type of oligopoly conduct, information requirement, time consistency and possibility of manipulative behaviour and conclude that the most robust policy setup is one in which the domestic government is unable to pre-commit to the level of its policy. We also study how the unit cost heterogeneity of the domestic firm affects trade protection.

1 Introduction

Conventional thinking promoted by the Washington Consensus implies that a prerequisite for a developing country or a country under transition to achieve a stable growth path is, among other things, to liberalize its trade. Rodr.Lguez and Rodrik (2000), however, show that the countries that initially follow a trade protection policy and other import substitution policies display respectable economic growth per capita for a substantial period of time. They also demonstrate that bad macro management and adverse external shocks, and not trade policies, are the main drivers of economic crises in developing countries. This in turn leads Rodrik (2001) to conclude that trade liberalization is an outcome rather than a precondition for successful economic development.

The above considerations suggest that it might be desirable for a developing economy to protect some of its industries that are believed to have a long-run perspective. Then delicate issues such as which industries should be protected and when and how the government should assist them arise. One would expect that the selected industry or firm would be one that is capable of narrowing the technological gap vis-à-vis its counterparts in developed countries by investing in innovation, or more likely, by adopting the advanced technology. Moreover, the initial technological level of the developing country firm should not lag too far behind so that it is unable to innovate and directly compete with the developed country' s firm, given an adequate protection policy.

A variety of policy instruments protect the domestic market and enhance domestic innovation or imitation. However, instead of focusing on a first-best policy mix, we look for a simple and transparent policy that does not put financial pressure on a developing country' s government. The first policies that come to mind are tariffs and voluntary export restrictions (VER), both standard tools for import protection used by developing countries. Tariffs are known to enhance both the innovative effort of the domestic firm and the social welfare of the country (see, for instance, Reitzes, 1991; Žigić, 2000; Bouët, 2001; Qiu and Lai, 2004). Moreover, permanent tariffs or temporary tariffs with a long enough expiration date speed up the adoption of new technology and move the adoption time to the social optimum (Miyagiwa and Ohno, 1995, 1999). However, quotas reduce the incentives to innovate, regardless of the time period for which they are set. As

Miyagiwa and Ohno (1999) point out, the lack of innovative effort that we can see in the last decades in several industries may be due to countries' preference for import quotas and VERs over tariffs. Therefore we choose to focus on tariff protection. And since, if a government' s commitment to temporary protection is not credible, protection tends to last a very long time (Matsuyama, 1990), and since governments in developing countries are often unable to commit to future policies (Bhattacharjea, 1995; Krugman, 1989), we choose to focus on permanent tariffs.

Our approach is distinct from the 'infant industry protection' analysis which is explicitly concerned with the economic consequences of trade liberalization, or the removal of the tariff barriers within a specific time horizon (see Wright, 1995; Leahy and Neary, 1999; Miravete, 2003). In our approach, the issue of removing tariff barriers is beyond the scope of the analysis. We assume that the protection lasts ' for a substantial period of time', as documented in Rodrik (2001), and that if trade liberalization is ever to happen, it would take place during an uncertain, very long period so that the protected firms do not take this into account in their economic calculations. As we already mentioned, such tariffs speed up the adoption of new technology (Miyagiwa and Ohno, 1995, 1999).

The optimal level of tariff protection is not likely to be prohibitive, as the presence of imports might be beneficial for consumers, might provide a domestic firm's incentive to innovate or imitate[1], and may be a source of funds for the state treasury.[2] Thus in our setup another 'policy tool' that complements tariffs is competition from the foreign firm in the form of imports.[3]

The aim of this study was to compare plausible variants of ' tariffs cum foreign competition' policy in terms of social welfare generated, with respect to: (a) the information required for implementation; (b) time consistency; and (c) vulnerability to strategic behaviour (manipulation) by the domestic firm. As a benchmark we use free trade and a hypothetical case in which the domestic government behaves as a (constrained) social planner that sets not only the tariff but also the domestic firm's level of innovation.[4]

The 'plausible variants' of our trade policy arise from several factors, the first and most familiar of these being that the market under consideration is likely to be oligopolistic. In oligopoly, both policy implementation and policy conclusions might be sensitive to factors like underlying oligopoly conduct (Eaton and Grossman, 1986). For example, depending on the type of market competition, levying both tax and subsidy can be an optimal trade policy when domestic and foreign firms compete in a third market.

The second source of possible variations in our policy setup lies in the (in)ability of the domestic government to commit to its policy (Karp and Perloff, 1995; Neary

[1]Žigić (2000) shows that the incentives to innovate in a duopoly are higher than those in a monopoly in the absence of unilateral R&D spillovers from the innovative firm to the receiving firm.

[2]However, foreign firms might ' jump over' the tariff by establishing affiliates (Motta, 1992). We exclude this case by assuming that there are prohibitively high entry (sunk) costs in the domestic market. Alternatively, one may assume that foreign direct investments are banned in the industry to avoid crowding out domestic entrepreneurship (Das, 2002).

[3]Although R&D subsidies are another standard policy tool that enhance innovation or imitation, the typical developing country does not have the financial resources required to effect such subsidies. In addition, implementing a subsidy might be troublesome because of the high information content required to implement the optimal subsidy and the distorting effects of taxes necessary to finance the subsidy (Bhattacharjea, 1995).

[4]An unconstrained social planner would also choose the quantity that the domestic firm produces.

and Leahy, 2000; Žigić, 2003). This idea can be traced back to Carmichael's (1987) observation that governments often set the level of their policy instrument only after firms have already chosen the level of some strategic variable. In this context domestic firms might influence (or manipulate) the government's policy response through the level of their choice variable. This strategic behaviour of the domestic firm against the local government causes inefficiencies that may lead to lower social welfare compared with the corresponding social welfare under free trade.

To discuss the above policy, we rely on a multistage game where we allow for strategic investment in technology catch-up by the domestic firms with the more efficient firms from a developed country. This investment may take the form of technological upgrading or costly imitation undertaken by the domestic firms in order to acquire the developed countrys technology. We consider two polar types of market conduct Cournot and Bertrand and two different timings of government intervention before investment in technological upgrading occurs and after it. With this model, we test the robustness and the informational requirement for the tariff policy across different competition types, as well as different government commitment levels.

Finally, our setup enables us to study the impact of the domestic firm's unit cost heterogeneity on the level of protection. Namely, in various and rather different models of trade protection, it has been shown that protection helps laggards more than firms that are closer to efficiency frontiers (Miyagiwa and Ohno, 1995), but that optimal protection is higher for more efficient than for less efficient firms (Neary, 1994). These theoretical results have been confirmed by the empirical studies of Acemoglu et al. (2006) and Konings and Vandenbussche (2007).

Our analysis is linked to the work of Bhattacharjea (1995) who also analyses tariff policy on the domestic market in the context of developing countries. He concludes that tariffs are robust in different market conditions, and that the informational requirement necessary for identifying their optimal level is not too large compared with, say, investment or output subsidies. In addition, the agency problem does not arise in Bhattacharjea's analysis. However, he considers neither prior strategic R&D investment by firms nor does he analyse the situation when the government can commit in advance to its policies. We show that tariffs are robust instruments even in complex setups where firms invest in innovation and where the timing of government intervention in the market and the firm's R&D investment might be reversed. Regardless of the government's ability to commit to its policy and regardless of the type of market conduct, the beneficial effect of tariffs in the form of foreign rent extraction, the reduction in the domestic oligopoly distortion and the stimulating effect on domestic innovation (or imitation) are strong enough to justify a positive tariff and to induce higher social welfare under protection than under free trade.

In addition we show that governments which cannot commit to a level of tariff in advance of the domestic firms' investment in R&D, as is the case for a typical government in developing countries, face fewer information requirements for the implementation of the optimal policy. These governments are less prone to manipulative behaviour by the domestic firm than governments which can commit to their policies in advance. This is because the 'committed' government that sets the tariff level to foster domestic innovation efforts first needs to know the domestic technology and production parameters, but the 'uncommitted' government does not. Thus, what could be thought at the outset to be a disadvantage for developing countries (namely, their governments' inability to commit to future policies) turns out to be an advantage.

With respect to unit cost heterogeneity, we find that, unlike Neary (1994), in our setup only governments that commit in advance of innovation to their policy instrument discriminate between less and more laggard companies by setting higher tariffs if domestic firms are of the former type. We also show that in the case of a 'committed' government, an increase in the level of protection induces higher innovation (at the margin) in laggards than in the firms that are closer to efficiency frontiers, and that applies to a wide range of investment functions.

The remainder of the paper is organized in seven sections. In the second section, we define the model. In Section 3 we describe the optimal R&D and tariff protection under the hypothetical setup where the domestic government chooses both. Sections 4, 5 and 6 derive the equilibria in the government 'non-commitment' regime, free trade and the government 'commitment' regime, respectively. In Section 7, we assess the considered policies based on their impact on social welfare, the information requirement, time consistency and agency problems. The last section summarizes the main findings of the paper.

2 The model

The action plays out in a developing country (the domestic economy). We assume that in this country two varieties of a good are consumed. These varieties are supplied by a domestic and a foreign firm that compete either in prices (Bertrand competition) or in quantities (Cournot competition) in the domestic country.[5] We also assume that the inverse demands for the differentiated goods are linear and are given by

$$p^d(g^d, q^f) = \alpha_d - \beta_d q^d - \gamma g^f \quad (1)$$
$$p^f(g^d, q^f) = \alpha_f - \beta_f q^f - \gamma g^d \quad (1')$$

where q^d and q^f denote the consumption of differentiated goods produced by the domestic and the foreign firm, respectively, and p^d and p^f are their respective prices. We make the usual assumptions: $\alpha_i > 0, \beta_i > 0$, for $i = d, f$, and $\beta_d \beta_f - \gamma^2 > 0, \alpha_i \beta_j - \alpha_j \gamma > 0$ for $i \neq j, i = d, f$. The parameter γ quantifies the type and the degree of differentiation between the two varieties. We assume that the two differentiated varieties are substitutes, so $\gamma \geq 0$.

The original technology of the domestic firm lags behind that of the foreign firm. It entails a pre-innovation unit cost of c, while the corresponding value for the foreign firm, c_f, is lower than c. For simplicity, c_f is set to zero. To catch up with its rival before facing its competitor in the market the domestic firm engages in process R&D activities. The decrease in marginal cost due to the innovative effort is denoted by x. To obtain an x ($\leq c$) decline in the unit production cost, the domestic firm has to incur $k \cdot i(x)$ costs, where $i(0) = 0, i'(x) \geq 0$, and $i''(x) \geq 0$, for any x on $[0, c]$. Any innovative effort aiming to decrease the marginal cost below zero brings the R&D costs to infinity. The

[5] We assume that there is no consumption of the differentiated variety in the foreign country. Alternatively, we can assume that the foreign and the domestic markets are segmented.

parameter k describes the efficiency of the innovative process and so k can be viewed as the indicator of the domestic firm's ability to narrow the technological gap. We further assume that the technology of the foreign firm is mature enough and does not require any R&D efforts.

The government in the domestic country considers raising the innovative activities of the local firm and social welfare by introducing a tariff. We assume a benevolent government that cares about all the agents in the domestic economy: consumers, the local producer and its own revenue. In what follows, the variable t stands for the specific tariff level ($t = 0$ when there is no tariff protection).

Depending on the government's ability to commit to its policy, we consider two related three-stage games. If the government can commit in advance, the actual level of tariff is set before the domestic firm sets its innovation effort. Then, in the first stage of the game the domestic government announces the tariff protection level (zero if there is no intervention). In the second stage, the domestic firm invests in R&D. Finally, in the third stage, the two firms meet in the domestic market where they compete either in prices or in quantities. We refer to this game as the government 'commitment' case. When the optimal tariff is chosen after the R&D is already in place but before competition takes place, the first and the second stages of the game are reversed. So, first the domestic firm chooses its level of innovation, then the domestic government sets the level of tariff protection. At the end, the competition in the market takes place. We call this game the government 'non-commitment' case.

Using the above notations, we can write the firms' profits in the domestic market as:

$$\pi^d(s^d, s^f; x) = q^d[p^d - (c - x)] - ki(x) \tag{2}$$
$$\pi^f(s^d, s^f; x) = q^f[p^f - t] \tag{2'}$$

where s stands for q if the firms compete in quantities and for p when they compete in prices. Running a separate analysis for the quantity competition and for price competition is arduous and cumbersome. In order to avoid this, we put both the Bertrand and Cournot analyses under a common umbrella. That is, we assume that each firm has an explicit conjecture about its competitor's output choice (Eaton and Grossman, 1986; Dixit, 1988; Martin, 1993). These conjectures are defined by parameters v_d, v_f. We can now regard the last stage of the game as a quantity decision subgame, and, depending on the values we use for parameters v_d and v_f, we obtain either the Cournot setup ($v_d = v_f = 0$) or the Bertrand setup[6]

$$v_d = -\frac{\frac{\partial p^f}{\partial q^d}}{\frac{\partial p^f}{\partial q^f}} = -\frac{\gamma}{\beta_f},$$
$$v_f = -\frac{\frac{\partial p^d}{\partial q^f}}{\frac{\partial p^d}{\partial q^d}} = -\frac{\gamma}{\beta_d}$$

[6]See Maggi (1996) for a different unified treatment of Bertrand and Cournot competition where the choice variables are prices and where the capacity constraint determines the equilibrium outcome (Cournot or Bertrand). Apart from conjectures describing Bertrand and Cournot equilibria, we do not use a full-fledged conjectural variation model (see Dixit, 1988, on the strengths and limits of this approach).

This unified treatment allows us to distinguish between the perceived and true values of certain important parameters, which in turn proves helpful in explaining the underlying economic intuition behind our results (see Helpman and Krugman, 1989, for such an approach). To simplify the notations and the formulas, we set $V_d = \beta_d + \gamma v_d$ and $V_f = \beta_f + \gamma v_d$ (an interpretation of V_d and V_f will be given later). It is straightforward to verify that for both the Bertrand and Cournot conjectures the property $V_d\beta_f - V_f\beta_d = 0$ holds. In what follows we assume that under tariff protection (with or without government commitment), the cost and demand parameters are such that the equilibria are characterized by interior solutions for the product competition stage and by levels of innovation higher than zero. Using the above notations, these requirements impose the following constraints on parameters:

$$c < \alpha_d \qquad (A1)$$

$$ki'(0) < \frac{2V_d(V_f+\beta_f)^2}{[(V_d+\beta_d)(V_f+\beta_f)-\gamma^2]^2}[\alpha_d - c - \frac{\gamma}{2V_f+\beta_f}\alpha_f] \qquad (A2)$$

$$ki'' > \frac{2V_d(V_f+\beta_f)^2}{[(V_d+\beta_d)(V_f+\beta_f)-\gamma^2]^2} \quad \forall x[0,c] \qquad (A3)$$

The first constraint, (A1), requires the home firm to be a viable monopoly, even without innovating. The second condition, (A2), guarantees R&D levels bigger than zero in the case of tariff intervention (with or without government commitment). It ensures that the domestic firm benefits from its first unit of innovation. The last assumption, (A3), ensures that the second-order conditions for the profit maximization problems are satisfied. Note that the assumptions (A2) and (A3) implicitly determine the lower and the upper bound of the RD efficiency parameter, k, in general. Namely, (A2) requires k to be sufficiently low so that the domestic firm is efficient enough and has a good R&D potential to benefit from its R&D, for its given market size. As for (A3), it requires k to be sufficiently high for domestic social welfare to be strictly concave in t. When necessary, to distinguish both the firm's and government's choices between the two different types of competition, we will use superscript C for variables in Cournot competition and superscript B to denote Bertrand values.

3 The constrained social planer equilibrium

We begin the social welfare analysis by deriving and discussing the hypothetical socially optimal equilibrium in which, in addition to choosing the tariff, the government would be able to choose directly the level of its firm's innovative (or R&D) effort. For convenience, we label this equilibrium the 'constrained social planner optimum', the constraint in question being that the oligopolistic market structure is taken as given. In this case tariff and innovation levels are chosen at the same time and the game is solved backwards (like all other games under consideration) in order to find the subgame perfect equilibria. The first-order conditions associated with the profit maximization problems are

$$p^d - (c - x) - V_d q^d = 0 \qquad (3)$$

$$p^f - t - V_f q^f = 0 \qquad (3')$$

where V_d and V_f are now readily interpreted as the slopes of the perceived inverse demands for the home and foreign firm, respectively (see Singh and Vives, 1984). The optimal quantities that solve the system of Equations (3) and $(3')aregivenby$

$$q^d(x,t) = \frac{1}{(V_d + \beta_d)(V_f + \beta_f) - \gamma^2}[(V_f + \beta_f)(\alpha_d - c + x) - \gamma(\alpha_f - t)] \tag{4}$$

$$q^f(x,t) = \frac{1}{(V_d + \beta_d)(V_f + \beta_f) - \gamma^2}[(V_d + \beta_d)(\alpha_f - t) - \gamma(\alpha_d - c + x)] \tag{4'}$$

Taking into account the first-order condition (3), the domestic firm's profit (2) can be rewritten as

$$\pi^d(x,t) = V_d(q^d(x,t))^2 - ki(x) \tag{5}$$

where $q^d(x,t)$ is given by equation (4)

We can now solve for the constrained social planner values of R&D and tariff. Since we assumed that the domestic government cares about all the agents in the economy, its social welfare function is given by

$$W = CS + \pi^d + tq^f = U(q^d, q^f) - [(c-x)q^d + ki(x)] - [p^f - t]q^f]. \tag{6}$$

It follows that an infinitesimal change in the subgame perfect equilibrium produces a social welfare effect

$$dW = (p^d - c + x)dq^d - q^f d(p^f - t) + tdq^f + (q^d - ki'(x))dx, \tag{7}$$

that is a combination of four different effects: (i) a domestic oligopoly distortion effect: from the social point of view, domestic output produced in equilibrium is too small since its marginal utility ($p^d dq^d$) exceeds its marginal cost ($(c-x)dq^d$); (ii) a positive terms of trade effect: a tariff causes net foreign price ($p^f - t$) to fall when the demand function is linear; (iii) a volume of trade effect: a decrease in the quantity of imported goods has a negative impact on the tariff revenue; (iv) a cost reduction effect: an increase in innovation has a positive effect on the domestic firm's profit. While the first three effects were present in Dixit (1988) and Cheng (1988)[7], the fourth effect is new and is specific to this setup with R&D innovation.

Using the foreign firm's first-order condition (3′) we rewrite the total social welfare effect (7) as

$$dW = (V_d q^d)dq^d - [V_f q^f - t]dq^f + (q^d - ki'(x))dx \tag{8}$$

Following Dixit (1988), we exploit the linearity of the model in differentials to express the changes in the social welfare as a function of changes in firm's choice variables x and q^d. In order to do this, we employ in Equation (8) the home firm's first-order condition (3) and the inverse demand (1), to obtain:

[7]Cheng (1988) calls the third effect an 'import consumption distortion effect'. A more detailed description of these first three effects can be found in this paper.

$$dW = (V_d q^d + V_f \frac{V_d + \beta^d}{\gamma} q^f - \frac{V_d + \beta^d}{\gamma} t) dq^d + (q^d - ki'(x) - V_f \frac{1}{\gamma} q^f + \frac{1}{\gamma} t) dx. \qquad (9)$$

From Equations (4) and $(4') we see that$q^d can be expressed independent of x as a function of q^f, t, and the model's parameters. Thus q^d and x are linearly independent variables. In this situation, to have $dW = 0$ for arbitrary values of dq^d and dx (not both zero), as the social welfare maximization problem requires, it is necessary and sufficient that the values of both parentheses in Equation (9) equal zero.

When we equate the first parenthesis of Equation (9) to zero we obtain the constrained social planner value of the tariff

$$t_{SO} = V_f q^f + \gamma \frac{V_d}{V_d + \beta_d} q^d. \qquad (10)$$

The optimal tariff serves to extract foreign duopoly rents and also to eliminate part of the domestic oligopoly distortion by enhancing the home firm's market share.[8]

By replacing in the optimal tariff formula (10) the actual quantities q^d and q^f from formulas (4) and (4), and by exploiting the fact that $V_d \beta_f V_f \beta_d = 0$ for both Bertrand and Cournot conjectures, we obtain a simplified form of this tariff

$$t_{SO} = \frac{\alpha_f}{2 + \frac{\beta_f}{V_f}}. \qquad (11)$$

The level of this tariff depends only on the intercept of the foreign inverse demand function and on the ratio between the foreign firm's elasticity of inverse demand and its perceived elasticity. It does not depend on the innovation level x. Consequently, social welfare (6), seen as a function of t and x, is separable with respect to these two variables.

To find the constrained social planner innovation level, we equate the second parenthesis of formula (9) with zero, and obtain

$$q^d - ki'(x_{SO}) - V_f \frac{1}{\gamma} q^f + \frac{1}{\gamma} t = 0 \qquad (12)$$

The government would use the innovation effort of its firm as an imperfect substitute for the output subsidy. That is, part of the domestic oligopoly distortion would be reduced through higher R&D investment, since a higher level of innovation would bring about higher domestic production, thereby reducing the gap between the price and the marginal cost. The government then faces a trade-off between the social benefits from a reduced domestic oligopoly distortion and the associated costs (the costs of innovation

[8]When tariff and innovation levels are chosen simultaneously (as is the case in this section) a change in tariff has a direct impact on q^d, q^f, and p^f) t but not on x, so only the first three effects from Equation (7) are present.

and the negative impact on the volume of trade). Therefore, when we employ the constrained social planner tariff (10) in (12) we obtain[9]

$$ki'(x_{SO}) = q^d(x_{SO}, t_{SO})\frac{2V_d + \beta_d}{V_d + \beta_d} \tag{13}$$

The constrained social planner equilibrium derived in the hypothetical case when the domestic government behaves as a social planner and chooses not only the specific tariff but also the R&D investment, will serve as a benchmark for the comparison with the optimal tariff under governments with different commitment levels and with the case of free trade. In the subsequent analysis we will continue to refer to t_{SO} and x_{SO} as constrained social planner socially optimal values.

4 The 'non-committed' domestic government

We first analyse the situation where the domestic government cannot commit in advance to its policy. If a tariff is introduced, its level is chosen only after the local firm has already selected the level of its R&D effort.

4.1 Tariff policy

The level of the optimal tariff maximizes the social welfare function (6). As noticed in the previous section, social welfare as a function of x and t is separable, so the optimal tariff will be equal to the constrained social planner value described by Equation (11), namely

$$t^{\star} = t_{SO}$$

This is a quite remarkable and somewhat unexpected result. The optimal tariff in a simple setup where the domestic government is not able to commit in advance coincides with the constrained social planner tariff. The reason for this is that the optimal tariff does not depend on the innovation effort, since R&D investment in our setup affects only the domestic marginal cost, which has no effect on the optimal tariff level.[10] However, the independence of the optimal policy instrument on domestic R&D breaks down in the case of subsidies. In a similar setup but with output subsidies rather than tariffs, we proved that the government's policy depends on the level of R&D investment and therefore is subject to manipulative behaviour from the domestic firm (Ionaşcu and Žigić, 2001). Another situation where the innovation effort influences the level of the optimal tariff arises when there are spillovers from the innovating to the non-innovating firm (Žigić, 2003).

[9] In the case of corner solutions for R&D investment ($x = c$), this equality becomes inequality: $ki'(x_{SO}) < q^d(x_{SO}, t_{SO})\frac{2V_d+\beta_d}{V_d+\beta_d}$. This will be the case for all the first-order conditions for the R&D level. Here we derive and prove all the results considering interior solutions for R&D. However, all the results still hold for corner solutions in innovation. The proofs are available on request.

[10] In contrast to the output subsidies, the optimal tariff depends only on the foreign firm's unit cost. If the foreign firm has a c_f marginal cost, then the level of the optimal tariff is $(\alpha_f - c_f)/(2 + \frac{\beta_f}{V_f})$.

One should note that t^* is a time-consistent tariff (Goldberg, 1995). This is particularly important in the developing country context, where governments often fail to ensure in advance the credibility of their policies (Bhattacharjea, 1995). Moreover, the tariffs formula holds for a large variety of R&D functions.[11]

When we replace the values of V_f corresponding to the two types of product competition, the optimal tariff in the Cournot competition case is given by

$$t^{*C} = \frac{\alpha_f}{3}$$

and in the case of Bertrand competition by

$$t^{*B} = \frac{\alpha_f}{3 + \frac{\gamma^2}{\beta_d \beta_f - \gamma^2}}$$

In the case of Cournot competition the policymakers need to know only the market size of the foreign firm, while in the Bertrand case some extra information regarding the sensitivity of prices to demand and the degree of differentiation is required. Nevertheless, since in both cases no information on domestic costs and R&D investment is required, the agency problem is precluded. In addition, unlike other government policies (Neary, 1994), the tariff does not discriminate between more and less laggard domestic companies.

Thus, tariffs as policy instruments prove to be robust and not too demanding in terms of informational requirements and seem to be a good alternative to the first-best policies a mix of tariffs and output and R&D subsidies/taxes so often criticized for their sensitivity to market conduct and extensive informational requirements. Nevertheless, there is a greater informational requirement in the Bertrand than in the Cournot type of market interaction. The optimal tariff in Cournot competition is higher than that in Bertrand. The reason for these differences lies in the role that the domestic tariff performs. The tariff helps to extract rents from the foreign firm and to reduce the consumption distortion induced by the oligopolistic competition. The tariff accounts for the latter effect directly, by enhancing domestic production and, indirectly, through its effect on innovation: domestic firms expecting that the imports will be subject to a tariff are likely to invest more in R&D than under free trade. The extent to which tariff protection could be used to extract foreign rents and to reduce the oligopoly distortion is determined by the ratio between the foreign firm's elasticity of inverse demand and their perceived elasticity (see expression (11)), which is in fact a measure of market competitiveness.[12] When markets are less competitive (a low ratio), as is the case with the Cournot type of market competition, there are more foreign profits to be extracted and there is a higher domestic oligopoly distortion to correct for. Therefore, $t^{*C} > t^{*B}$. To compute the ratio between true and perceived elasticity, more information is needed in the case of price competition.

[11] The essential restrictions that support these results are the assumptions of only one firm investing in R&D and a constant unit cost.

[12] A firm operating in a less competitive market perceives its demand as being less elastic to changes in prices than a firm performing in a more competitive environment. Consequently, it produces less at higher prices and accrues higher profits.

4.2 Optimal R&D effort

Anticipating that the domestic government will adopt the tariff t^*, the domestic firm chooses an R&D level, x^*, that satisfies the first-order condition associated with the maximization problem for the profit (5) evaluated in t^*, namely

$$ki'(x^*) = 2V_d q^d(x^*, t^*)\frac{\partial q^d}{\partial x}(x^*, t^*). \tag{14}$$

When we replace the first derivative of the quantity q^d given by Equation (4) with respect to x in Equation (14) we get

$$ki'(x^*) = \frac{2V_d(V_f + \beta_f)}{(V_d + \beta_d)(V_f + \beta_f) - \gamma^2} q^d(x^*, t^*). \tag{15}$$

The comparison between the constrained social planner equilibrium and the equilibrium for the 'non-committed' domestic government, as well as some characteristics of the latter are given below in Proposition 1 (proofs are relegated to the Appendix).

Proposition 1

1. *The social welfare is below the constrained social planner level in both types of market conduct.*
2. *In both Cournot and Bertrand setups, the domestic firm underinvests in R&D, from the social point of view.*
3. *The optimal R&D effort in the Cournot setup always exceeds the optimal R&D effort in the Bertrand setup for any level of product differentiation, c. That is, $x^{*C} > x^{*B}$.*
4. *The optimal tariff in the Cournot setup is higher than in the Bertrand setup. That is, $t^{*C} > t^{*B}$.*
5. *Finally, the optimal tariff does not depend on the cost efficiency of the domestic firm.*

Thus, regardless of the market conduct, the social welfare is below the 'first-best level'. The same is true for R&D investment. Protected by a tariff policy, the domestic firm would find an innovative effort that results in a x_{SO} decrease in marginal cost too expensive, since it ignores the fact that at the margin the gains in consumer surplus still offset the losses in profits and tariff revenue for x levels slightly above x^*. In addition, the possibility of socially wasteful over-investment in R&D is precluded by the fact that the optimal tariff in the non-commitment regime does not depend on the level of innovation, x, so there is no potentially damaging manipulative behaviour of the domestic firm.

The third part of Proposition 1 is consistent with the Schumpeterian tradition, suggesting that more monopolistic markets generate more innovation. The intuition behind this result is that in Cournot competition there are more profits to be gained, and therefore there are higher returns from a decrease in marginal cost. Alternatively, the expected ranking between x^{*C} and x^{*B} might be roughly predicted by referring to the FudenbergTirole taxonomy of business strategies, where, in the Bertrand case, the firms competing in prices (being strategic complements) pursue a so-called 'puppy dog' strategy that asks for 'underinvestment' in the strategic variable, x. On the other hand, Cournot competition requires a so-called 'top dog' strategy that implies 'overinvestment' in R&D (Fudenberg and Tirole, 1984; Tirole, 1991).[13] Yet, the presence of the optimal tariff proves to be crucial in determining the ranking of R&D investment in the respective market conduct. A higher anticipated tariff in Cournot competition provokes larger investment in R&D compared with Bertrand competition. As Bester and Petrakis (1993) have shown, in the absence of tariff protection, with high levels of γ, the ranking is reversed so that $x^{*B} > x^{*C}$.

5 Free Trade

Free trade equilibrium serves as an important general benchmark for comparison with other policy options. In our case, the comparison of free trade with the 'non-commitment' policy regime is of special interest, given the critique that the government's inability to pre-commit to its policy may lead to a lower social welfare compared with free trade (Grossman and Maggi, 1998; Ionaşcu and Žigić, 2001; Karp and Perloff, 1995; Neary and Leahy, 2000).

If the domestic government commits to free trade, the level of R&D investment maximizes the profits given by Equation (5) for a zero tariff:

$$ki'(x_{ft}) = 2V_d q^d(x_{ft}, 0)\frac{\partial q^d}{\partial x}(x_{ft}, 0),$$

or after appropriate substitution

$$ki'(x_{ft}) = \frac{2V_d(V_f + \beta_f)}{(V_d + \beta_d)(V_f + \beta_f) - \gamma^2} q^d(x_{ft}, 0). \tag{16}$$

Regardless of the type of competition in the market, the level of R&D induced by the anticipated tariff protection is always higher than the optimal level of innovation under free trade. To show this, we first recall from Equation (4) that $q^d(x, t)$ is increasing in t. Then for x^*,

$$ki'(x^*) - \frac{2V_d(V_f + \beta_f)}{(V_d + \beta_d)(V_f + \beta_f) - \gamma^2} q^d(x^*, 0) > 0.$$

When we take the first derivative with respect to x of the function on the left-hand side we get

[13] However, the notion of 'under'- and 'over'- investment in the Fudenberg and Tirole (1984) approach is defined with respect to the non-strategic firm's behaviour and not relative to the constrained social planner social optimum.

$$ki''(x) - \frac{2V_d(V_f + \beta_f)^2}{[(V_d + \beta_d)(V_f + \beta_f) - \gamma^2]^2} > 0 \quad \text{due to the assumption (A3).}$$

Therefore, x should decrease to reach equality again.

The optimal levels of R&D effort across the different regimes are displayed in Figure 1 (RHS_{so}, RHS and RHS_{ft} stand for the right-hand side of the Equations (13), (15) and (16), respectively). Note that as k decreases, innovation becomes cheaper, the optimal R&D levels increase and it is more likely to have corner solutions as shown by the dashed line in Figure 1.

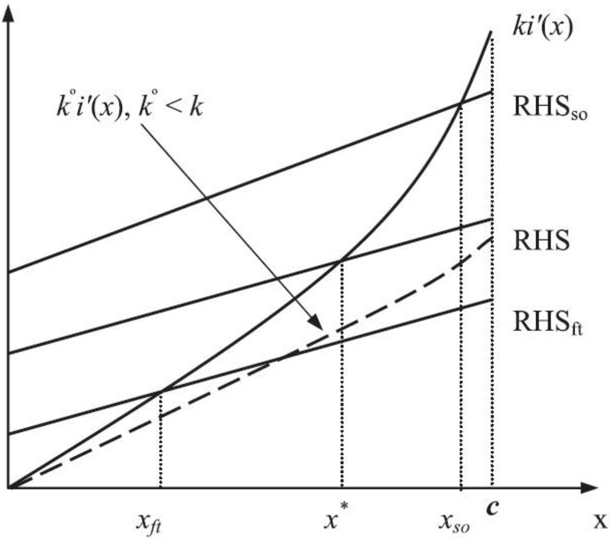

Figure 1: The innovation levels chosen under constrained social planner, free trade and non-commitment regimes.

The above results are consistent with the infant industry argument in favour of tariff policies. Indeed, the anticipation of tariff protection enhances the innovative efforts of the domestic firm and therefore positively impacts the domestic firm's production costs.

The comparisons of the relevant equilibrium values in free trade and in the noncommitment regime are given in Proposition 2 below.

Proposition 2 *Regardless of the type of market conduct:*

1. *Social welfare in the non-commitment regime is higher than in the free trade regime.*
2. *The optimal R&D effort (or unit cost reduction) in the non-commitment regime is always bigger than the optimal cost reduction under free trade. That is,* $x^* > x_{ft}$.

3. *The domestic firm earns a higher profit under tariff protection than under free trade.*

The anticipation of the optimal tariff and therefore, of a higher market share and a higher profit, motivates the domestic firm to enhance its R&D effort compared to free trade. Moreover, the joint impact of increased domestic firm profit and tariff revenue under tariff protection exceeds potential losses in consumer surplus, and thus leads to an increase in social welfare with respect to free trade.

6 The 'committed' domestic government

When the domestic government can credibly commit in advance to its policy, it announces the level of the tariff protection before the domestic firm invests in R&D. If a tariff was announced in stage one, the domestic firm chooses an innovation level that maximizes Equation (5). Thus, the optimal RD choice for a given t, which we denote X, satisfies

$$ki'(X) = \frac{2V_d(V_f + \beta_f)}{(V_d + \beta_d)(V_f + \beta_f) - \gamma^2} q^d(X, 0). \tag{17}$$

Regardless of the type of market conduct, the level of innovation increases when the tariff increases. To see this, we take the first derivative of Equation (17) with respect to t,

$$\frac{dX}{dt}(ki''(X) - \frac{2V_d(V_f + \beta_f)^2}{[(V_d + \beta_d)(V_f + \beta_f) - \gamma^2]^2}) = \gamma \frac{2V_d(V_f + \beta_f)}{[(V_d + \beta_d)(V_f + \beta_f) - \gamma^2]^2} \tag{18}$$

Since the term in brackets is positive due to assumption (A3), and since the right-hand side is also positive, the impact of an increase in tariff protection on the R&D level is positive. It follows that the R&D investment under tariff protection is higher than under free trade.

Furthermore, we investigate how the level of inefficiency of the domestic firm, measured in terms of the height of initial unit costs, affects (at the margin) investment in R&D due to marginal increase in tariff. To do so we need to know the sign of $d^2X/dtdc$.We start by differentiating the equality (18) with respect to c,

$$\frac{d^2X}{dtdc}(ki''(X) - \frac{2V_d(V_f + \beta_f)^2}{[(V_d + \beta_d)(V_f + \beta_f) - \gamma^2]^2}) + \frac{dX}{dt} ki'''(X) \frac{dX}{dc} = 0$$

Note that dX/dc is negative since the first derivative of Equation (17) with respect to c gives us

$$\frac{dX}{dc}(ki''(X) - \frac{2V_d(V_f + \beta_f)^2}{[(V_d + \beta_d)(V_f + \beta_f) - \gamma^2]^2}) = -\frac{2V_d(V_f + \beta_f)^2}{[(V_d + \beta_d)(V_f + \beta_f) - \gamma^2]^2}$$

Therefore the sign of $d^2X/dtdc$ is the same as the sign of $i'''(X)$, which, depending on the shape of $i()$, could be positive, negative or even zero. However, if we make the plausible assumption that $i^{''}(x^*) > 0$, we obtain that a laggard firm benefits more at the margin than a more efficient firm from an increase in tariff.[14] In this case, our finding is in line with both the theoretical predictions stemming from Miyagiwa and Ohno (1995) and the empirical findings of Konings and Vandenbussche (2007) that a less efficient domestic firm profits more from trade protection than a more efficient firm.

In the commitment regime, from the domestic social welfare point of view, the government can do at least as well as without commitment, simply by choosing a tariff equal to t^* and therefore inducing an R&D level of x^*, as can be seen from Equation (17). Consequently, social welfare when the government can commit in advance to its policy is never lower than the optimal social welfare under a noncommitment situation.[15]

The domestic government chooses a level of tariff protection $T*$ that maximizes Equation (6). Since the first-order condition (3) still holds, for an infinitesimal change in the Nash equilibrium in quantities, Equation (9) is still valid. When we plug it into the domestic firm's first-order condition with respect to innovation (17), we obtain

$$dW = (q^d V_d + \frac{(V_d + \beta_d)(V_f q^f - T)}{\gamma} + \frac{2V_d(V_f + \beta_f)(\gamma q^d - \gamma k i'(X) - (V_f q^f - T))}{\gamma k i''(X)((V_d + \beta_d)(V_f + \beta_f) - \gamma^2)})dx \quad (19)$$

The government then chooses a level of tariff T^* such that the value of the square brackets is zero. By using $ki'(X)$ given by Equation (17), the values for q^d and q^f given by Equations (4) and (4′), and the fact that for Bertrand and Cournot conjectures $V_d\beta_f - V_f\beta_d = 0$ we obtain

$$T^* = t^* + \gamma \frac{2\beta_f^2 V_f[\beta_d(V_f + \beta_f)^2 - \gamma^2(2V_f + \beta_f)]q^d}{(2V_f + \beta_f)[\beta_d(V_f + \beta_f)^2 - \gamma^2\beta_f][ki''(X)(\beta_d(V_f + \beta_f)^2 - \gamma^2\beta_f) - 2V_f\beta_f]}. \quad (20)$$

As in the non-commitment case, besides extracting foreign rents, the optimal tariff corrects for domestic oligopoly distortion. However, in this case the tariff also corrects for the level of innovation that, as we saw in the non-commitment case, tends to be sub-optimal.[16] Hence, the optimal tariff, T^*, exceeds its corresponding counterpart, t^*,

[14]Note that there is a whole class of exponential and power functions, $i()$, that appropriately describe the cost function of innovation and that verify the condition $i'''(x^*) > 0$. See, for instance, Ronnen (1991) or Zhou et al. (2002) for a similar requirement on the third derivative of the cost function in a somewhat different setup.

[15]As Žigić (2003) shows, this is generally not true when there are R&D spillovers from the innovating to the non-innovating firm. However, R&D spillovers are not a real possibility in our setup.

[16]To underline this new role of tariff as a direct instrument for enhancing the innovation level, we look at what happens when the domestic government uses R&D subsidies to correct for sub-optimal levels of innovation. When the government chooses an R&D subsidy, r, together with the level of tariff protection, the welfare becomes $W = CS + \pi^d + tq^f - rki(x) = U(q^d, q^f) - [(c-x)q^d + ki(x)] - [p^f - t]q^f$ Since there is no change in the home and the foreign firm's first-order conditions (3) and (3′), the Equations (7), (8) and (9) still hold. With an R&D subsidy in place, a^d and x again become independent variables, so once more we get the first-order conditions of the welfare maximization problem (commitment case) by setting the values in the parentheses to zero. The first parenthesis = 0 gives us again formula (11) for the tariff level. The second parenthesis of (9) = 0 gives (12). When we replace in (12) the formula

without government commitment (it is easy to check that the second part in expression (20) is positive).

Unlike the optimal tariff in the non-commitment case, the level of the optimal tariff T^* is influenced by the initial level of inefficiency of the domestic firm, c. Although it is difficult to get analytically the sign of the derivative of T^* with respect to c for a general R&D function, for a specific functional form for the R&D effort, $i(x) = x^2/2$, T^* decreases with an increase in c in both Cournot and Bertrand competition (see Appendix B). Thus in this case, Neary's (1994) result holds.

The optimal level of R&D, $X^* = X(T^*)$, is higher than the optimal level of innovation for a non-committed government, but still below the constrained social planner optimal level. The results concerning the commitment regime are summarized in Proposition 3.

Proposition 3 *Regardless of the type of the market conduct:*

1. *The optimal tariff protection in the 'commitment' regime is higher than the optimal tariff protection in its 'non-commitment' counterpart. That is, $T^* > t^*$.*

2. *The domestic firm exhibits greater R&D effort in the 'commitment' regime, that is, $X^* > x^*$ and higher social welfare, that is, $W^*_{com} > W^*_{ncom}$*

3. *The R&D efforts in both the 'commitment' and 'non-commitment' regimes are below the constrained social planner value. That is, $x^* < X^* < x_{so}$.*[17]

4. *The higher the initial level of inefficiency of the domestic firm, the higher the benefit at the margin obtained from an increase in trade protection, providing that $i'''(x) > 0$. However, the more efficient domestic firm commends a larger optimal tariff.*

7 Assessment of the considered policies

Before moving to the policy analysis under asymmetric information, we briefly discuss the pros and cons of the three policies government commitment regime (GCR), government non-commitment regime (GNCR) and free trade (FT) with respect to four criteria: (a) the social welfare that they generate; (b) the information requirement for their implementation; (c) the time consistency issue; and (d) the agency problems. The rankings and the characteristics of the policies are given in Table 1.

Table 1 shows that the only strength of the government commitment regime is that it yields the highest social welfare. The information requirement for its implementation is likely to be prohibitively high and, consequently, such a policy is susceptible to all kinds of agency problems between the domestic firm and governments. In addition, the

(11) for the tariff level, and the domestic firm's first-order condition with respect to R&D,$ki'(x) = 2V_d q^d (V_f + \beta_f)/((V_f + \beta_f) - \gamma^2)((1-r)((V_d + \beta_d)(V_f + \beta_f) - \gamma^2))$, we find that the optimal subsidy is $r = k[\beta_d - 2V_d\gamma^2/((2V_d + \beta_d)((V_d + \beta_d)(V_f + \beta_f) - \gamma^2))] > 0$ for both Bertrand and Cournout conjectures.

[17] Although it is not the primary goal of our analysis, comparing the corresponding Cournot and Bertrand equilibria, as we did in a previous section, would be of some interest. However, the expressions are prohibitively complex so that it is not possible to have an analytical comparison leading to close form solutions. Using simulations, we found that for a specific functional form for the R&D effort, $i(x) = x^2/2$, and for $\alpha_d = \alpha_f = 1$ and $\beta_d = \beta_f = 1$, $T^{*C} > T^{*B}$ and, consequently, $X^{*C} > X^{*B}$.

Table 1: Rank (characteristics) of discussed policies according to various criterions

Policy Criterion	**Social welfare**	**Inform. requirement**	**Time consistency**	**Agency problems**
GCR	1(largest)	3(high)	2(credibility problem)	2(agency problems)
GNCR	2(second-largest)	2(low)	1(time consistent)	1(no agency problem)
FT	3(lowest)	1(zero)	2(credibility problem)	1(no agency problem)

capability of the developing country's government to pre-commit to a given level of tariff is questionable at best, so the time consistency issue may arise.

The government non-commitment regime on the other hand has a rather low information requirement, and is not prone to the agency problems and manipulative behaviour of the domestic firm. Moreover, the optimal tariff in this regime is time consistent. The social welfare that it generates is lower than in the commitment regime but higher than in free trade.

Finally, free trade is the most convenient policy as far as the information constraint is concerned, but the worst one from the social welfare point of view. The free trade regime is also not without time consistency problems. The government's announcement of free trade may not be credible, since it would be optimal to intervene via tariff ex post (that is, after innovation takes place).

So the above short discussion suggests that a 'middle-of-the-road' policy government non-commitment regime fares best in the above qualitative assessments, with two second ranks (social welfare, information requirement) and two first ranks (time consistency, no manipulation). However, these rankings are probably not enough to proclaim the government non-commitment regime as the champion. If the social welfare that the government non-commitment regime generates is only slightly above that of free trade, then it may be better to stick to free trade due to its zero information content requirement if the government can somehow commit to it. On the other hand, if the difference in generated social welfare between the government commitment regime and the government non-commitment regime is 'very large', then it might be worth investigating how to overcome the problems associated with the former policy regime. Thus, in addition to a comparative qualitative assessment, we also need a comparative quantitative assessment of the social welfare that the three policies generate.

As we show in Appendix C, the quantitative analysis only reinforces the virtues of the government non-commitment regime (the quantitative analysis is done using the quadratic investment function $i(x) = \frac{1}{2}kx^2$, and assuming, for simplicity, that $\alpha_d = \alpha_f = \beta_d = \beta_f = 1$, and $k = 2$). First, comparing the corresponding social welfares in the government non-commitment regime and free trade, it is clear that the optimal tariff has a significant, positive impact on the domestic country's social welfare. The gains from tariff protection are, depending on the model parameters, roughly between 10 and 32 percent in Bertrand competition and between 10 and 57 percent in Cournot competition (see Tables C1 and C2 in Appendix C). As for the key comparisons between the government commitment regime and the government non-commitment regime, we can see that, regardless of the type of market competition, the percentage loss in social welfare when the government cannot commit in advance to its policy is negligible. The loss ranges between a meagre 0.00002 percent and an upper rough limit of 1.92 percent for Bertrand competition and of 0.14 percent for Cournot competition (see Tables C3 and C4 in Appendix C). Our results do not change significantly when we vary parameter k.

To conclude, the government non-commitment regime is decidedly superior to the other policy options (at least within the assumed specific functional forms). Therefore, the often-expressed worries that the developing country governments are unable to pre-commit to a policy choice do not seem to be well founded, at least where simple tariff policy is concerned.

8 Concluding remarks

We focused on a simple and, in reality, most frequently used policy 'tariffs cum foreign competition' designed to protect a domestic industry and enhance its competitive position. This policy can appear in several variants due to reasons such as the mode of the oligopoly conduct, and the (in)ability of the domestic government to commit to its policy.

We assumed a perfect, symmetric information setup and explored the role of oligopoly conduct and the ability of the domestic government to commit to the level of its policy instrument. We considered three policy options: the government commitment regime, the government non-commitment regime, and free trade. We found that, regardless of the market conduct and the ability of the domestic government to commit in advance to the level of its policy, the optimal tariff protection enhances not only domestic social welfare but also the innovative effort of the domestic firm. However, free trade, as a policy option per se, also has its virtues, since the information requirement for its implementation is virtually zero. Thus, to evaluate the policy options under consideration, we introduced other policy criteria beyond generated social welfare: the information requirement, time consistency, and the risk of agency and manipulative behaviour. We found that the most robust policy choice is the government 'non-commitment' regime that has a low information requirement, has a time consistent optimal tariff, and no risk of manipulation by the domestic firm. In addition, the social welfare loss vis-à-vis the government commitment regime is negligible.

Furthermore, we show that the initial level of cost inefficiency of the domestic firm has no influence on the non-commitment tariffs while in the commitment regime a higher level of inefficiency, under plausible conditions, enhances the marginal investment in R&D induced by an increase in tariff. However, a domestic firm with an initial technology closer to the technology frontier entails a higher optimal tariff. An independent and interesting result of the analysis is the comparison between the corresponding equilibrium values of the innovative efforts and tariffs. Thus in the government 'non-commitment' regime the optimal Cournot tariff is higher than the analogous Bertrand tariff and consequently, the innovative effort of the Cournot type of firm exceeds that of the Bertrand type. The same relation between R&D efforts and tariffs seems to hold in a commitment regime, but we managed to prove this only in the case of the specific functional form of the innovative cost function.

Appendix A

Proof of Proposition 1:

Since tariffs are the same under both policies, and since the government can choose any R&D level when maximizing social welfare, including x^*, the social welfare under the 'first-best' policy is higher than under the 'non-committed' government for any market conduct.

$x^* < x_{so}$: as (A3) holds, the right hand sides of the Equation (15) and the curve $ki'(x)$ have the single crossing property. In addition

$$t^* = t_{so} \quad \text{and} \quad \frac{2V_d(V_f+\beta_f)}{(V_d+\beta_d)(V_f+\beta_f)-\gamma^2} < \frac{2V_d+\beta_d}{V_d+\beta_d}$$

Therefore $x^* < x_{so}$. Moreover, Cournot competition yields higher R&D levels than its Bertrand counterpart does, thus $x^{*B} < x^{*C}$.

We have already shown that $t^{*B} < t^{*C}$.

To prove that $x^{*B} < x^{*C}$, we first eliminate V_d in Equation (15) by using the fact that $V_d\beta_f - V_f\beta_d = 0$. Then we differentiate the resulted equation with respect to V_f and we get

$$\frac{dx}{dV_f}(ki''(x^*) - \frac{2\beta_d\beta_f V_f(V_f+\beta_f)^2}{[\beta_d(V_f+\beta_f)^2-\beta_f\gamma^2]^2})$$
$$= \frac{2\beta_d\beta_f V_f[\beta_d(V_f+\beta_f)^2-(2V_f+\beta_f)^2]}{[\beta_d(V_f+\beta_f)^2-\beta_f\gamma^2]^2}q^d$$
$$+\frac{2\beta_d\beta_f V_f(V_f+\beta_f)}{[\beta_d(V_f+\beta_f)^2-\beta_f\gamma^2]^2}((\alpha_d-c+x^*)-\frac{\alpha_f\beta_f}{(2V_f+\beta_f)^2}).$$

Because of assumption (A3), the left hand side parenthesis is bigger than zero. In addition, for both Bertrand and Cournot conjectures$\beta_d(V_f+\beta_f)^2-(2V_f+\beta_f)^2 > 0$

Then, the right-hand side is positive so dx/dV_f is positive, and since $V_f^C > V_f^B$, we find that x$^{*B]<x^{*C}}$.

Proof of Proposition 2:

The social welfare function (6) is separable in t and x. Its first derivative with respect to t is given by $V_d q^d + v_f\frac{v_d+\beta_d}{\gamma}q^f - \frac{v_d+\beta_d}{\gamma}t = 0$ and is a linear function in t, positive in $t=0$. Consequently, as long as the tariff increases towards $t^* = t_{so}$, the domestic social welfare increases. With respect to x, the first derivative is given by Equation (12) or equivalently, by $q^d(x,t_{so})\frac{2v_d+\beta_d}{v_d+\beta_d} - ki'(x) \geq 0$. Because of assumption (A2) this derivative is strictly positive in $x=0$. Moreover, the solution of this derivative equal to zero is the socially optimum investment level x_{so}. Consequently, as long as the level of investment increases towards x_{so}, domestic social welfare increases. Since 0 (the free trade level for tariff) $< t^*$ and since for product substitutes, $x_{ft} \leq x^* \leq x_{so}$ (with equality if we have corner solutions for the R&D level), free trade brings lower social welfare than the optimal tariff does.

When we take the total derivative of the domestic profit given by Equation (5) with respect to t and use in it the envelope theorem (for the R&D choice) we obtain that $d\pi^d/dt = 2V_d q^d(\partial q^d/\partial t)$, where q^d is given by Equation (4). Since $\partial q^d/\partial t$ is positive, the domestic profit increases as the tariff increases.

Proof of Proposition 3:

We use the fact that the social welfare function $W(x,t)$ is separable in t and x and we denote by $\partial W/\partial t = \partial W(x,t)/\partial t$ and by $\partial W/\partial x = \partial W(x,t)/\partial x$. We recall from the discussion in the proof for Proposition 2 that $\partial W/\partial t$ is positive for $t < t^*$ and negative otherwise, and that $\partial W/\partial x$ is positive for $x < x_{so}$. As we saw, from Equation (17) it follows that $\partial W/\partial t \geq 0$ (with equality only for corner solutions in R&D).

When the optimal tariff is chosen before the domestic firm decides on its innovative effort, the domestic government solves

$$\frac{dW}{dt} = \frac{\partial W}{\partial t} + \frac{\partial W}{\partial x}\frac{\partial x}{\partial t} = 0$$

This will yield a different solution than when the government cannot commit in advance to its policy. In that case it only solves $\partial W/\partial t = 0$ and thus chooses the tariff t^*. However at t^* tariff protection the domestic firm chooses a level of R&D investment equal to x^*, a level which is below the corresponding socially optimal value. Thus at t^* $dW = dt$ is positive. If the government chooses a $t < t^*$ then $\partial W/\partial t > 0$ and moreover $\partial W/\partial x > 0$ (since such a tariff will induce a level of R&D lower than or equal to x^*). Thus at $t < t^* dW = dt$ remains positive. Consequently the optimal tariff should be above or equal to t^* with equality holding for $x^* = c$. If x^* is below c, if the tariff is high enough to induce investment levels above or equal to x_{so}, $dW = dt$ becomes negative $(\partial W/\partial t < 0, \partial W/\partial t \leq 0)$. To conclude, the optimal tariff T^* should be higher than the optimal one without government commitment, but not so high as to induce the socially optimal level of innovation. Thus $x_{so} > X^* > x^*$.

Appendix B:

The case when $i(x) = \frac{x^2}{2}$

When we replace in Equation (17) the quadratic form of the investment function and the formula (4) for $q^d(X,t)$ we find that, given the level of tariff t, in the second stage the domestic firm chooses a level of R&D of

$$X(t) = \frac{2V_d(V_f + \beta_f)}{k[(V_d + \beta_d)(V_f + \beta_f) - \gamma^2]^2 - 2V_d(V_f + \beta_f)^2}\,[(V_f + \beta_f)(\alpha_d - c) - \gamma(\alpha_f - t)]$$

To derive the optimal tariff level we replace this formula in (20) together with the formulas for Cournot and Bertrand conjectures and we get

$$T^{*C} = \frac{\alpha_f}{3} + \gamma \frac{4k\beta_f(4\beta_d\beta_f - 3\gamma^2)[3\beta_f(\alpha_d - c) - \alpha_f\gamma]}{3[3k^2(4\beta_d\beta_f - \gamma^2)^3 - 64k\beta_d\beta_f^2(3\beta_d\beta_f - \gamma^2) + 48\beta_d\beta_f^2]} \qquad (i)$$

for quantity competition and

$$T^{*B} = \frac{\alpha_f}{3 + \frac{\gamma^2}{\beta_d\beta_f - \gamma^2}} + \gamma \frac{2k\beta_d\beta_f^3(4\beta_d\beta_f - 3\gamma^2)(2\beta_d\beta_f - \gamma^2)[(3\beta_d\beta_f - 2\gamma^2)(\alpha_d - c) - \alpha_f\beta_d\gamma]}{(3\beta_d\beta_f - 2\gamma^2)D_B} \qquad (ii)$$

where

$$D_B = k^2(4\beta_d\beta_f - \gamma^2)^3(3\beta_d\beta_f - 2\gamma^2)(\beta_d\beta_f - \gamma^2) - 8k\beta_f(2\beta_d\beta_f - 2\gamma^2)^2 \times(6\beta_d^2\beta_f^2 - 6\beta_d\beta_f\gamma^2 + \gamma^4) + 4\beta_f^2(2\beta_d\beta_f - \gamma^2)^2(3\beta_d\beta_f - 2\gamma^2)$$

for price competition. It is then straightforward to show that the first derivative of T^{*C} and T^{*B} with respect to c are negative.

We did not make the comparison between T^{*C} and T^{*B} so one could have conjectured that $T^{*C} > T^{*B}$ as was the case in the non-commitment regime (that is, $t^{*C} > t^{*B}$). However, this is not completely clear since we should recall that in the commitment case the government influences the level of the domestic firm's R&D level and unit cost reduction and, to the extent that these levels are more suboptimal in the Bertrand case than in the Cournot case, we may expect that the difference, $T^{*B} - t^{*B}$ is bigger than $T^{*B} - t^{*C}$. In other words, the optimal commitment tariff may increase in the case of Bertrand competition even above its non-commitment counterpart than is the case in Cournot competition. So it is *a priori* unclear whether this impact can be strong enough to drive the optimal Bertrand tariff above the Cournot one in the commitment regime. The expressions for T^{*C} and T^{*B} are rather complex so we were unable to find the exact relation between T^{*C} and T^{*B}. However, in our example with quadratic investment function, when we considered symmetric demands with $\alpha_d = \alpha_f = 1$ and $\beta_d = \beta_f = 1$ we could show by simulations that T^{*B} is never bigger than T^{*C}.

Appendix C:

The investment function is assumed to be quadratic and is given by $i(x) = \frac{1}{2}kx^2$. We also set $\alpha_d = \alpha_f = \beta_d = \beta_f = 1$, and $k = 2$. In order to avoid underestimating the overall gains from introducing a tariff, we rule out the possibility of having corner solutions for the innovation levels. Therefore, apart from satisfying the (A1)(A3) assumptions, parameters c and γ should also be such that the reduction in marginal costs, x, are smaller than c.

Free trade versus the non-commitment policy regime

The optimal levels of increase in efficiency under a non-committed government, x^{*B} and x^{*C}, are implicitly given by formula (15). Having a quadratic investment function, we can explicitly solve Equation (15). When we substitute the corresponding levels of V_d and V_f in this equation and solve for x we find that the level of increase in efficiency in the case of Bertrand competition ($V_d = V_f = 1 - \gamma^2$), x^{*B}, equals

$$x^{*B} = \frac{2(2-\gamma^2)^2[(1-c)((3-2\gamma^2)-2\gamma^2)]}{(3-2\gamma^2)[k(1-\gamma)^2(4-\gamma^2)^2-2(2-\gamma^2)^2]}$$

while the level of increase in efficiency for Cournot competition (($V_d = V_f = 1, x^{*C}$, is given by

$$x^{*C} = \frac{8[3(1-c)-\gamma]}{3k(4-\gamma^2)^2-24}$$

The fact that these levels of x should be smaller than c adds to the (A1)(A3) assumptions lower bound restrictions on c. In Bertrand competition, the marginal cost, c, should be at least as high as

$$c > \frac{(3+2\gamma)(2-\gamma^2)^2}{(1+\gamma)(3-2\gamma^2)(4-\gamma^2)^2} \qquad (A4)$$

while in Cournot competition it should be no lower than

$$c > \frac{4(3-)}{3(4-\gamma^2)^2} \qquad (A5)$$

in order to have interior solutions for R&D investment.

The percentage gains in social welfare from having an optimal tariff protection set by a non-committed government with respect to the free trade outcome is given in Tables C1 and C2. In Table C1 we consider the case when firms choose prices and we assume that (A1)(A4) hold. To generate Table C2, we assume that firms set quantities and conditions (A1)(A3), (A5) hold.

Apart from the clear dominance of the GNC regime in terms of social welfare, it is interesting to note in the case of Cournot competition, the performance of a tariff protection regime with respect to free trade increases with an increase in the initial domestic firm's marginal cost level, c, and with a decrease in the level of product differentiation. Similar relations hold in the case of Bertrand competition when products are not very similar ($\gamma \leq 0.65$). Finally, at least for medium and low levels of $\gamma(\gamma \leq 0.65)$, and values of c that satisfy both (A4) and (A5) restrictions, we can see that the percentage gains from tariff protection relative to free trade are quite similar in both types of market conduct.

Non-commitment versus commitment regime

As in the above section, we take into consideration only interior solutions for the innovation levels. Thus, as before, besides satisfying the (A1)(A3) assumptions, parameters c and γ should be such that X^{*B} and X^{*C} are smaller than c.

Table C1. Percentage differences between domestic social welfare under free trade and non-commitment when firms compete in prices*

γ/c	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9
0.05	9.99	11.00	12.14	13.43	14.89	16.52	18.34	20.33	22.47	24.71	26.96	29.09	30.94	32.34
0.15	10.85	11.94	13.17	14.56	16.12	17.85	19.74	21.80	23.95	26.14	28.23	30.09	31.55	
0.25	11.63	12.79	14.09	15.56	17.18	18.97	20.89	22.93	25.00	27.01	28.81	30.24	31.15	
0.35	12.34	13.56	14.92	16.42	18.08	19.86	21.74	23.66	25.51	27.18	28.51	29.36		
0.45	13.02	14.27	15.65	17.16	18.78	20.48	22.20	23.84	25.30	26.43	27.10			
0.55	13.70	14.96	16.31	17.75	19.23	20.70	22.06	23.21	24.01	24.34				
0.65	14.49	15.68	16.91	18.13	19.26	20.21	20.87	21.12						
0.75	15.70	16.63	17.43	17.99	18.18	17.91	17.11							
0.85	19.22	18.50	16.79	14.08										

Note: $*100\frac{W^{*C}_{nc}-W^{*C}_{ft}}{W^{*C}_{ft}}$.

To compute the optimal levels of increase in efficiency, we first replace in (17) the quadratic form of the investment function and the formula (4) for $q^d(X,t)$. We find that, given the level of tariff t, in the second stage the domestic firm chooses a level of R&D of

$$X(t)=\frac{V_d(V_f+1)}{[(V_d+1)(V_f+1)-\gamma^2]^2-V_d(V_f+1)^2}[(V_f+1)(1-c)-\gamma(1-t)]$$

Next, we derive the optimal tariff levels by replacing the above formula in (23) together with the formulas for Cournot and Bertrand conjectures. The optimal tariff protection for quantity competition is

$$T^{*C}=\frac{1}{3}+\gamma\frac{4k(4-3\gamma^2)[3(1-c)-\gamma]}{3[3k^2(4-\gamma^2)^3-64k(3-\gamma^2)+48]}$$

and for price competition

$$T^{*B}=\frac{1-\gamma^2}{3-2\gamma^2}+\gamma\frac{2k(4-3\gamma^2)(2-\gamma^2)[(3-2\gamma^2)(1-c)-\gamma]}{3-2\gamma^2 D_B}$$

where

$$D_B=k^2(4-\gamma^2)^3(3-2\gamma^2)(1-\gamma^2)-8k(2-\gamma^2)^2(6-6\gamma^2+\gamma^4)+4(2-\gamma^2)^2(3-2\gamma^2)$$

Finally, we obtain the optimal levels of increase in efficiency, X^{*B} and X^{*C}, by replacing in the formula for $X(t)$ the corresponding levels of V_d and V_f and of tariff protection. The level of X^{*B} is given by

Table C2. Percentage differences between domestic social welfare under free trade and non-commitment when firms compete in quantities*

γ/c	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9
0.05	10.01	11.02	12.17	13.47	14.93	16.56	18.38	20.38	22.53	24.78	27.04	29.18	31.04	32.45
0.15	11.04	12.16	13.43	14.85	16.45	18.23	20.19	22.31	24.54	26.81	29.00	30.94	32.47	33.41
0.25	12.18	13.42	14.82	16.39	18.15	20.09	22.20	24.44	26.75	29.00	31.06	32.73	33.84	
0.35	13.45	14.83	16.39	18.13	20.07	22.19	24.47	26.84	29.19	31.39	33.24	34.54		
0.45	14.89	16.44	18.19	20.14	22.29	24.62	27.08	29.58	31.96	34.03	35.57	36.37		
0.55	16.54	18.30	20.28	22.49	24.90	27.49	30.16	32.78	35.13	36.98	38.07			
0.65	18.47	20.50	22.78	25.31	28.07	30.97	33.89	36.62	38.87	40.35				
0.75		23.14	25.83	28.80	32.02	35.34	38.57	41.39	43.42	44.31				
0.85		26.41	29.68	33.30	37.18	41.11	44.76	47.65	49.28					
0.95		30.57	34.74	39.40	44.39	49.35	53.70	56.69						

Note: $*100\frac{W_{nc}^{*C}-W_{ft}^{*C}}{W_{ft}^{*C}}$.

$$X^{*B} = \frac{2(2-\gamma^2)^2[k(4-\gamma^2)-2][(1-c)(3-2\gamma^2)-2\gamma^2]}{k^2(4-\gamma^2)^3(3-2\gamma^2)(1-\gamma^2)-8k(2-\gamma^2)^2 6-6\gamma^2+\gamma^4)+4(2-\gamma^2)^2(3-2\gamma^2)}$$

and the level of X^{*C} is given by

$$x^{*C} = \frac{8[k(4-\gamma^2)-2][3(1-c)-\gamma]}{3k^2(4-\gamma^2)^3-64k(3-\gamma^2)+48}$$

These levels of increase in efficiency are below c if

$$c > \frac{(3-\gamma-2\gamma^2)(3-\gamma^2)(2-\gamma^2)^2}{144-364\gamma^2+332\gamma^4-138\gamma^6+27\gamma^8-2\gamma^10} \quad (A6)$$

in Bertrand competition, and if

$$c > \frac{4(3-\gamma)(3-\gamma^2)}{144-124\gamma^2+36\gamma^4-3\gamma^6} \quad (A7)$$

in Cournot competition.

The percentage gains in social welfare from having the optimal tariff protection set by a committed government rather than a non-committed one are given in Table C3 for price competition and in Table C4 for quantity competition. In the first case we assume that (A1)(A3) and (A6) hold while in the latter case we assume that conditions (A1)(A3), and (A7) are satisfied.

Table C3. Percentage differences between domestic social welfare under non-commitment and commitment when firms compete in prices*

γ/c	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9
0.05	0.00060	0.00057	0.00053	0.00050	0.00045	0.00041	0.00036	0.00031	0.00025	0.00020	0.00014	0.00009	0.00005	0.00002
0.15	0.00550	0.00519	0.00484	0.00445	0.00403	0.00357	0.00308	0.00257	0.00204	0.00153	0.00104	0.00061	0.00028	
0.25	0.01645	0.01540	0.01423	0.01295	0.01156	0.01006	0.00848	0.00684	0.00521	0.00366	0.00227	0.00114	0.00036	
0.35	0.03674	0.03408	0.03114	0.02793	0.02446	0.02077	0.01694	0.01308	0.00936	0.00598	0.00317	0.00115		
0.45	0.07389	0.06767	0.06086	0.05347	0.04559	0.03737	0.02904	0.02095	0.01353	0.00730	0.00277			
0.55	0.14562	0.13092	0.11493	0.09782	0.07993	0.06179	0.04419	0.02812	0.01475	0.00521				
0.65	0.30081	0.26206	0.22055	0.17721	0.13356	0.09178	0.05461	0.02515						
0.75		0.58953	0.45113	0.31499	0.19068	0.08962	0.02321							
0.85		1.92371	0.96067	0.27264										

Note: $*100\frac{W_c^{*B}-W_{nc}^{*B}}{W_{nc}^{*B}}$.

Table C4. Percentage differences between domestic social welfare under non-commitment and commitment when firms compete in quantities*

γ/c	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9
0.05	0.00060	0.00056	0.00053	0.00049	0.00045	0.00041	0.00036	0.00030	0.00025	0.00020	0.00014	0.00009	0.00005	0.00002
0.15	0.00524	0.00494	0.00461	0.00425	0.00385	0.00341	0.00295	0.00246	0.00196	0.00146	0.00100	0.00059	0.00027	0.00007
0.25	0.01435	0.01345	0.01245	0.01136	0.01016	0.00887	0.00750	0.00608	0.00466	0.00329	0.00207	0.00106	0.00036	
0.35	0.02794	0.02601	0.02388	0.02154	0.01899	0.01627	0.01342	0.01051	0.00768	0.00505	0.00281	0.00114		
0.45	0.04614	0.04264	0.03877	0.03454	0.02997	0.02511	0.02010	0.01510	0.01036	0.00617	0.00286	0.00074		
0.55	0.06904	0.06329	0.05694	0.05001	0.04256	0.03475	0.02681	0.01909	0.01205	0.00621	0.00210			
0.65	0.09622	0.08742	0.07771	0.06715	0.05589	0.04421	0.03257	0.02161	0.01212	0.00494				
0.75		0.11312	0.09920	0.08411	0.06814	0.05182	0.03596	0.02165	0.01013	0.00262				
0.85		0.13482	0.11642	0.09653	0.07566	0.05472	0.03504	0.01828	0.00623					
0.95		0.13825	0.11730	0.09469	0.07122	0.04821	0.02751	0.01136						

Note: $*100\frac{W_c^{*C}-W_{nc}^{*C}}{W_{nc}^{*C}}$.

Free Trade versus Strategic Trade as a Choice between Two 'Second Best' Policies: A Symmetric versus Asymmetric Information Analysis

We analyse the following policy dilemma: strategic trade policy versus free trade when the domestic government is bound to intervene only after the domestic firm's strategic variable in the form of R&D investment is chosen, and when the information can be either symmetric or asymmetric. The novel feature of our model is that the information asymmetry stems from the assumption that the government may not a priori know the true mode of competition. The intervention in the above set-up allows the domestic firm to manipulate the domestic government and results in a socially inefficient choice of the strategic variable. However, commitment to free trade leads to forgoing the benefits from profit-shifting. Yet, from the social point of view, free trade may be optimal even under the assumption of symmetric information. Due to costly signalling, this result is reinforced in the case of asymmetric information.

1 Introduction

Theoretical arguments seem to favour strategic trade policy over free trade in imperfectly competitive markets, but the practical application of strategic trade appears to be plagued by both operational and political economy considerations. Operationally, the optimal intervention depends critically on details concerning market structure and market conduct that enforce a demanding information requirement on policy makers. The most striking example in this respect is that of Eaton & Grossman (1986), which showed that, depending on the type of market competition, levying both tax and subsidy can be an optimal trade policy if domestic and foreign firms compete in a third market. The well-known political economy concerns about the use of strategic trade are the likely applying of political pressure, lobbying, or rent seeking.[1] It is, however, important to note that the likely lack of key information and the rent-seeking '...would speak against all forms of government intervention, inasmuch as policy makers rarely have all the information they need to implement the policies prescribed by economic theory' (Grossman & Maggi, 1998) and inasmuch as they are exposed to interest groups pressure.

The motivation of this paper is to provide an explicit model that takes into account some of the problems that constrain the application of unilateral strategic trade policy. It seems that Eaton & Grossman's (1986) critique sets the course for subsequent research in this field. They emphasized the importance of the mode of market competition in the design of the optimal strategic trade policy. In this light, their criticism calls for an approach that looks for more robust policy instruments than the standard tools export subsidies or taxes. Thus, Maggi (1996) shows that capacity subsidy is generally a welfare improving policy regardless of the mode of competition, and Bagwell & Staiger (1994)

[1] In fact, there is also a third argument not dealt with in our paper that also constrains the use of strategic trade policy, namely, that strategic trade policy enacted in one country (that can in principle be welfare enhancing) may spur the usage of trade policies in the affected countries making everybody worse off ultimately.

indicates that R&D subsidies might also be the best policy in both Cournot and Bertrand set-ups.[2]

Grossman & Maggi (1998) have initiated a somewhat different strand of research. They explicitly analysed the impact of uncertainty on the key policy dilemma free trade versus strategic trade policy in a plausible set-up in which the domestic firm displays a manipulative behaviour against its government. The uncertainty, in their model, comes from the unknown cost efficiency of the domestic firm while the manipulative behaviour stems from the possibility of the domestic firm to extract a high export subsidy from the government by over-investing in R&D.

Our approach aims to merge the Grossman & Maggi (1998) model of the impact of uncertainty on the desirability of strategic trade vis-à-vis free trade and the Eaton & Grossman (1986) finding regarding the importance of the mode of competition for the design of the optimal strategic trade policy. More specifically, we assume that the uncertainty for the domestic government stems from the unknown mode of competition. As Grossman & Maggi themselves admitted, this type of uncertainty[3] '... might appear more crucial than our cost parameter.'

We consider a so-called 'third market' model (see Brander, 1995, for a survey of this class of models) in which a domestic and a foreign firm produce differentiated products and compete in a third country's market. The exportable good is not consumed domestically.[4] We examine a (potentially)four-stage dynamic game. In the first stage the domestic government decides whether or not to commit to free trade.[5] Given that, in the second stage, the domestic firm chooses how much to invest in process innovation (R&D investment), this leads to marginal cost reduction.[6] The chosen level of the marginal cost reduction crucially depends on whether the government has committed to free trade or not. If the government did not commit to free trade, it would find it optimal to intervene *ex post* by adopting the output subsidy rule in the third stage. The rational firm would anticipate this when choosing its level of R&D investment. Finally, in the fourth stage, the firms compete in either price or quantity. The government can be either perfectly or imperfectly informed about the mode of competition, which, we assume, can be either of the Bertrand or the Cournot type.

Much like Grossman & Maggi (1998), the crucial assumption in this model is that between the announcement of intervention and the actual setting of the trade policy, the domestic firm can take some strategic action (investment in R&D in this case) that influences the optimal level of subsidy and distorts the social welfare.[7] Therefore, the first best policy under perfect information in this set-up would be for the government to

[2]However, Neary & Leahy (2000) pointed out that R&D subsidies are only a second-best choice. A first best policy would be a combination of R&D tax (subsidy) with export subsidy (tax).

[3]For a somewhat different modelling of the strategic trade policy under asymmetric information see for instance, Qiu (1994) and Maggi (1999).

[4]This oversimplification is made with the purpose of focusing exclusively on the strategic aspects of trade policy. As Helpman & Krugman (1989: 84) pointed out, a model that neglects the consumer surplus '... may be useful in isolating some interesting effects ... '.

[5]See Hwang & Schulman (1992) for a related timing of the game.

[6]Like Grossman & Maggi (1998), we also assume that only a domestic firm invests in R&D. This asymmetry can arise if the domestic firm is, for instance, from a developed country, whereas its competitor comes from the developing country, where traditionally R&D investment is low or absent.

[7]The fact that usually there is a lag between the policy announcement and its implementation provides a justification for such *ex post* intervention.

introduce an R&D subsidy (tax, if negative) in the second stage of the game in order to correct for the manipulatory behaviour of the domestic firm and then subsidize (tax, if necessary) output at a later stage of the game in order to induce profit shifting towards the domestic firm (see Spencer & Brander, 1983 and Neary & Leahy, 2000). However, under our assumptions the government can use only output subsidies and thus, is unable to directly counteract the manipulatory behaviour of the domestic firm. This set-up seems more realistic than the 'first best' policy especially when we extend our analysis to the incomplete information case where committing to any policy before observing the R&D signal may be harmful.[8]

Our analysis reveals several interesting findings. First, the standard results in which the Bertrand firm under-invests while the Cournot firm over-invests in marginal cost reduction is reinforced in the applied set-up due to the manipulating behaviour of the domestic firm. Secondly, the Grossman & Maggi (1998) result obtained under the assumption of Cournot competition and the homogeneous products in which government intervention is optimal for high R&D investment costs, carries over to our set-up with product differentiation and is valid for both Cournot and Bertrand types of competition. In other words, a perfectly informed government will enact a trade policy (regardless of the type of competition in the market) when the R&D investment costs are 'high' enough, while free trade will be optimal when these costs are 'low'. However, the degree of product differentiation affects the critical level of 'high' versus 'low' R&D and, thus, influences the border line between free trade and policy intervention.

Finally, our key finding is that with asymmetric information, there may be an additional manipulating effect in the case where the government does not commit to free trade and competition is *à la* Cournot. This manipulating effect, manifested through costly signalling, leads to even larger overinvestment than is the case under perfect information and therefore the social welfare in this case is always lower than in the corresponding free trade regime. The government prefers to opt for free trade in general unless the probability of the Bertrand competition is 'high' and the unit cost of R&D investment is 'large enough' to justify intervention. Thus, free trade has a special role in the given set-up: it serves as a device that protects the government from the socially costly manipulation of domestic firms. The paper is organized in the following way. The next section deals with the case of perfect information and identifies the optimal output policy for each of the two types of competition. The section after analyses the game in an asymmetric information context in which the domestic government is not fully informed about the type of market interaction. The final section discusses the findings of this paper.

2 The Model: The Symmetric Information Case

Consider a differentiated product market in which there are only two firms firm $F1$, the domestic firm, and firm $F2$, the foreign firm competing *à la* Bertrand or *à la* Cournot in a third market. In order to get the explicit solution of the model we use a version of

[8]The other reasons might be that a government has a constraining budget to conduct the first best policy when R&D subsidies are optimal (see Neary & Leahy, 2000, for more about both 'first' and the 'second best' policy).

the linear inverse demand for firms' products of the following type[9]

$$p^i(q^i, q^j) = 1 - (q^i = \gamma g^j) \qquad (i)$$

whereas the corresponding direct demands are

$$q^i(p^i, p^j) = \frac{(1 - \gamma - p^i + \gamma p^j)}{(1 - \gamma^2)} \qquad (ii)$$

where γ is the product differentiation parameter and takes values between 0 and 1 $(0 < \gamma < 1)$.

Both firms have initially the same efficiency translated into the same constant marginal cost $c(0 < c < 1)$. However, through research and development (R&D) activity firm $F1$ is able to decrease its production cost. In order to get x decrease in its marginal cost, firm $F1$ has to invest kx^2 in R&D, where parameter k measures the efficiency of R&D investment. The latter specification is standard in the strategic R&D literature (see for instance D'Aspremont & Jacquemin, 1988; Hinloopen, 1997; Leahy & Neary, 1997; Grossman & Maggi, 1998).

For the moment we assume that the type of competition in the market is known by the firms as well as by the government. For the reasons explained in the introduction, we assume that the domestic government is considering interfering in the market only through an export (output) subsidy. Then the timing of the game is the following: the domestic government's decision whether to commit to free trade or not precedes firm $F1's$ R&D investment. Once the investment is in place the government sets the level of the output subsidy s (or tax if this subsidy is negative) according to the observed investment level. If the government commits itself to free trade at the first stage, the level of subsidy/tax will be zero. In the end, production and competition in the market will take place. In what follows, we consider this set-up of the model for each type of competition separately.

We do not discuss corner solutions. We consider only ranges of parameters for which all the sufficient second-order conditions hold, and all solutions are interior solutions (i.e. parameters are such that both firms are in the market in the Nash equilibrium, and the optimal level of increase in efficiency is smaller than c).[10] Therefore, the following inequalities should hold

$$\frac{2 - \gamma}{2k(2 - \gamma^2)^2 - \gamma} < c < 1 - \frac{\gamma}{2 - \gamma^2} \qquad (A1)$$

and

[9]We normalize both intercept and (as suggested by the referee) the slope parameter of the inverse demand function to be unity.

[10]For several reasons, we do not think that by ignoring the corner solutions we lose any interesting results. First, we would like to characterize markets in which there are at least two competitors. Second, in real life nothing can be produced with 0 marginal cost, regardless of the amount of effort oriented to innovation.

$$k > \frac{4-3\gamma^2}{2(1-\gamma)(2+\gamma)(2-\gamma^2)^2} = \underline{k} \qquad (A2)$$

More specifically, the upper bound on c set by the assumption (A1) guarantees positive duopoly profits under free trade as well as under government intervention (with or without commitment), regardless of the type of market competition (Cournot or Bernard). In addition, the lower bounds set on c and on k by the assumptions (A1) and (A2), respectively, ensure that regardless of the market conduct or of the government policy (free trade, intervention with or without commitment) the R&D cost and the marginal cost are high enough so that it is too costly for the domestic firm to invest in innovation, so much so as to drive it to zero. Therefore, the decrease in marginal cost due to R&D investment does not exceed the initial marginal cost, c.

Cournot Competition.

Considering the above specifications, the profits π^1 and π^2 of firm $F1$ and firm $F2$ respectively are given by

$$\begin{aligned} \pi^1(q^1, q^2; x, s) &= q^1[p^1(q^1,q^2) - (c - x - s)] - kx^2 \\ \pi^2(q^1, q^2; x) &= q^2[p^2(q^1,q^2) - c] \end{aligned}$$

where the inverse demands are given by (i) and where the level of subsidy s is zero in the case of free trade (no government intervention).

Firms choose their equilibrium quantities according to the first-order conditions

$$\begin{aligned} 1 - (c - x - s) - 2q^1 - \gamma q^2 &= 0 \\ 1 - c - 2q^2 - \gamma q^1 &= 0 \end{aligned} \qquad (1)$$

Subsequently the corresponding demands are given by

$$\begin{aligned} q^1(x,s) &= \frac{(2-\gamma)(1-c) + 2(x+s)}{4-\gamma^2} \\ q^2(x,s) &= \frac{(2-\gamma)(1-c) - \gamma(x+s)}{4-\gamma^2} \end{aligned} \qquad (2)$$

The impact of R&D and the subsidy on quantities is positive for the domestic firm and it is negative for the foreign firm.

Free Trade.

If the government announced free trade during the first stage of the game, firm $F1$ chooses a level of x that maximizes the following profit function

$$\pi^1(x,0) = \frac{1}{(4-\gamma^2)^2}[(2-\gamma)(1-c) + 2x]^2 - kx^2 \qquad (3)$$

Consequently, the domestic firm will choose a level of decrease in unit cost

$$x_{ft}^C = \begin{cases} \frac{2(2-\gamma)}{k(4-\gamma^2)^2-4}(1-c), & \text{if } c > \frac{2(2-\gamma)}{k(4-\gamma^2)^2-2\gamma} \\ c, & \text{otherwise} \end{cases} \tag{4}$$

that will generate the following domestic profit and social welfare

$$\pi_{ft}^C = W_{ft}^C = \frac{k(2-\gamma)^2}{k(4-\gamma^2)^2-4}(1-c)^2 \tag{5}$$

Strategic trade.

Without commitment to free trade, a subsidy programme will be implemented based on the government's objective function[11]

$$W(s) = \pi^1(x,s) - sq^1(x,s)$$

which coincides with F1s net-of-subsidy profit. The first order condition implies[12]

$$\frac{dW}{ds} = 0 \Rightarrow \frac{dq^1}{ds}(x,s)[p^1(x,s) - c + x] = -q^1(x,s)\frac{\partial p^1}{\partial s}(x,s) \tag{6}$$

The rationale for a policy intervention in this set-up is that in a pure Nash equilibrium, the domestic firm while choosing its quantity does not take into account its impact on the quantity of its opponent. Thus, there is a discrepancy between the perceived and the 'true' demand function that the domestic firm faces. The policy intervention is enacted in order to correct for this discrepancy (see Helpman & Krugman, 1989).

After solving the first order condition (6) we get

$$s^C = \frac{\gamma^2}{4(2-\gamma^2)}[(2-\gamma) - 2(c-x) + \gamma c] \tag{7}$$

Whatever the domestic firm's choice of investment strategy, the government will interfere in the market through an output subsidy.[13] The higher the investment effort of the domestic firm, the higher the payment received from the government.[14]

[11]We assume that the government puts equal weight on both the firm's profit and its expenditures for subsidy or in jargon, there is no divergence between the marginal social valuation of corporate profit and subsidy revenue. However, Neary (1994) discusses the reasons and the welfare implications when this may not be the case.

[12]The second order condition requires $\frac{d^2W}{ds^2} = \frac{\partial^2 q^1}{\partial s^2}(x,s)[p^1(x,s) - c + x] + 2\frac{\partial q^1}{\partial s}(x,s)\frac{\partial p^1}{\partial s}(x,s) + q^1(x,s)\frac{\partial^2 p^1}{\partial s^2}(x,s) < 0$ Since $\frac{\partial^2 q^1}{\partial s^2}(x,s) = 0$, $\frac{\partial q^1}{\partial s}(x,s) > 0$, $\frac{\partial p^1}{\partial s}(x,s) < 0$ & $\frac{\partial^2 p^1}{\partial s^2}(x,s) = 0$ this condition is verified.

[13]Allowing the foreign government to set the subsidy simultaneously with the domestic government would make the analysis much more complex but it would not change the incentive of the domestic government to intervene nor would it qualitatively change the properties of the solution (see Brander, 1995).

[14]However, Neary (1994) has shown that this relationship cannot be unambiguously determined for the general demand function. Nevertheless, the relation holds for linear demand, and under reasonable conditions, for the constant elasticity demand function.

The subsidy s^C allows the firm $F1$ to commit to the Stackelberg outcome in the quantity game in which no subsidy or tax is in place (see Brander & Spencer, 1985 and Helpman & Krugman, 1989). If the domestic firm tries to increase its quantity and to reach this desirable outcome on its own (instead of the lower Nash profits), it exposes itself to the unstable situation that follows, and therefore risks earning even lower profits than the Nash equilibrium ones. However, if the domestic government interferes in the market through an export subsidy, it alters the perceived unit costs, shifts $F1's$ reaction function outward, and thus provides a new sustainable Nash equilibrium that coincides with the Stackelberg outcome with no subsidy.

The domestic firm chooses the investment level that maximizes its profit function

$$\pi^1(x, s^C(x)) = \frac{1}{4(2-\gamma^2)^2}[(2-\gamma)(1-c)+2x]^2 - kx^2 \tag{8}$$

In general, a change in the level of innovation affects domestic firm's profit in this set-up through three effects: a direct, a strategic and a manipulation effect

$$\frac{d\pi^1}{dx} = \underbrace{\frac{\partial \pi^1}{\partial x}}_{\text{direct effect}} + \underbrace{\frac{\partial \pi^1}{\partial q^2}\frac{\partial q^2}{\partial x}}_{\text{strategic effect}} + \underbrace{\left(\frac{\partial \pi^1}{\partial s} + \frac{\partial \pi^1}{\partial q^2}\frac{\partial q^2}{\partial s}\right)\frac{ds^c}{dx}}_{\text{manipulation effect}} \tag{9}$$

The direct effect accounts for the positive impact of an increase in x on the marginal cost but also for the costs of doing so. The strategic effect captures the 'profit shifting' benefits of an increase in R&D and is always positive. The last effect the manipulation effect illustrates the positive impact of x on the level of subsidy and, through it, on the profit. Therefore this effect is also always positive.

The optimal level of marginal cost reduction for which the direct effect offsets the other two effects is, in our model, given by

$$x_s^C = \begin{cases} \frac{2-\gamma}{2[k(2-\gamma^2)^2]-1}(1-c), & \text{if } c > \frac{2-\gamma}{2k(2-\gamma^2)^2-\gamma} \\ c, & \text{otherwise} \end{cases} \tag{10}$$

With such a level of decrease in the marginal cost, firm $F1$ gains a profit of

$$\pi_s^C = \frac{k(2-\gamma)^2}{4[k(2-\gamma^2)^2]-1}(1-c)^2 \tag{11}$$

and the social welfare in the domestic country equals

$$W_s^C = \frac{k(2-\gamma)^2[k(2-\gamma^2)^3-2]}{8[k(2-\gamma^2)^2-1]^2}(1-c)^2 \tag{12}$$

The x_s^C level of the increase in efficiency is higher than its 'first-best' counterpart. Let us denote by $\tilde{x}_s^C$ the first-best socially optimal level of marginal cost reduction that the government would select, were it in a situation to choose x. Since $\frac{\partial \pi^1}{\partial s}\frac{\partial s}{\partial x} = q^1(\frac{\gamma^2}{2(2-\gamma^2)}) > 0$

at $\tilde{x}_s^C$ and therefore, the firm will choose a higher R&D level than the first-best optimum. The concrete value of $\tilde{x}_s^C$ is given by equation (13)

$$\tilde{x}_s^C = \begin{cases} \frac{2-\gamma}{4k(2-\gamma^2)-2}(1-c), & \text{if } c > \frac{2-\gamma}{4k(2-\gamma^2)-\gamma} \\ c, & \text{otherwise} \end{cases} \tag{13}$$

This is the result of both strategic and manipulatory actions conducted by the domestic firm on the government. The domestic firm invests more compared with the non-strategic benchmark in order to enjoy higher payments from the government and to gain strategic advantages over its competitor. As Neary & Leahy (2000) pointed out, if the government were able to use R&D policies before investment occurs, it would set up an R&D tax that will offset exactly the manipulatory behaviour of the local firm.

In addition, it is easy to verify that the optimal marginal cost reduction under tariff protection is higher than its corresponding level under a free trade regime (x_{ft}^C, x_s^C). This is the consequence of $F1$'s manipulatory actions when there is policy intervention: the firm increases investment in order to receive higher payments (subsidies) from the government. The government's decision to commit or not to free trade is based on the corresponding social welfare comparison. This, in turn leads to the following condition

$$k > \frac{2(5-2\gamma^2)}{(2-\gamma^2)^3} = k_s^C \tag{14}$$

Namely, when the R&D investment is inexpensive, that is, $k < k_s^C$, it pays to commit to free trade, since the socially wasteful over-investment is significant and it outweighs the positive benefits of the intervention while the inverse is true when $k > k_s^C$. Grossman & Maggi (1998) obtained an analogous result for the case of the homogeneous goods.[15] Nonetheless, the new feature here is that the degree of product differentiation affects the critical value of k; the less differentiated the products, the higher is k_s^C. In other words, free trade is preferred for a given k and a high enough γ (see Figure 1).

To explain this result first we notice that, in the case of free trade, only the direct effect and the strategic effect of R&D on the domestic profit are present, while in the case of intervention, there is, in addition, a manipulation effect. It can be shown that for a given k, an increase in γ leads to a widening gap between the strategic and manipulative effect, with the latter effect becoming relatively stronger.[16] The underlying intuition is that a rise in γ brings about an inward shift of the firms' demand curves (thus a shrink in the market) that results in tougher market competition and lower total profit generated. As a consequence, a domestic firm has less room for gains from profit shifting and lower possibilities to recoup the costs of R&D investment through its sales profits. Therefore, qualifying for a higher compensation from the government becomes more important.

[15] Beside the case of expensive R&D investment, Grossman & Maggi (1998) have noted that a regime of output subsidy is also optimal in the case of very low R&D costs. This difference between their result and ours is due to the fact that we find it plausible to ignore the corner solution (that is, zero marginal costs).

[16] Note also that the manipulation effect always dominates the strategic effect. As k decreases, the gap between these two effects increases.

Faced with such manipulative behaviour, the government constrained to a second best policy may prefer to commit to free trade rather than to allow a wasteful use of social resources. In order to measure the magnitude of this excessive R&D investment when the government intervenes, we use the difference between the first-best social level of marginal cost reduction, $\tilde{x}_s^C$, and its second-best counterpart, x_s^C, labelled $D^I = x_s^C - \tilde{x}_s^C$. When the government does commit to free trade, the corresponding measure is the difference between the first-best and free trade levels, $D^{FT} = x_{ft}^C - \tilde{x}_s^C$ (see Figure 2). The critical value of γ, labelled γ^*, indicates the switching point from the intervention to the free trade regime.

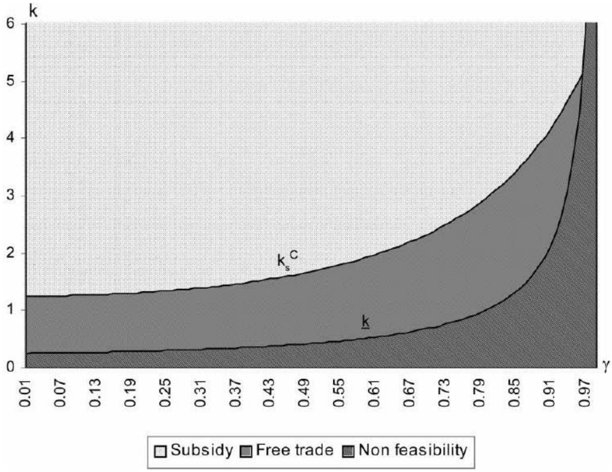

Figure 1: Free trade versus intervention respective parameter regions of k and γ in Cournot competition. Note:We label 'non-feasibility' the area formed by pairs (k, γ) that do not verify both assumptions (A1) and (A2).

Bertrand Competition

Since most of the results that we discussed in detail in the case of Cournot competition can be easily adapted for the case of Bertrand competition, we will only briefly discuss the latter case.

$$\pi^1(p^1, p^2; x, s) = q^1(p^1, p^2)[p^1 - (c - x - s)] - kx^2$$
$$\pi^1(p^1, p^2; x) = q^2(p^1, p^2)[p^2 - c]$$

After substituting the direct demands (ii) into the above profit functions and differentiating the resulting functions with respect to the corresponding prices we get the first-order conditions

$$(1 - \gamma) - [2p^1 - (c - x - s)] + \gamma p^2 = 0 \quad (15)$$
$$(1 - \gamma) - [2p^2 - c] + \gamma p^1 = 0 \quad (15')$$

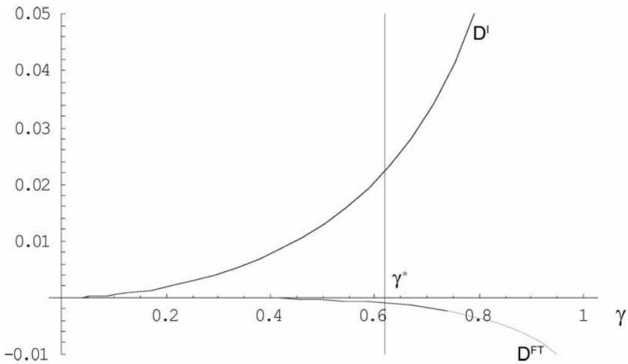

Figure 2: D^{FT} **and** D^{I} **in case** $k = 2, c = 0.4, \gamma^{*} = 0.618$.

Solving the system (15)(15') we obtain the inverse demands in terms of the initial parameters c and γ, and of the choice variables x and s

$$p^{1}(x,s) = \frac{(2-\gamma-\gamma^{2})+2(c-x-s)+\gamma c}{(4-\gamma^{2})} \qquad (16)$$
$$p^{2}(x,s) = \frac{(2-\gamma-\gamma^{2})+2c+\gamma(c-x-s)}{(4-\gamma^{2})} \qquad (16')$$

Note that both prices are decreasing in s and x. Following equations (16), (16') and (ii), the demands for good 1 and good 2 are given by

$$q^{1}(x,s) = \frac{(2-\gamma-\gamma^{2})(1-c)+(2-\gamma^{2})(x+s)}{(1-\gamma^{2})(4-\gamma^{2})} \qquad (17)$$
$$q^{2}(x,s) = \frac{(2-\gamma-\gamma^{2})(1-c)-\gamma(x+s)}{(1-\gamma^{2})(4-\gamma^{2})} \qquad (17')$$

Free Trade

When the government opts for no intervention in the very first stage of this game, the domestic firm decides on the level of R&D investment by maximizing the following profit function

$$\pi^{1}(x,0) = \frac{1}{(1-\gamma^{2})(4-\gamma^{2})^{2}}[(2-\gamma-\gamma^{2})(1-c)+(2-\gamma^{2})x]^{2} - kx^{2} \qquad (18)$$

and therefore chooses an x given by

$$x_{ft}^{B} = \begin{cases} \frac{(2-\gamma-\gamma^{2})(2-\gamma^{2})}{k\beta(1-\gamma^{2})(4-\gamma^{2})^{2}-(2-\gamma^{2})^{2}}(1-c) & \text{if } c > \frac{(2-\gamma-\gamma^{2})(2-\gamma^{2})}{k\beta(1-\gamma^{2})(4-\gamma^{2})^{2}-\gamma(2-\gamma^{2})} \\ c & \text{otherwise} \end{cases} \qquad (19)$$

With this level of x in place, the domestic firm's profit, and therefore social welfare, is given by

$$\pi^B_{ft} = W^B_{ft} = \frac{k(2-\gamma-\gamma^2)^2}{k(1-\gamma^2)(4-\gamma^2)^2-(2-\gamma^2)^2}(1-c)^2 \tag{20}$$

Strategic trade.

If the government did not commit to free trade, the welfare maximizing government would intervene by introducing a subsidy or tax programme, since it would be *ex post* optimal. Its decision is based on the following objective function

$$W(s) = \pi^1(x,s) - sq^1(x,s).$$

Much like in equation (6), the first-order condition implies

$$\frac{dW}{ds} = 0 \Rightarrow \frac{\partial q^1}{\partial s}(x,s)[p^1(x,s)-c+x] = -q^1(x,s)\frac{\partial p^1}{\partial s}(x,s) \tag{21}$$

By solving equation (21) we obtain the optimal value of subsidy:

$$s^B = \frac{-\gamma^2}{4(2-\gamma^2)}\left[(2-\gamma-\gamma^2)-(2-\gamma^2)\underbrace{(c-x)}_{\text{F1's marginal cost}}+\gamma\underbrace{c}_{\text{F2's marginal cost}}\right] \tag{22}$$

Since $x < c < 1$, regardless of the domestic firm's investment level, the subsidy is always negative. Thus, the optimal policy is a tax on output whose level is given by $t^B \equiv -s^B$. This level of tax allows the firm F1 to commit to the Stackelberg price in the price game if no subsidy or tax is in place.

Note that the optimal tax t^B increases with the increase in x (from equation (22), $dt^B/dx > 0$). An increase in the innovation level raises the output and enables the government to collect more revenue by charging a higher tax rate. In addition, the higher the R&D investment, the larger the decrease in marginal cost, x, and the more severe the subsequent price competition. To soften this detrimental competition, the government uses tax as a 'facilitating device' (rather than a profit-shifting tool). The domestic firm anticipates the government's action and invests less in R&D and produces less than without the tax in place.

Firm F1 chooses a level of R&D that maximizes its own profit

$$\pi^1(x,t^B(x)) = \frac{1}{16(1-\gamma^2)}[(2-\gamma-\gamma^2)(1-c)+(2-\gamma^2)x]^2 - kx^2 \tag{23}$$

As in the Cournot case, a change in the level of innovation affects this profit in three ways

$$\frac{d\pi^1}{dx} = \underbrace{\frac{\partial \pi^1}{\partial x}}_{\text{direct effect}} + \underbrace{\frac{\partial \pi^1}{\partial p^2}\frac{\partial p^2}{\partial x}}_{\text{strategic effect}} + \underbrace{\left(\frac{\partial \pi^1}{\partial t}+\frac{\partial \pi^1}{\partial p^2}\frac{\partial p^2}{\partial t}\right)\frac{dt^B}{dx}}_{\text{manipulation effect}} \tag{24}$$

The main difference is that both indirect effects are now negative. The R&D increases the price competition so the strategic effect is negative. As for the manipulation effect, the net effect in the bracket above seems to be ambiguous: on the one hand, $\partial\pi^1 = \partial t < 0$ because the firm has to pay higher taxes, and on the other hand, $(\partial\pi^1/\partial p^2)(\partial p^2/\partial t) > 0$ because a higher tax helps firms to commit to higher prices. However, it is easy to show that the first effect always dominates and this, together with the fact that $dt^B/dx > 0$, leads to the negative sign of manipulation effect.

After solving the maximization problem for x_s^B we obtain the optimal decrease in unit cost as a result of R&D investment for the Bertrand competition

$$x_s^B = \begin{cases} \frac{(2-\gamma-\gamma^2)(2-\gamma^2)}{16k(1-\gamma^2)-(2-\gamma^2)^2}(1-c), & \text{if } c > \frac{(2-\gamma-\gamma^2)(2-\gamma^2)}{16k(1-\gamma^2)-\gamma(2-\gamma^2)} \\ c, & \text{otherwise} \end{cases} \tag{25}$$

Consequently, firm F1 will gain

$$\pi_s^B = \frac{k(2-\gamma-\gamma^2)^2}{16k(1-\gamma^2)-(2-\gamma^2)^2}(1-c)^2 \tag{26}$$

will the domestic social welfare will be

$$W_s^B = \frac{k(2-\gamma-\gamma^2)^2[32k(1-\gamma^2)-(2-\gamma^2)^3]}{(2-\gamma^2)[16k(1-\gamma^2)-(2-\gamma^2)^2]^2}(1-c)^2 \tag{27}$$

Note that now the decrease in marginal cost, x_s^B, is actually smaller than the corresponding first-best social optimum, $\tilde{x}_s^B$. The reason for this is that besides a positive effect on domestic profits, the innovation increases the tax base through the increase in equilibrium F1's output, and so the government values more the R&D than does the domestic firm. If the government were able to use R&D policies before investment occurs, it would set an R&D subsidy that would exactly offset the strategic behaviour of the domestic firm inducing the domestic firm to choose a marginal cost reduction of $\tilde{x}_s^B$.

The domestic firm invests more in unit cost reduction in a free trade environment than it does when an output tax is in place ($x_{ft}^B > x_s^B$) since in case of intervention F1 manipulates the level of tax payments through the level of R&D investment. To establish when the domestic government would choose to interfere in the market through a tax on output and when it would prefer to commit to free trade we have to determine under which conditions the welfare in the case of taxation (see expression (27)) is greater than the welfare in the case of free trade (see expression (20)). It follows that when

$$k > \frac{(10-\gamma^2)(2-\gamma^2)^2}{32(1-\gamma^2)} = k_t^B \tag{28}$$

the government levies an output tax. Roughly speaking, when the investment becomes expensive enough, the government interferes in the market (see Figure 3), while the low cost of R&D investment calls for free trade.

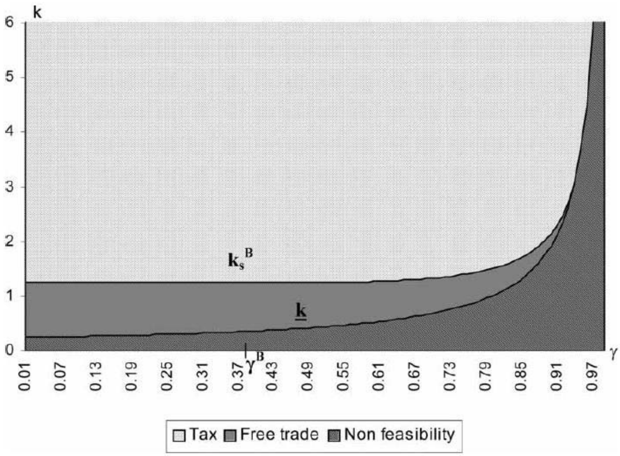

Figure 3: Free trade versus intervention respective parameter regions of k and γ in Bertrand competition.

To explain this result we have to recall that, in the presence of an output tax, firm F1 reduces its investment in R&D in order to pay a lower tax. This has a negative impact on the efficiency of firm F1. When the investment is costly enough, even if the firm would ignore the effect of investment on tax it would choose a 'low' level of R&D investment. Low investment means smaller tax and, therefore, less incentive for the domestic firm to reduce its R&D in order to manipulate the level of the output tax. As a result, the welfare losses due to manipulatory actions are lower than the increase in the net profits in the presence of a tax. However, this is no longer the case when investment cost is small.

The level of k is positively related to γ after a certain threshold level is reached ($\gamma^B = 0.3971$) that is, beyond γ^B, the less differentiated the products, the higher the critical value of k that delineates the desirability of intervention from the free trade region. As competition gets tougher, the contribution of the net profit to the overall increase in profit becomes less significant than the gains following a decrease in the tax payments.

We can now summarize the main findings of this section.

Proposition 1

(1) Regardless of the type of competition in the market, the domestic firm chooses a positive level of investment in R&D. If the government does not commit to free trade, it always intervenes with an appropriate tax/ subsidy scheme. The Cournot firm always invests more in R&D than its Bertrand counterpart and, consequently, the marginal cost decrease of the Cournot firm is strictly higher than that of the Bertrand firm, that is, $x_s^C > x_s^B$.

(2) The domestic government interferes in the market only when the cost parameter of R&D investment is high enough. If the competition is Bertrand and $k > k_t^B$ the government levies an output tax while if the competition is Cournot and $k > k_s^C$, it pays an output subsidy.[17] *In addition, critical value k_s^C is an increasing function of the product differentiation parameter, γ, on its whole range whereas k_t^B is an increasing function in γ when $\gamma > \gamma^B$.*

Proof See Appendix 1 for a proof of point (1). All the results in point (2) have already been derived.

It is interesting to note that when the domestic firm competes in quantities, it invests more in R&D than when it competes in prices. As Lin & Saggi (2002) noticed, this can be explained by the different signs that the indirect effects (see formulas (9) and (24)) have under Cournot and Bertrand competition. The presence of the manipulation effect is crucial here since, as Bester & Petrakis (1993) showed, the strategic effect alone cannot ensure this ranking of R&D's for all parameters. When only the strategic effect is present and the toughness of competition increases (high levels of γ), the growth in market share due to a decrease in marginal cost becomes larger in Bertrand competition than in a Cournot one, creating therefore a stronger incentive for firms competing in prices to innovate. However, the negative effect that an increase in R&D has on profits in Bertrand competition through the manipulative effect decreases firms' incentives to invest in R&D to such extent that even for high levels of γ a F1 competing in quantities invests more in R&D than its counterpart competing in prices.

Finally, before moving to the issue of the asymmetric information, we point out that the welfare losses of the 'second best' policy relative to the first best policy are generally very small where, as already mentioned, the 'first best' policy in a perfect information framework is comprised of the tax (subsidy) on the R&D expenditures and the output subsidy (tax) when the market stage competition is of the Cournot (Bertrand) type. (The complete derivation of the first-best polices under both Cournot and Bertrand set-ups as well as the extensive comparison of the differences between social welfare under first-best and second-best policies can be found in our CERP discussion paper: Ionaşcu & Žigić , 2001.)

3 The Model: The Asymmetric Information Case

In order to isolate the consequences of the uncertainty of the mode of competition on the optimal design of the strategic intervention, we now assume that the only missing information for the government is the type of market interaction between the domestic and foreign firm. This assumption leads us to modify the timing of the symmetric information model somewhat: first the nature moves and chooses the type of market interaction. With probability η it will choose Bertrand competition, and with $1 - \eta$ Cournot competition, where η is assumed to be a common knowledge.[18] Next, the domestic government

[17] All the results obtained thus far could be got with the most general linear inverse demands, namely $p^i(q^i, q^j) = \alpha_i + \beta_i q^i + \delta q^j$.

[18] However, Maggi (1996) has demonstrated that the type of competition arises endogenously in a capacity-price game ranging from the Bertrand to the Cournot outcome, as capacity constraints become more important.

will announce whether it will commit to free trade or not. Non-commitment implies that the government would interfere in the market through output subsidies (taxes if these subsidies are negative). Based on the government's announcement, the domestic firm will choose the level of R&D investment. After investment has occurred, the 'noncommitted' government will establish the appropriate level of trade policy.

Finally, competition in the market takes place. If the government does not commit to free trade, it pays attention to the level of marginal cost reduction, x, chosen by the domestic firm. Based on this, the government may update its prior probability η and infer the type of competition in the market. However, since the domestic firm will correctly predict it, it may be beneficial for the firm to mislead the government. More precisely, it is possible that the Bertrand firm mimics the behaviour of a Cournot firm and chooses higher R&D than otherwise in order to benefit from the government's help rather than pay a tax.[19] Thus, in the asymmetric information set-up the government might also be subject to manipulation by the domestic firm. Such actions are costly from the social point of view and may further decrease the desirability of a trade policy. In order to avoid such actions, the government can commit itself to free trade. However, this would imply foregoing the benefits from profit shifting.

We start the analysis of the equilibria of the game with the government's decision of intervention versus free trade. The government will compare

$$EW_{ft} = \eta W_{ft}^B + (1-\eta) W_{ft}^C \tag{29}$$

$$EW_{st} = \eta W_{st}^B + (1-\eta) W_{st}^C \tag{30}$$

and will choose the policy that will bring the highest expected welfare. From the previous section, we know the levels of welfare under the free trade regime for each of the market interaction types, e.g. Bertrand (welfare given by equation (5)) and Cournot (where welfare is given by equation (20)). Hence, the expected welfare without government intervention is given by

$$EW_{ft} = k(1-c)^2 \left(\eta \frac{(2-\gamma-\gamma^2)^2}{k(1-\gamma^2)(4-\gamma^2)^2 - (2-\gamma^2)^2} + (1-\eta) \frac{(2-\gamma)^2}{k(4-\gamma^2)^2 - 4} \right) \tag{31}$$

When the government does not commit to free trade, the domestic firm competing in the Cournot manner may prefer to convey its type to the government, and hence to qualify for subsidies rather than pay tax. However, a Bertrand firm may find it optimal to mimic the behaviour of a Cournot firm in order to enjoy the government's assistance in the form of output subsidies. If this is the case, we can expect the Cournot firm to incur some extra investment costs to signal its type by a 'large' marginal cost decrease, x, (or equivalently, a high level of R&D investment) where 'large' is defined as the level of x that is unprofitable for the Bertrand firm to undertake even when it is perceived as Cournot. When such a signalling strategy is not too expensive and its costs are more than offset by the augmentation in profits due to output subsidies, we will end up with a separating equilibrium configuration in the market.

[19]Note that the domestic firm's profits are increasing in the level of subsidy, regardless of the type of market competition.

Separating Equilibrium

We look for separating Perfect Bayesian equilibria in which the Cournot firm would find it optimal to signal its type by adopting a higher increase in efficiency than it would undertake in the symmetric information case. Let us denote

$$\pi_p^r(s^p(x), x) = q^1(x)[p^1(x) - (c - x - s^p(x))] - kx^2$$

where $s^p(x) = argmax_s W^p(x, s)$.

This is the profit that a domestic firm, which has invested kx^2 in R&D, competes *à la* r, and is perceived by government as p, will get (r and p stand for either Cournot or Bertrand). Let also[20]

$$\bar{\pi}_p^r = \max_{\text{x}} \pi_p^r(s^p(x), x)$$
$$\bar{x}_p^r = arg \max_x \pi_p^r(s^p(x), x)$$

Then, for a given level of model parameters, the separating equilibrium is given by the pair $[\bar{x}_B^B, x_C]$such that x_C satisfies

$$\bar{\pi}_B^B \geq \pi_C^B(s^C(x_C), x_C) \quad (32)$$
$$\pi_C^C(s^C(x_C), x_C) \geq \bar{\pi}_B^C \quad (32')$$

and the government's beliefs:

$$\begin{cases} x_C - & \text{Cournot type of competition} \\ \forall x \neq x_C - & \text{Bertrand type of competition} \end{cases} \quad (33)$$

The first condition prevents a Bertrand firm from mimicking the behaviour of a Cournot firm by undertaking the same level of R&D, whereas the last condition ensures that a firm competing *à la* Cournot would be better off by revealing its type through signalling than being perceived as a Bertrand firm.

The existence of the separating equilibrium depends on the relations between the corresponding profit functions $\pi_r^p(s^p(x), x)$ and on domestic government's beliefs given by equation (33). It follows that the necessary conditions for a separating equilibrium to exist are

$$\pi_B^B < \pi_C^B \text{ and } \pi_B^C < \pi_C^C \quad (s1)$$

and there is an interval $[x_l, x_h]$ such that

$$\bar{\pi}_B^B = \pi_C^B(s^C(x_l), x_l)$$
$$\pi_C^C(s^C(x_h), x_h) = \bar{\pi}_B^C \quad (s2)$$

[20]With these new notations, $\bar{x}_B^B = x_s^B$ and $\bar{x}_C^C = x_s^C$.

and $x_l < x_h$. [21]

In a separating equilibrium, a Bertrand firm cannot do better than choosing its optimal value $x_B^B = x_s^B$. Therefore, the welfare, in the case of nature choosing Bertrand competition, is the same in separating equilibria as in the perfect information equilibrium. However, this will not be the case for Cournot market competition. A Cournot firm will have to signal its type by incurring some additional costs. This result is captured in the following lemma.

Lemma 2 *The symmetric-information outcome cannot be supported as a separating equilibrium, that is,* $\bar{\pi}_B^B \leq \pi_C^B(s^C(\bar{x}_C^C), \bar{x}_C^C)$.

Proof *For the proof see Appendix 2.*

The above lemma points out that in a separating equilibrium it would be necessary that $x_C > \bar{x}_C^C$. However, this lemma says nothing regarding the existence of such equilibrium and it is independent on the necessary conditions (s1) and (s2). It might be the case that, whatever the level of desired increase in efficiency a Cournot firm is willing to pursue, a Bertrand firm may find it profitable to mimic the Cournot firm in order to qualify for output subsidies instead of paying output taxes. Nevertheless, in the separating equilibrium (if it exists), a Cournot firm would invest in R&D more than it does in a symmetric information set-up with government intervention. This implies that the socially wasteful over-investment will be even greater than it is in the analogous symmetric-information case.

In our set-up, the condition (s1) is always satisfied since, regardless of the type of market interaction, the domestic firm's profit is increasing in the level of subsidy. It follows that, $\pi_B^B < \pi_C^B$ and $\pi_B^C < \pi_C^C$, since perceived Bertrand competition attracts an output tax and perceived Cournot an output subsidy. In fact, in our model, the ranking $\pi_B^B < p_B^C < \min\{\pi_C^B, \pi_C^C\}$[22] holds regardless of the value of the parameters. In addition, in order for the interval $[x_l, x_h]$ to exist and therefore (s2) to hold, it is necessary that π_C^B, π_C^C.

Therefore, in our set-up we require the ranking of profit functions to be

$$\pi_B^B < \pi_B^C < \pi_C^B < \pi_C^C \qquad (s3)$$

in order for a separating equilibrium to exist (see Figure 4).[23]

The ranking (s3) applies as soon as $g < 0.9783$, implying that goods are not 'too close' substitutes and k exceeds a certain critical value k (see Appendix 3, point 3).[24]

[21] As a referee noted, the uniqueness of separating equilibrium can be ensured by applying the intuitive criterion (see Cho & Kreps, 1987) since the only equilibrium satisfying the intuitive criterion is $x_C = x_l$. However, the uniqueness of the equilibrium is not relevant for the purpose of our analysis.

[22] See Appendix 3 for the proof of this relation (point 1) and of $\bar{\pi}_B^B < \bar{\pi}_B^C$(point 2).

[23] The depicted ranking between the optimal values might change since $\bar{x}_B^B$ might be bigger than $\bar{x}_B^C$ and $\bar{x}_C^B$ might be bigger than $\bar{x}_C^C$. (Upon request we can provide a discussion of the ranking of the optimal values depending on the parameters.) Whatever the relationship between these values, as long as the relationship between profits remains as in Figure 4, a separating equilibrium exists.

[24] When $1 > \gamma > 0.9783$, so that products are very alike, a Bertrand firm perceived as Cournot, earns a higher profit than a correctly identified Cournot firm for all levels of x, that is $\pi_C^B(x) > \pi_C^C(x)$. This is the consequence of tougher competition in the Bertrand case, so that the R&D investment leads to a higher output and higher market share, resulting in higher subsidy revenue and higher total profit for the Bertrand firm.

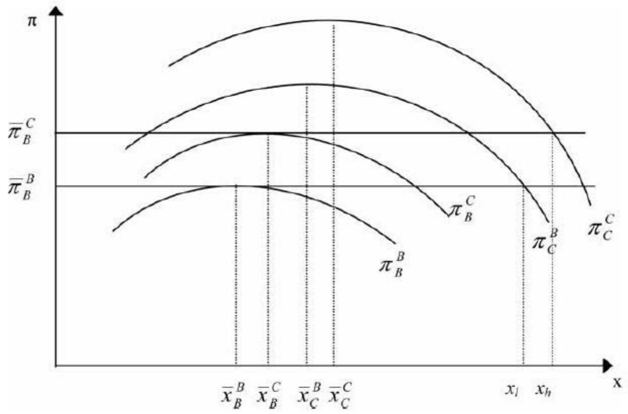

Figure 4: The necessary relationship between profits for the existence of a separating equilibrium.

Moreover, as soon as $g < 0.9257$, the interval $[x_l, x_h]$ exists (conditions (s2) hold) for values of k higher than a certain critical level k^{**} (see Appendix 3, point 4).[25] Given the natural restriction that $\gamma < 1$, and the fact that the feasibility argument requires higher k for higher γ (see Figure 1), the necessary conditions for the existence of a separating equilibrium are fulfilled for the majority of the parameter space.

The existence of a separating equilibrium depends (i) on the beliefs that domestic government holds about the type of market competition for all possible levels of R&D investment (ii) and, as discussed above, on the existence of an interval $[x_l, x_h]$ such that $x_l \leq x_C \leq x_h$. The existence of the interval $[x_l, x_h]$ is proved by means of a simulation technique. As Bhattacharjea (2002) points out, it is usually very difficult to solve analytically for these conditions and such a task 'ultimately relies on numerical simulations to demonstrate the existence and social welfare properties of signaling equilibria, even with linear demands and constant costs'.

We summarize the above discussion in the form of Proposition 2.

Proposition 2

(1) If the goods in question are not 'too close' substitutes, and the R&D investment parameter (k) is not 'too low', then a separating equilibrium exists with beliefs defined by equation (33).

(2) If there is a separating equilibrium, and competition is of the Cournot type, the commitment to free trade would always yield higher social welfare than government

[25] Whenever the products are quite alike so that $0.9783 > g > 0.9257$, a Bertrand firm can successfully mimic the behaviour of a Cournot firm (since it is too costly for a firm competing in quantities to differentiate itself through high enough levels of investment). Even when the cost of R&D is very high, a Bertrand firm would opt for high levels of investment and therefore high R&D costs and output subsidies, rather than for harsh competition combined with output taxes.

intervention in form of an output subsidy. A domestic government would therefore interfere in the market only if it has high expectations that the competition in the market takes place á la Bertrand (high level of η) and the investment costs, k, are such that $k > k_t^B$.

However, as stated in part 2 of Proposition 2, the fact that such equilibrium exists offers no guarantee that the government will opt for it. Since the overinvestment in the case of asymmetric information is always larger than it is in the symmetric information case (that is, $x_C > \bar{x}_C^C$), the expected welfare in a separating equilibrium under an output policy regime is always smaller than in the corresponding symmetric information case. Thus, for all the parameters for which a fully informed government opts for free trade regardless of the market structure, a government facing information asymmetry would opt for free trade as well. In order to identify all the ranges of parameters for which free trade is the optimal policy under asymmetric information, we have to compare the expected welfare in case of non-intervention (equation (31)) with that of government intervention. The latter one can be computed from formula (30), where

$$W_{st}^B = \frac{k(1-c)^2(1-\gamma)^2(2+\gamma)^2[32k(1-\gamma^2)-(2-\gamma^2)^3]}{(2-\gamma^2)[16k(1-\gamma^2)-(2-\gamma^2)^2]^2} = W_s^B \tag{34}$$

and

$$W_{st}^C = \frac{[(1-c)(2-\gamma)+2x_C]^2 - 8kx_C^2(2-\gamma^2)}{8(2-\gamma^2)} < W_s^C \tag{35}$$

As obtained through the computer simulation, in a separating equilibrium, the social welfare under free trade is always higher than the welfare in the Cournot separating equilibrium.

To sum up, it is optimal to intervene only when the competition in the market is very likely to be Bertrand and k exceeds the critical level k_t^B even though a separating equilibrium exists for a wide range of parameters. This is a consequence of the socially costly signalling. Due to the strategic behaviour towards the rival and the possibility of manipulation in a perfect information set-up, a Cournot firm incurs higher investment than is socially optimal. The presence of asymmetric information and the need for signalling drive the investment even further from the socially desirable level. Moreover, a tax policy for a Bertrand firm increases its incentives to mimic the behaviour of a Cournot one. All these actions and incentives drive the welfare with asymmetric information in case of Cournot competition below the free trade level.

4 Conclusions

In this paper, we put forward a simple yet realistic variant of the so-called 'third market' model, in which foreign and domestic firms compete in either quantity or price in a third market and the domestic government is bound to intervene only after the realization of the domestic firm's strategic variable (R&D investment in our case) takes place. This set-up implies that the domestic government is unable to commit inter-temporally to the output policy, allowing the domestic firm to manipulate the government through the chosen level of R&D since it foresees that the welfare maximizing government will find it optimal to intervene *ex post.* Such manipulative behaviour results in a socially inefficient level of R&D investment and thus, may induce the government to consider commitment to free trade as a device to prevent this kind of strategic behaviour of the domestic firm. In a sense, the government is constrained to choosing between two 'second best policies': i.e. *ex post* strategic trade intervention *versus* free trade. The former enables the domestic firm to achieve the Stackelberg outcome vis-à - vis its rival and enjoy the benefits of profit shifting while society's welfare declines due to the firm's inappropriate investment level. The latter option sacrifices profit shifting gains in order to avoid the either socially excessive (Cournot competition) or socially insufficient (Bertrand competition) R&D investment. Both policies fall short of the 'first best' ideal which requires the government to have, apart from the output policy, an R&D policy instrument before the firm's investment is made.

The above notions of both the first and the second best intervention are defined in the framework of symmetric, perfect information set-up. The only purpose of the first best policy outcome is to serve as a relevant benchmark, while the main focus of the analysis is on the more realistic second best policy that seems especially suitable when we consider the case of asymmetric information.

In terms of relevant results under the assumptions of perfect information and the second best policy framework, we found that the standard results in which firms competing in prices under-invest in R&D while firms competing in quantities over-invest in R&D are reinforced in our set-up due to the manipulative behaviour of the domestic firm. Further, Grossman & Maggi's (1998) finding that government intervention is optimal for high unit R&D investment costs, k, extends to our set-up with product differentiation and is valid for both Cournot and Bertrand types of competition. Moreover, the degree of product differentiation affects the threshold between the free trade and intervention as the optimal regimes.

As for asymmetric information, there is an additional social cost that arises from the signalling when the government does not commit to free trade and the competition on the market is of the Cournot type. This effect manifests itself through even greater over-investment compared with the corresponding case of the perfect information to the extent that it makes the intervention always more costly than free trade in terms of social welfare loss. Thus, free trade seems to be a robust policy choice as conjectured by Krugman (1987) and the imperfectly informed government opts for free trade in general unless the probability of Cournot competition is rather 'small' and the unit cost of investment is 'large enough' to justify the intervention. Moreover, free trade has a special role in the given set-up, a role that is distinctive from the traditional argument favouring free trade. That is, it may serve, irrespectively of whether the information is symmetric or not, as a device that protects the government from the manipulating and socially inefficient behaviour of domestic firms.

Appendix A:

We have to prove that $x_s^B < x_s^C$. All the other results in this proposition were already discussed and proved before.

$$x_s^C - x_s^B = \gamma^2(1-c)^2 \frac{2k(16-4\gamma-24\gamma^2+6\gamma^3+8\gamma^4-\gamma^5-\gamma^6)-\gamma(2-\gamma^2)}{2[k(2-\gamma^2)^2-1][16k(1-\gamma^2)-(2-\gamma^2)^2]} \qquad (a)$$

since $16-4\gamma-24\gamma^2+6\gamma^3+8\gamma^4-\gamma^5-\gamma^6 > 0$ for all γ on (0,1) the numerator of the above expression is an increasing function on k. If at $\underline{k}$ this numerator is positive, it follows that for all the range of possible k it will be positive. At $\underline{k}$ this numerator equals

$$\frac{64+32\gamma-104\gamma^2-36\gamma^3+56\gamma^4+10\gamma^5-12\gamma^6-\gamma^7+\gamma^8}{(2+\gamma)(2-\gamma^2)^2}$$

Since $64+32\gamma-104\gamma^2-36\gamma^3+56\gamma^4+10\gamma^5-12\gamma^6-\gamma^7+\gamma^8 > 0$ for all γ on $(0,1)$, the numerator in expression (a) is positive for all feasible ks. Moreover, $g^2(1-c)^2$ and the denominator of the above mentioned expression are positive as well. Therefore $x_s^B < x_s^C$.

Appendix B: Proof of Lemma 1

We can distinguish two situations corresponding to two possible relations between $\bar{x}_C^B$ and $\bar{x}_C^C$. Therefore, first we study the relationship between these two maxima.

When $k > \tilde{k} = 2/(8-8\gamma-4\gamma^2+2\gamma^3+\gamma^4)$, $\bar{x}_C^B < \bar{x}_C^C$. However, since $\bar{x}_C^B$ and $\bar{x}_C^C$ are discontinuous in $1/4(1-\gamma^2)$ and $1/(2-\gamma^2)^2$ respectively, and since the first one is the biggest one, we have to access the position of k with respect to it. Only when $\gamma < 0.857$, is k bigger than zero; moreover, $1/4(1-\gamma^2) < \underline{k} < \tilde{k}$. Yet, when $\gamma > 0.875$, $\tilde{k}$ is negative and $\bar{x}_C^B(1/4(1-\gamma^2)) \to \infty$ while $\bar{x}_c^B(1/4(1-\gamma^2)) \to\ finitevalue$, hence $\bar{x}_C^B > \bar{x}_C^C$ for all $k > \underline{k}$. It follows from the above discussions that

$$\min\{\bar{x}_C^B, \bar{x}_C^C\} = \begin{cases} \bar{x}_C^B & \text{if } k > \tilde{k} \text{ and } \gamma < 0.857 \\ \bar{x}_C^C & \text{otherwise} \end{cases}$$

Two cases regarding the behaviour of π_C^B arises from the above relation between $\bar{x}_C^B$ and $\bar{x}_C^C$.

(1) When π_C^B is a decreasing function on $(\bar{x}_C^C, c)$, then parameters k and γ are in the same range as when $\bar{x}_C^B = \min\{\bar{x}_C^B, \bar{x}_C^C\}$

(2) When π_C^B is a increasing function on $(\bar{x}_C^C, \bar{x}_C^B)$ (more precisely on $(0, \bar{x}_C^B)$)

Case 1

Since the parametrical form of $\pi_C^B(s^C(\bar{x}_C^C), \bar{x}_C^C)$ is very complicated we designed a x_{high} such that $x_{high} = ((2-\gamma)/(2[4k(1-\gamma^2)-1]))(1-c) > \bar{x}_C^C$ and $\pi_C^B(s^C(x_{high}), x_{high})$ can be reduced to a less complicated value, namely $\pi_C^B(s^C(x_{high}), x_{high}) = (k(1-\gamma^2)(8-$

$4\gamma - 2\gamma^2 - \gamma^3)^2 - \gamma^6)/(4(4-\gamma^2)^2(1-\gamma^2)[4k(1-\gamma^2)-1])(1-c)^2$. If we subtract from this expression π_B^B we can show that in the resulting expression, the numerator is an increasing function on k when $k > 2/(8-8\gamma-4\gamma^2+2\gamma^3+\gamma^4)$. The denominator is positive. Since, for $k = 2/(8-8\gamma-4\gamma^2+2\gamma^3+\gamma^4)$ the numerator is positive (equal to $f(\gamma)(1-c)^2/(8-8\gamma-4\gamma^2+2\gamma^3+\gamma^4)^2$ where $f(\gamma)$ is a polynomial function of degree 18 with no root on $[0,1]$, positive in 0), then $\bar{\pi}_b^B < \pi_C^B(s^C(x_{high}), x_{high}) < \pi_C^B(s^C(\bar{x}_C^C), \bar{x}_C^C)$.

Case 2

As in case 1, since the value of $\pi_C^B(s^C(\bar{x}_C^C), \bar{x}_C^C)$ looks very complicated we use, instead of $\bar{x}_C^C$, a x_{low} such that $x_low = (1-\gamma)/(4k(1-\gamma^2)-1)(1-c) < \bar{x}_C^C$. For such an investment, we obtain $\pi_C^B(s^C(x_{low}), x_{low}) = (4k(1-\gamma^2)(8-4\gamma-2\gamma^2-\gamma^3)^2 - (4-3\gamma^2)^2\gamma^2)/(16(4-\gamma^2)^2(1-\gamma^2)[4k(1-\gamma^2)-1])(1-c)^2$. If we subtract from this expression $\bar{\pi}_B^B$ we can show that in the resulting expression, the numerator is an increasing function on k. The denominator is positive. Since for $k = (4-3\gamma^2)/(2(1-\gamma)(2+\gamma)(2-\gamma^2)^2)$ the numerator is positive (equal to $(g(\gamma)(1-c)^2)/((2+\gamma)^2(2-\gamma^2)^4)$ where $g(\gamma)$ is a polynomial function of degree 20 with no root on $[0,1]$, positive in 0), then $\bar{\pi}_B^B < \pi_C^B(s^C(x_{low}), x_{low}) < \pi_C^B(s^C(\bar{x}_C^C), \bar{x}_C^C)$.

Appendix C:

1. Assume that the government had chosen the level s for the subsidy and that the domestic firm invested x in innovation. In this case, depending on the type of competition in the market, the firm's profits are given by

$$\pi^1_{Bertrand}(x,s) = \frac{1}{(1-\gamma^2)(4-\gamma^2)^2}[(2-\gamma-\gamma^2)(1-c)+(2-\gamma^2)(x+s)]^2 - kx^2$$
$$\pi^1_{Cournout}(x,s) = \frac{1}{(4-\gamma^2)^2}[(2-\gamma)(1-c)+2(x+s)]^2 - kx^2$$

We can infer from the above expression that, regardless of the type of market interaction, the domestic firm's profits are increasing in the level of subsidy. It follows that, since Bertrand competition attracts an output tax and Cournot an output subsidy, $\pi_B^B < \pi_C^B$ and $\pi_B^C < \pi_C^C$. The profits π_B^B and π_C^C are given by the formulae (8) and (23) respectively, and π_C^B and π_B^C by

$$\pi_C^B(s^C(x),x) = \frac{1}{4(1-\gamma^2)}\left[\left(1-\gamma\frac{4+\gamma^2}{8-2\gamma^2}\right)(1-c)+x\right]^2 - kx^2$$
$$\pi_B^C(s^B(x),x) = \frac{1}{4}\left[\left(1-\gamma\frac{4-3\gamma^2}{8-6\gamma^2+\gamma^4}\right)(1-c)+x\right]^2 - kx^2$$

But both above functions are increasing in x. However, $\sqrt[4]{\pi_C^B(s^C(x),x)+kx^2}$ is increasing faster in x than $\sqrt[4]{\pi_B^C(s^B(x),x)+kx^2}$. Since

$$\pi_C^B(s^C(0), 0) = \frac{(1-c)^2}{4(1-\gamma^2)}\left(1 - \gamma\frac{4+\gamma^2}{8-2\gamma^2}\right)^2$$
$$\pi_B^C(s^B(0), 0) = \frac{(1-c)^2}{4}\left(1 - \gamma\frac{4-3\gamma^2}{8-6\gamma^2+\gamma^4}\right)^2$$

then $\pi_B^C < \pi_C^B \sqrt[4]{\pi_B^C(s^B(x), x) + kx^2}$ is increasing slower in x than $\sqrt[4]{\pi_B^B(s^B(x), x) + kx^2}$. Therefore, if $\pi_B^B(s^B(c), c) < \pi_B^C(s^B(c), c)$ then $\pi_B^B < \pi_B^C$. So $((\pi_B^C(s^B(c), c) - \pi_B^B(s^B(c), c))/(\gamma^3))16\beta(1-\gamma^2)(8-6\gamma^2+\gamma^4)^2$ is given by

$$\begin{aligned} 128 - 128\gamma - 160\gamma^2 + 176\gamma^3 + 48\gamma^4 - 76\gamma^5 + 4\gamma^6 + 11\gamma^7 - 2\gamma^8 - \gamma^9 \\ -c^2\gamma(64 - 80\gamma^2 + 24\gamma^4 + \gamma^6) - 2c(64 - 64\gamma - 80\gamma^2 + 80\gamma^3 \\ +24\gamma^4 - 24\gamma^5 + 2\gamma^6 - \gamma^7 - \gamma^8) \end{aligned}$$

Since this is a decreasing function of c and, since it is still positive in the highest value that c can take $(1 - (\gamma/2 - \gamma^2))$, then $\pi_B^B(s^B(c), c) < \pi_B^C(s^B(c), c)$.

If γ and c are on a grey area in Figure 5, then we have $\bar{x}_C^B < \bar{x}_C^C$.

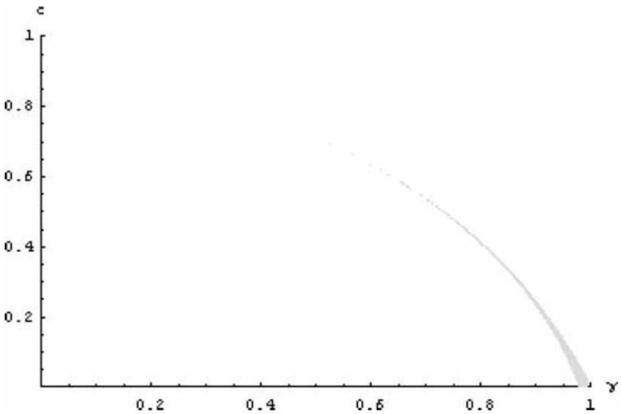

Figure 5: The values of γ and c for which $\bar{x}_C^B < \bar{x}_C^C$

2. Since $\pi_B^B < \pi_B^C$ for all $x > 0$, then $\bar{\pi}_B^B < \bar{\pi}_B^C$.
3. In order to show that $\pi_C^C < \pi_C^B$ when $\gamma > 0.9783$, we consider

$$\frac{\pi_C^C(s^C(x), x) - \pi_C^B(s^C(x), x)}{\gamma^3} 16(1-\gamma^2)(8-6\gamma^2+\gamma^4)^2$$

that equals $e1(x)$ where

$$\begin{aligned} e1(x) &= (1-c)^2(128-128\gamma-96\gamma^2+80\gamma^3+32\gamma^4-12\gamma^5-4\gamma^6-\gamma^7) \\ &+4(1-c)x(32-32\gamma-24\gamma^2+16\gamma^3+8\gamma^4-2\gamma^5-\gamma^6)-4x^2\gamma(4-\gamma^2)^2 \end{aligned}$$

The first derivative with respect to x is

$$\frac{\partial e1}{\partial x}(x) = 4(4-\gamma^2)[(1-c)(8-8\gamma-4\gamma^2+2\gamma^3+\gamma^4)-2x\gamma(4-\gamma^2)].$$

Since, for $\gamma > 0.857$, this derivative is negative $(8-8\gamma-4\gamma^2+2\gamma^3+\gamma^4<0)$, the function $e1(x)$ has its maximum at x=0. But

$$e1(0) = (1-c)^2(128-128\gamma-96\gamma^2+80\gamma^3+32\gamma^4-12\gamma^5-4\gamma^6-\gamma^7)$$

and is negative for $\gamma > 0.978$.

4. We would like to identify the conditions under which the necessary conditions $(s2)$ do not hold, for any level of investment cost k. It is immediate that whenever $\pi_C^C < \pi_C^B$, the necessary conditions $(s2)$ are never verified if $\max_x\{\pi_C^C-\pi_C^B\} < \min_k\{\bar{\pi}_B^C-\bar{\pi}_B^B\}$.

For $\gamma > 0.8576$, the first derivative of $\pi_C^C-\pi_C^B$ with respect to x is always negative for $x\in[0,c]$. Therefore, this function reaches its maximum when there is no investment $(x=0)$, and

$$\max_x\{\pi_C^C-\pi_C^B\} = (1-c)^2\gamma^3\frac{128-128\gamma-96\gamma^2+80\gamma^3+32\gamma^4-12\gamma^5-4\gamma^6-\gamma^7}{16(1-\gamma^2)(8-6\gamma^2+\gamma^4)^2} \qquad (b)$$

$\bar{\pi}_B^C-\bar{\pi}_B^B$'s first derivative with respect to k has a sign given by

$$\begin{aligned} &sign\{-2(2-\gamma^2)^5(4-2\gamma^2-\gamma^4)+2k(2-\gamma^2)^2 \\ &\quad\times(128-128\gamma-160\gamma^2+176\gamma^3+48\gamma^4-76\gamma^5+4\gamma^6+11\gamma^7-2\gamma^8-\gamma^9) \\ &\qquad -4k^2(1-\gamma)^2(512+256\gamma-896\gamma^2-256\gamma^3+704\gamma^4 \\ &\qquad\quad +96\gamma^5-288\gamma^6-24\gamma^7+64\gamma^8+12\gamma^9-4\gamma^{10}-\gamma^{11})\} \end{aligned}$$

The later function is always negative for any $k > \underline{k}$. Hence, $\min_k\{\bar{\pi}_B^C-\bar{\pi}_B^B\}$ is reached for $k\to\infty$ and equals

$$\min_k\{\bar{\pi}_B^C-\bar{\pi}_B^B\} = (1-c)^2\gamma^3\frac{128-160\gamma^2+16\gamma^3+64\gamma^4-12\gamma^5-8\gamma^6+3\gamma^7+\gamma^8}{16(1+\gamma)(8-6\gamma^2+\gamma^4)^2} \qquad (c)$$

Whenever $\gamma > 0.9257$, the expression (b) is smaller that (c). Consequently, regardless of the level of parameters, when $\gamma > 0.9257$, the (s2) conditions do not hold.

Part II

Competition Policy and Market Leaders

We study the potential loss in social welfare and changes in incentives to invest in R&D that result when the market leading firm is deprived of its position. We show that under plausible assumptions like free entry or repeated market interactions there is a social value of market leadership and its mechanical removal by means of competition policy is likely to be harmful for society.

1 Introduction

One of the key objectives of competition policy is to affect market structure and market conduct if they are deemed to be socially undesirable. When, for instance, market concentration exceeds a certain threshold, government usually undertakes measures to decrease the concentration by banning mergers or requiring large firms to divest. Such an approach, however, may yield an opposite outcome to the desired one. The reason is that the traditional approach, in which usually the height of Herfindhal-Hirschman index determines whether market concentration is 'excessive' or not, is often too rough and it does not lie on solid theoretical grounds (see more on this in Motta 2004).

Based on rigorous game theoretic analysis, Sutton (1991) and Etro (2007) demonstrated that high market concentration is in fact an outcome of tough (both price and non-price) competition rather than an indicator of market power and lack of competitive forces when conditions of free (or more generally, endogenous) entry prevail.[1] The presence of a market leader can further enhance the competitive pressure and the toughness of price competition. Thus, in a recent empirical paper by Czarnitzki et al. (2008), the authors show that market leaders under free entry invest more intensively in R&D than their followers or a firm in a market without free entry. Hence, shifting market structure and related market conduct away from market leadership may soften competition and, consequently have undesirable social welfare effects. This is especially likely in dynamic markets (like, for example, the software market) characterized by investment in R&D and free entry. One way the government can engineer such a shift is to deprive the leading firm of its patented product or of its superior technology by forcing it to reveal secret pieces of information to its competitors. In the software industry, for instance, by forcing a dominant firm to reveal the source code of the most popular operating system (through compulsory licensing), the government may, among other things, strip the firm of its leading market position. So in the longer run, there will be firms of similar power competing in the market. In terms of market conduct, this situation could be described as a change from Stackelberg leadership to an ordinary oligopoly of firms with more evenly distributed market power.

In this paper we aim to study a positive and normative aspect of the above situation in which the dominant firm is deprived of its leading position by means of competition policy. Our analysis is motivated by an actual decision of the European Commission (EC) recently confirmed by the European Court of First Instances, to impose a legal requirement on a firm with a dominant position (Microsoft) to license its proprietary technology and intellectual property rights (IPR) to its competitors so that they can

[1] Note that the assumption of free entry is a reasonable one in characterizing of the long run equilibria.

incorporate that same technology into their own competing products.[2] This verdict is based on the reasoning that industry-wide innovation will be boosted in the long-run if the leading firm is deprived of its exclusive intellectual property rights. More specifically, according to the EC, this is justified when 'on balance, the possible negative impact of an order to supply on Microsoft's incentives to innovate is outweighed by its positive impact on the level of innovation of the whole industry (including Microsoft).'[3] Thus, the EC decision seems to establish a new balancing test under which they can order compulsory licensing. However, it seems that there is no underlying economic analysis on the side of the EC that would support the above claims.

The above considerations motivate our paper. We analyze two otherwise identical setups: one in which there is a technological and market leader and the other in which all firms are identical. Our paper is divided into two parts, each with its own setup outlining plausible scenarios where leadership is beneficial both to social welfare and R&D.

Microsoft has been the subject of two major cases in competition policy, the first involving the US government and the second, which we mention above, involving the European Commission. While we were prompted into writing this paper by the wording in the EC decision, our work is not intended to be a direct commentary on the case itself. Gilbert and Katz (2001), Klein (2001) and Whinston (2001) provide economic analysis on US vs. Microsoft, whereas Vickers (2009) summarizes EC vs. Microsoft. Our work is only aimed at illustrating that the statement of the EC quoted above is too strong and unjustified by economic theory.

The natural analytical framework to tackle the effects of market leadership is the Stackelberg leader-followers model. We use this framework in section 2. Reviving and refreshing this modeling approach, Etro (2004, 2007, 2008) has recently provided us with important insights about the behavior of market leaders when entry in the market is endogenous, and has applied his approach to analyze, among other things, some positive and normative aspects of the dynamic markets of the New Economy (see chapters 4 and 6 in Etro, 2007).[4]

Since we are interested in technological leadership as well, we extend Etro's approach by allowing the market leader to also have the first mover advantage in conducting innovations. That is, the leader is not only assumed to choose its market variable (like price or quantity) as the first but also has the technological first mover advantage in selecting its strategic variable like R&D investments.

The whole Stackelberg concept, however, rests on the idea that the market (and in our case) technological leadership is given without questioning its origin. Moreover, the features of dynamic markets of the New Economy might require a more dynamic modeling approach like repeated market interactions. Therefore, in section 3 we also look for an alternative approach where i) leadership could arise endogenously and ii) there are repeated interactions in the market among the firms.

Boone (2002, 2004) has shown that in the presence of repeated interactions and cost asymmetries the most cost efficient firms have incentives to assume a leadership role in

[2] Commission decision in Case COMP/C-3/37.792, *EC Commission v. Microsoft.*

[3] See footnote [4].

[4] Entry in a market is considered to be endogenous when in the long run equilibrium there are no profitable opportunities to be exploited by potential entrants and the author argues convincingly that this is the standard situation in the vast majority of contemporary markets.

the market.[5] Thus, in the second part of our paper we adopt Boone's (2004) approach, which we modify to allow the firms to invest in R&D improve their production technology. Some firms, however, might be more efficient than the others in this process and that, in turn, may change the distribution of unit costs and create asymmetries among them. This asymmetry is exactly at the heart of the Boone's (2004) insight. He argues that casual observation and theoretical and empirical evidence suggests that the presence of significant differences in cost efficiency levels among the firms (and their repeated interactions) induce the most efficient firms to act aggressively and impose an outcome that is more beneficial for them. To make things very simple, we assume one of the firms to be more efficient than the others in the R&D process in order to explicitly model the issue of technological and market leadership.

2 Theory of Market Leaders: Cournot *versus* Stackelberg with R&D and Free Entry

In our first scenario we explore the classical Stackelberg leadership concept accompanied by free entry. In order to mimic the above situation where the leader is artificially deprived of its leading position, we first consider the *ex post* situation where firms are on an even technological level (symmetric Cournot equilibrium) and compare it with the *ex ante* (before enacted competition policy) situation when there exists a technological and market leader (Stackelberg equilibrium). We use a simple dynamic setup of two- and three-stage games where all firms invest in R&D and where there is endogenous number of firms. The latter assumption captures the notion of long run equilibrium. We will only consider symmetric equilibria.

Apart from the first mover advantage of the leader in the Stackelberg case, the markets are identical. The firms compete in quantities of imperfect substitutes. The inverse demand facing each firm i is $P_i(q_i, q_{-i}) = a - q_i - b\sum_{j\neq i} q_j$, where $b \in (0,1)$ captures the degree of substitutability. Furthermore, all firms must pay fixed setup cost $F > 0$ to enter, and they incur $c - x_i$ marginal cost, where $c > 0$ is *constant* and x_i is R&D investment of firm i.[6] The cost of this investment is x_i^2/γ , where γ measures the efficiency of R&D.

2.1 Cournot Competition

The structure of the game in this environment is the following:

- There is a large number of potential entrants who decide whether to enter by incurring a setup cost of F or not.

[5]van Damme and Hurkens (1999) and Boone (2002, 2004) have shown that firms with lower costs may assume the role of leader for sufficiently asymmetric costs. Similary, Rotemberg and Saloner (1990) and Deneckere et al. (1992) have shown, respectively, that with better information or a bigger share of loyal customers a firm can also assume leadership. See also Hamilton and Slutsky (1990) and Syropoulos (1994, 1996).

[6]Note that x can also be interpreted as the investment in marketing and product development that enhances the size of the market captured by the parameter a.

- All entrants choose their investments x_i and their output quantities q_i simultaneously. So, to simplify the analysis, we assume that R&D investments are not chosen strategically to affect the subsequent competition in quantities but are simply set to minimize total cost, $TC(x_i) = (c - x_i)q_i(x_i) + x^2/\gamma + F$. Allowing for strategic choice of investment will make the analysis less transparent and will not change its main insights.

By backward induction we first find the optimal strategy of a firm if n firms have decided to enter. After that we compute total output, price and profits to determine the equilibrium number of firms, n^*.

In the last stage each firm solves

$$\max_{q_i, x_i} \Pi^i(q_i, x_i, q_{-i}) = (P_i - c + x_i)q_i - x_i^2/\gamma - F. \tag{1}$$

Taking the first order conditions of equation (1) and solving for symmetric output and investment we obtain

$$q_i^*(n) = \frac{2(a-c)}{2b(n-1) + 4 - \gamma}, \qquad x_i^*(n) = \frac{\gamma(a-c)}{2b(n-1) + 4 - \gamma}. \tag{2}$$

Notice that the levels of q and x are always proportional to each other in equilibrium, namely $x_i = (\gamma/2)q_i$. This result carries over to all firms in the market; hence, it is also valid for aggregate market output and R&D. Plugging (2) into the inverse demand and profit functions, we can solve for π_i^C as a function of n:

$$\Pi_i^C(n) = \frac{(4-\gamma)(a-c)^2}{[2b(n-1) + 4 - \gamma]^2}. \tag{3}$$

Finally, to find the equilibrium number of entrants we impose the condition that each firm's gross profit must justify its entry costs, that is, $\pi_C^i(n) \geq F$. For simplicity we will solve for a continuous n^* and use equality

$$n^* = \frac{(a-c)\sqrt{4-\gamma} - \sqrt{F}(4 - \gamma - 2b)}{2b\sqrt{F}}. \tag{4}$$

Hence, by plugging n^* into (2) we can solve for equilibrium firm output and investment:

$$q_i^* = \frac{2\sqrt{F}}{\sqrt{4-\gamma}}, \qquad x_i^* = \frac{\gamma\sqrt{F}}{\sqrt{4-\gamma}}.$$

The corresponding market output and investment are

$$Q_C^* = \frac{(a-c)\sqrt{4-\gamma} - \sqrt{F}(4 - \gamma - 2b)}{b\sqrt{4-\gamma}}, \text{ and}$$

$$X_C^* = \frac{\gamma[(a-c)\sqrt{4-\gamma} - \sqrt{F}(4 - \gamma - 2b)]}{2b\sqrt{4-\gamma}}.$$

Finally, the equilibrium price charged by firm i is given by

$$P_i^C = c + \frac{\sqrt{F}(2-\gamma)}{\sqrt{4-\gamma}}. \tag{5}$$

In the next section we will solve for the Stackelberg equilibrium and compare the outcomes with the ones we just reached.

2.2 Stackelberg Competition

In this setup firm l (the leader) invests in technology improvement before any other firm and enters the market before the others.[7] This, in turn, enables the firm to assume the role of the market leader. More formally, the timing of the game is now the following:

- The leader enters and pays setup cost, F, and immediately chooses investment x_l and output q_l.
- The other firms, the followers, decide whether to enter by paying F each.
- Those who enter decide on their x_i and q_i simultaneously.

By backward induction, we solve the followers' problem taking the leader's output q_l and the number of followers, m, as given. After that we solve for m as a function of q_l and finally we use this 'response' of the number of entrants and each q_i as conditions in the leader's problem. Hence, each follower's problem is

$$\max_{q_i, x_i} \Pi^i(q_i, x_i, q_{-i}, q_l) = (P_i - c + x_i)q_i - x_i^2/\gamma - F. \tag{6}$$

Taking the first order conditions and solving for the symmetric equilibrium we get

$$q_i^*(m, q_l) = \frac{2(a - c - bq_l)}{2b(m-1) + 4 - \gamma}, \qquad x_i^*(m, q_l) = \frac{\gamma(a - c - bq_l)}{2b(m-1) + 4 - \gamma}. \tag{7}$$

We can now find the profit of each follower and solve for the number of followers as a function of the leader's strategy, $m(q_l)$. Much like in section 2.1, we use the zero profit condition to obtain

$$m(q_l) = \frac{(a - c - bq_l)\sqrt{4 - \gamma} - \sqrt{F}(4 - \gamma - 2b)}{2b\sqrt{F}}. \tag{8}$$

Not surprisingly, the number of followers falls with q_l, the more aggressively the leader behaves, the less room there is in the market for followers. It is interesting however, to see how the output of each firm changes with the leader's output, because there are two opposite effects at work. The first is the direct response effect because $\partial q_i^*(m, q_l)/\partial q_l$ is negative as seen from (7). However, at the same time an increase in the leader's output reduces the numbers of followers in equilibrium and thus has positive effect on the follower's output since $(\partial q_i^*(m, q_l)/\partial m)(dm/dq_l) > 0$. We can plug (8) into (7) to get the net response in both follower strategies:

$$q_i^*(q_l) = \frac{2\sqrt{F}}{\sqrt{4 - \gamma}}, \qquad x_i^*(q_l) = \frac{\gamma\sqrt{F}}{\sqrt{4 - \gamma}}.$$

We note two features of this result: first, the two above described effects exactly offset each other so the followers' actions do not change with the leader's strategy. Second, their strategies (outputs) are the same as in the Cournot game under free entry that we solved earlier. The finding that the equilibrium strategy of a follower is not affected by

[7] In addition, $F \leq (a - c)^2/16$ for this entry to take place.

the leader's strategy when entry is free holds for a rather general setup and for a large variety of market conducts (Etro, 2008, see). Hence, q_l will only affect the total output of the followers through m, not q_i^*.

We can now come to the final set of equations that will be derived by the leader's problem:

$$\max_{q_l, x_l} \Pi^l(q_l, x_l) = \{[a - bm(q_l)q_i^* - q_l] - c + x_l\}q_l - x_l^2/\gamma - F. \tag{9}$$

Taking first order conditions and solving them, we obtain the equilibrium values

$$q_l^* = \frac{2(4-\gamma-2b)\sqrt{F}}{(4-\gamma-4b)\sqrt{4-\gamma}}, \qquad x_l^* = \frac{\gamma(4-\gamma-2b)\sqrt{F}}{(4-\gamma-4b)\sqrt{4-\gamma}}.$$

By substituting them into (9) we get the leaders equilibrium profit

$$\Pi_l^S = \frac{4b^2F}{(4-\gamma)(4-4b-\gamma)}.$$

In order to obtain positive values for q_l^* and x_l^*, $4-\gamma-4b > 0$ has to hold.[8] Comparing the leader's output and R&D with the followers', we see that the leader produces and researches more than each follower:

$$\frac{q_l^*}{q_i^*} = \frac{x_l^*}{x_i^*} = \frac{4-\gamma-2b}{(4-\gamma-4b)} > 1.$$

We can now also solve for the equilibrium number of followers m^* by plugging q_l^* in (8) and compute the difference between the number of firms, n^*, in the Cournot setup and number of firms, m^*+1, in the Stackelberg setup:

$$n^* - (m^*+1) = \frac{2b}{4-\gamma-4b} > 0$$

Hence, we have found that when one firm has a first mover advantage, we observe fewer firms in equilibrium. Furthermore, if we compare the total output[9] and R&D investment in Stackelberg and Cournot equilibria, we see that they are equal:

$$\begin{aligned} Q_S^* = Q_C^* &= \frac{(a-c)\sqrt{4-\gamma} - \sqrt{F}(4-\gamma-2b)}{b\sqrt{4-\gamma}}; \\ X_S^* = X_C^* &= \frac{\gamma[(a-c)\sqrt{4-\gamma} - \sqrt{F}(4-\gamma-2b)]}{2b\sqrt{4-\gamma}}. \end{aligned}$$

Finally, to compare with (5), here are the equilibrium prices of follower i and the leader:

$$P_i^S = c + \frac{\sqrt{F}(2-\gamma)}{\sqrt{4-\gamma}}, \tag{10}$$

$$P_l^S = c + \frac{\sqrt{F}(4-\gamma-2b)(2-\gamma-2b)}{\sqrt{4-\gamma}(4-\gamma-4b)}. \tag{11}$$

[8] Nonnegativity of production costs places a more stringent restriction on parameters. We elaborate on this in Appendix 4.

[9] Etro (2007) showed that aggregate output in both the Stackelberg and Cournot framework is the same in a rather general setup provided that entry is endogenous.

A comparison of equations (5) with (10) and (11) reveals that Stackelberg followers charge the same price as Cournot firms, while the leader charges a lower price. Hence, despite the lower number of varieties in the Stackelberg setup, there are gains in consumer surplus since the lower price of the leader more than compensates for it. This result is formally shown in 4.

The above results are obtained under the implicit assumption that entry deterrence is not a preferable strategy for the leader. As is well known, when the products get less differentiated, the entry deterrence eventually becomes an optimal strategy (see 4). However, unlike in the standard Stackelberg setup with exogenously given number of potential entrants, the leader's accommodation profit in our setup is increasing in differentiation parameter b (see 4). The intuition is that when products get more alike, competition becomes tougher, and, as a consequence, fewer firms enter in equilibrium. In other words, the leader can afford to squeeze more potential entrants out of the market as products become less differentiated.[10] Consequently, increasing product differentiation (letting b move towards zero), leads to the non-standard but intuitive result. In this case, the number of firms entering the market tends to infinity and the profit of the leader goes to zero as well (see 4). Thus in the limit, we obtain a (kind of) long-run monopolistic competition outcome with the leader earning zero profits rather than a monopoly outcome as would be the case with an exogenous number of firms and b tending to zero (see Dixit (1979) for the latter).

2.3 Long Run *versus* Short Run

The above characterizations are aimed at portraying two long-run equilibria: a Stackelberg as one before the policy implementation and a Cournot after the policy was in place for a long time. However, we should also be able to tell more about the intermediate situation that occurs soon after the leader has been deprived of its position but before the industry adjusts to its long run equilibrium. This intermediate or short run situation can be described as a Cournot equilibrium with exogenous number of firms. Recall that in a Stackelberg equilibrium there is one leader and m^* followers. Now assume that as a result of the government intervention, the leader loses its advantage and, hence, the market transforms itself into a Cournot-like setup with $m^* + 1 < n^*$ firms.

As seen from (2), each firm's $q_i^*(n)$ and $x_i^*(n)$ go up during this adjustment period. Aggregate output, $nq_i^*(n)$, and total R&D investment, $nx_i^*(n)$, however, fall.[11] Hence, if we treat the number of firms as exogenously set to $n = m + 1$, the total output and R&D will be lower compared to the setup with the leader and endogenous entry, when the total output and R&D are the equal to the Cournot equilibrium with n^* firms.

We can, therefore, conclude that the statement of the EU Commission does not hold in our setup: '[...] on balance, the possible negative impact of an order to supply on Microsoft's incentives to innovate is *not* outweighed by an increase in the R&D intensity of other firms. Consequently, there is *no* [...] positive impact on the level of innovation

[10] By the same token, and again completely opposite from the case with an exogenous number of firms, the leader's accommodation profit increases in setup costs parameter F, since it also leads to a lower number of entrants in equilibrium.

[11] The first derivatives with respect to the number of firms, n, are $\frac{2(a-c)(4-\gamma-2b)}{[4-\gamma+2b(n-1)]^2} \geq 0$ for $nq_i^*(n)$ and $\frac{\gamma(a-c)(4-\gamma-2b)}{[4-\gamma+2b(n-1)]^2} \geq 0$ for $nx_i^*(n)$.

of the whole industry (including Microsoft).'[12] Although positive profits would reemerge for each follower in this interim period, the total social welfare would be still lower than in the initial setup with the leader and free entry.

Thus, the considered action of the antitrust authorities will clearly help the competitors of (the former) leader since they will now be able to generate positive profits (at least in the short run) while the consumers will be definitely worse off.

3 Market Leadership in Repeated Interactions

As already indicated, in this section of the paper we consider a somewhat different market scenario based on Boone (2002) and (2004). We now assume that there is repeated market competition in prices but the produced goods are assumed to be homogeneous. All firms move at the same time to choose their R&D expenditure and post their market price. One of the firms, however, has an advantage over the others in terms of R&D productivity. We will call this firm the leader, because, although the game is played simultaneously each period, this advantage will enable it to assume technological and market leadership. Note that in this case we do not have the same type of (classic) leadership we had in section 2, where the leader was the only firm allowed to move first. In this case the advantage in R&D technology will translate into assumed leadership.

As for the solution of such a repeated game, Boone (2004) developed an equilibrium refinement that focuses on outcomes Preferred by Efficient Players (PEP). To apply the PEP refinement, we must distinguish between two types of deviations. The first type is the classical strategy of one firm slightly lowering its price to gain the whole market, in which case the other firms would retaliate to punish the deviant. Otherwise, a firm can lower the price to such levels that it can only be matched by some of the firms. The survivors would gain from this change and accept it as a new equilibrium. Hence, the most efficient firms act as market leaders.

Following Boone (2002), we further assume that firms collude on one price from the interval of sustainable prices. When firms are similar in efficiency and the second type of deviation is not viable, they will all agree to charge high prices. If it is possible to exclude some firms from the market to the benefit of all who remain, however, the latter will price more aggressively. Thus, using the PEP refinement on collusion strategies, the toughness of the market is endogenous and it depends on the heterogeneity in efficiency levels.

All firms who enter choose a price p_i and a level of R&D expenditure x_i. Each firm faces a constant marginal cost $c_i(x_i)$, where $c_i > 0$, $c_i' < 0$ and $c_i' > 0$ at all levels of x_i. The leader's cost function differs from the other firms by $c_L(x) < c_F(x)$ for all $x > 0$ and $c_L(0) = c_F(0)$. The demand is $D(p)$ where $D' < 0$. Finally, the firms compete in prices over an infinity of periods and discount the future by a rate r. In such setup, the Folk theorem predicts that there is a multitude of potential equilibria. We, however, invoke the above PEP refinement to focus on a unique equilibrium. For that purpose we also assume that there is sufficient difference in R&D efficiencies between the leader and followers, which will enable the leader to undercut all other firms, and that this equilibrium is more profitable for the leader.

[12] See footnote [4].

3.1 Market without Leader

Much like in the previous section, we are interested to see what happens in this market if the leader loses its advantage over other firms. If all firms are identical there is a perfect 'balance of power', so the firms will reach a tacit collusion and the above PEP refinement suggests that they will charge a monopoly price.[13] We now assume that the cost function is the same $c_L(x_i)$ for all firms.[14] Under this strategy, all firms keep to the monopoly price unless one of them undercuts it. In that case all charge $p = c(x)$ for all remaining periods, that is, the equilibrium reverts to a standard Bertrand outcome on the market with homogenous goods. Hence, each potential deviant is caught between a full monopoly profit in this period and none afterwards or an infinite stream of shared monopoly profits.[15] For the collusion equilibrium to be sustainable and assuming that there are n identical firms, we need

$$D(p^m)[p^m - c_L(x_i)]/(rn) - x_i \geq D(p^m)[p^m - c_L(x_i)] - x_i, \tag{12}$$

which holds if and only if $r \leq 1/n$. We will assume henceforth that this condition holds, that is, a market where all firms are identical would result in them charging monopoly price p^m. Each firm chooses a level of R&D, x^a that maximizes

$$x^a = \arg\max_x \{D(p^m)[p^m - c_L(x)]/n - x\}.$$

Taking the first order conditions we find the following rule that implicitly defines x^a:

$$c'_L(x^a) = -\frac{n}{D(p^m)}. \tag{13}$$

3.2 Market with Leader

Now we return to the assumption that one firm, the leader, has a cost advantage for all positive values of x. Assuming x_L is positive in equilibrium, if this advantage is large enough, it would be optimal for the leader to charge a price that would exclude all n followers and still make a profit. The leader would have to charge a price p^d that is defined by

$$\max_x \{D(p^d)[p^d - c_F(x)] - x\} = 0. \tag{14}$$

But even if charging p^d and selling to the whole market produces a positive profit, it would have to produce more profit than the alternative solution: accommodating the followers' entry and sharing the monopoly profits. Hence, the leader will deter entry if and only if

$$\max_x \{D(p^d)[p^d - c_L(x)] - x\} \geq \max_x \{D(p^m)[p^m - c_L(x)]/n - x\}. \tag{15}$$

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[13] Such a collusive outcome can also be sustained in standard infinitely repeated games by grim trigger strategy if the discount r is low enough.

[14] The same outcome will be supported by PEP even if firms have different unit costs with variance lower than the critical level that triggers aggressive behavior of the more efficient firm(s).

[15] The deviant would only undercut marginally, therefore getting (slightly less than) a monopolist's profits for a single period.

Again, for the sake of our argument, we will assume this condition to hold. That is, if there is a firm that has a (large enough) cost advantage, it will deter all the other firms from entry by charging $p^d < p^m$ and assume the market leadership position. Note that from here we can already say that the leader will produce a higher consumer surplus due to the lower deterrence price. Moreover, the ensuing market structure is closer to the competitive equilibrium which entails larger social welfare.

The leader's optimal choice of R&D in these circumstances is

$$x^d = \arg\max_x \{D(p^d)[p^d - c_L(x)] - x\}.$$

The first order condition gives us the implicit rule for the optimal R&D

$$c'_L(x^d) = -\frac{1}{D(p^d)}. \tag{16}$$

Comparing equations (13) and (16) we can see that $x^d > x^a$ because $c'_L(x^d)$ is equated to a smaller (in absolute value) number than $c'_L(x^a)$ and $c'_L > 0$.[16] However, it remains unclear whether the single firm spends more on R&D or less than the n collusive firms. That is, whether $x^d > nx^a$ or the other way around depends on the properties of $c_L(x)$ and the demand function. In the case of linear demand and the standard 'R&D production function' displaying decreasing returns (like the one of the form $c_L(x) = c - \sqrt{\gamma x}$), the setup with the technological leader and $n-1$ followers results in higher R&D investment and more innovation than the corresponding symmetric setup without the leader.[17] Furthermore, as proven in 4, a sufficient condition for the leader spending more on R&D than the other firms is that the elasticity of $c'_L(x) \in [-1, 0)$.

4 Conclusion

The main message of our analysis is that under plausible assumptions like free entry or repeated market interactions, there is a social value of market leadership and its mechanical removal by means of competition policy is likely to be harmful for society. As stated in Economic Focus of *The Economist* sometime ago '...antitrust authorities should be especially careful when trying to stamp out monopoly power in markets that are marked by technical innovation. It could still be that firms like Microsoft are capable of using their girth to squish their rivals; the point is that continued monopoly is not cast-iron evidence of bad behavior [...] The fact that a dominant firm remains on top might actually be strong evidence of vigorous competition. [...] The very ease of entry, and the aggressiveness of the competitive environment, are what spur monopolists to innovate so fiercely'. '(Slackers or Pace-setters,' 2004)

In section 2 we showed that the Stackelberg leadership outcome mimics that of the Cournot as far as total output and R&D investments are concerned but with a smaller number of firms and with leader charging a lower price than the followers. This corresponds to a higher social welfare in the Stackelberg leader setup due to fewer setup costs

[16] The number is smaller for two reasons. First, the numerator of the derivative of (13) is n instead of 1. Second, its denominator $D(p^m)$ is lower than $D(p^m)$ because $p^m > p^d$.

[17] See 4.

to be paid and higher consumer surplus. Furthermore, we have also shown that there is further social welfare loss in the aftermath of an applied policy that removes the leadership position. As the industry moves from one long run equilibrium to the other, output and investment are lower and the price is higher. Consequently, the only beneficiaries of such a policy are the competitors that benefit at the expense of consumers and the leader.

An interesting byproduct of our analysis in section 2 is the comparative static of the key parameter, b, that measures the degree of product differentiation. Unlike in the standard Stackelberg setup with barriers to entry (that is, with the number of firms exogenously given), the leader's accommodation profit in our setup increases in b. The reason is that competition becomes tougher when products get more alike, and consequently, fewer firms enter in equilibrium. Even more interestingly, increasing product differentiation (letting b move towards zero) results in the number of firms entering the market going to infinity and the profit of the leader going to zero. Thus, in the limit, we obtain a monopolistic competition outcome rather than the standard monopoly outcome that occurs with exogenous number of firms.

In section 3 we study the effect of leadership on research intensity with competition in prices when there are repeated interactions among the potentially different firms. We show that when there is a distinctive technological leader, it converts its technological advantage into market leadership. The leader behaves aggressively, charges lower price, generates larger social welfare, and (under plausible conditions) invests more in R&D than would be the case in a similar setup without the technological and market leader. As a consequence, entry is deterred and the followers are forced to leave the market.

Appendix A: The Difference in Consumer Surplus with and without Leader

In this appendix we compare the consumer surplus in each equilibrium, with and without leader. Since we are dealing with several horizontally differentiated markets, we employ the method used in Spence (1976) to compute the total surplus in each situation. From that we subtract the area which is given to the firms as revenue to get the consumer surplus.

Due to the symmetry between firms, in the Cournot equilibrium (section 2.1) we have

$$\begin{aligned} CS^C &= \sum_{i=1}^{n} \int_0^{q_i} \left(a - s - b \sum_{j=1}^{i-1} q_j \right) ds - nq_i P_i \\ &= \left[\sum_{i=1}^{n} q_i \left(a - b \sum_{j=1}^{i-1} q_j \right) - q_i^2/2 \right] - nq_i P_i \\ &= n \left[aq_i - q_i^2/2 - b(n-1)q_i^2/2 \right] - nq_i P_i, \end{aligned} \tag{17}$$

where n and q_i denote Cournot equilibrium number of firms and each firms' output respectively and we have used the equality of outputs in equilibrium, $q_i = q_j$. We have also dropped the asterix notation for simplicity.

Similarly, we can compute the total consumer surplus in the Stackelberg case. We have to separate the leader from the symmetric fringe, assuming in the leader's case that the other firms do not exist. For simplicity, we compute the surplus due to the leader separately

$$\begin{aligned} CS_l^S &= \int_0^{q_l} (a-s)ds - q_l P_l^S \\ &= aq_l - q_l^2/2 - q_l P_l^S, \end{aligned} \tag{18}$$

and also the surplus due to the followers taking the leader for given

$$\begin{aligned} CS_f^S &= \sum_{i=1}^{m} \int_0^{q_i} \left(a - s - bq_l - b\sum_{j=1}^{i-1} q_j \right) ds - mq_i P_i^S \\ &= \left[\sum_{i=1}^{m} q_i \left(a - bq_l - b\sum_{j=1}^{i-1} q_j \right) - q_i^2/2 \right] - mq_i P_i^S \\ &= m\left[aq_i - bq_i q_l - q_i^2/2 - b(m-1)q_i^2/2 \right] - mq_i P_i^S. \end{aligned} \tag{19}$$

The consumer surplus in Stackelberg equilibrium is then simply the sum of (18) and (19). We can now compare the consumer surplus under the two markets. If we take the difference we get

$$CS^S - CS^C = \frac{4bF(1-b)(4-2b-\gamma)}{(4-\gamma)(4-4b-\gamma)^2} \geq 0.$$

Appendix B: The Number of Followers in Stackelberg Equilibrium

In this appendix we show some properties of the equilibrium number of firms in the Stackelberg setup, m^*. Our main purpose is to show that m^* is decreasing in the differentiation parameter b and that it behaves as expected.

To begin with, below is the full form of m^* (in the text we only show its relationship to n^*, the Cournot equilibrium number of firms)

$$m^* = \frac{(a-c)\sqrt{F(4-\gamma)} - \frac{F(4-2b-\gamma)^2}{4-4b-\gamma}}{2bF}.$$

Ignoring γ for the moment we can show that $\partial m^*/\partial b < 0$ for all $b \in [0,1]$. The expression for m^* is now

$$m^* = \frac{a-c}{b\sqrt{F}} - \frac{2-b}{2(1-b)} - \frac{b}{2} + 1.$$

The derivative with respect to b is then

$$\frac{\partial m^*}{\partial b} = \frac{1}{b^2}\left[\frac{(2-b)(2-3b)}{(1-b)^2} - \frac{2(a-c)}{\sqrt{F}} \right],$$

so the sign of the derivative is the same as the sign of the expression in brackets. We will label the term in brackets as B for simplicity of notation.

Note that B attains maximal value at the limit value of $b = 0$ since the first part of B is clearly positive and increases as b tends to zero while the second part does not depend on b at all. To see this we label the first part of B as B_1 so

$$B_1 = \frac{(2-b)(2-3b)}{(1-b)^2}$$

and its first derivative is

$$\frac{dB_1}{db} = \frac{2b}{(b-1)^3} < 0.$$

Taking the limit of B when b tends to zero we obtain

$$\lim_{b \to 0} = 4 - \frac{2(a-c)}{\sqrt{F}}. \tag{20}$$

Despite the fact that (20) is the highest value of B, it has to be still negative given our assumption. Namely negativity of (20) would imply that

$$F < (a-c)^2/4.$$

However, from footnote 7 we recall that

$$F < (a-c)^2/16$$

for an equilibrium to be viable. Thus $B(0) < 0$ and therefore $B(b) < 0$ for all values of b and that consequently $\partial m^*/\partial b < 0$.

Alternatively, negativity of (20) also implies that $\sqrt{F} < (a-c)^2$, that is, the optimal output of a monopolist has to be bigger than the output of a follower in a free entry equilibrium.

From here it is easy to show that the above analysis generalizes to other values of $\gamma > 0$ because the introduction of R&D only changes the number of firms insignificantly. Figure 4 illustrates this result, where values of m^* for $\gamma = 0.4$ (in grey solid line) and $\gamma = 0.7$ (in black dashed line) almost overlap (the other parameters were set to $a = 10$, $c = 3$ and $F = 4$).

Appendix C: Complete vs. Partial Entry Deterrence

In an endogenous entry setting, like our section 2 model, the leader always manages the number of followers to some extent. Therefore, in these cases we always have deterrence of some competitors. What we intend to discuss in this appendix is whether the leader would prefer to deter entry completely, that is, not allow any followers to enter. For simplicity we will refer to this scenario as entry deterrence.

But before we move on to the leader's choice over entry, we must consider another restriction on our parameters. This restriction comes from the nonnegativity of production costs, $c - x_i$. Since we know that the leader is the one who invests most heavily in

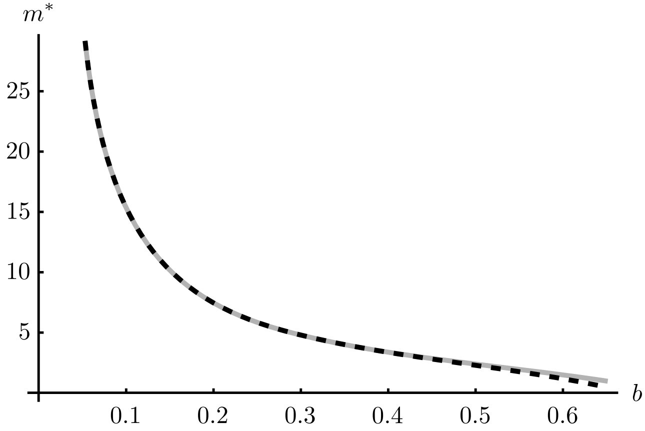

Figure 1: The equilibrium number of followers, m^*.

research, the relevant condition is $c - x_l^* \geq 0$. Perhaps the best way to represent this restriction on parameters would be in the form of a *critical b,*

$$b^c = \frac{(4-\gamma)(c\sqrt{4-\gamma} - \gamma\sqrt{F})}{4c\sqrt{4-\gamma} - 2\gamma\sqrt{F}},$$

where for given parameters γ, F and c, any feasible b has to be such that $b < b^c$.

Figure 4 shows graphically the feasible set of parameter b plotted against γ (filled) and our other constraint $4 - \gamma - 4b > 0$ to show that nonnegativity of production costs imposes harder restrictions than nonnegativity of output. To draw the graph we have used the following values: $a = 10$, $F = 4$ and $c = 3$. We will use the same parameters in other graphs unless stated otherwise.

Having established the feasible range of parameters, we go on to compare the profit of the maximizing leader (internal solution) to the profit of the leader who maximizes his profit by producing enough output to make it unprofitable for even one follower to enter (corner solution). Formally, to find the entry deterring output from the leader, we use q_l^D that solves

$$m(q_l^D) = 1,$$

because by definition of $m(\cdot)$, this will set the profit of a single follower to zero.

The algebraic expressions, while well defined and straightforward to compute, are too cumbersome to be represented here, therefore we will limit ourselves including some graphs of profit levels as a function of the differentiation parameter b. Figure 3 shows the monopoly profit (dotted), the accommodating leader's profit (solid) and the deterring leader's profit (dashed) as functions of b over the feasible range (for $\gamma = 0.5$).

As it is clearly seen from the graph in Figure 4, the leader chooses to allow entry when b is smaller than some limit value. Our analysis in section 2 is valid for these values of b where there is no complete entry deterrence.

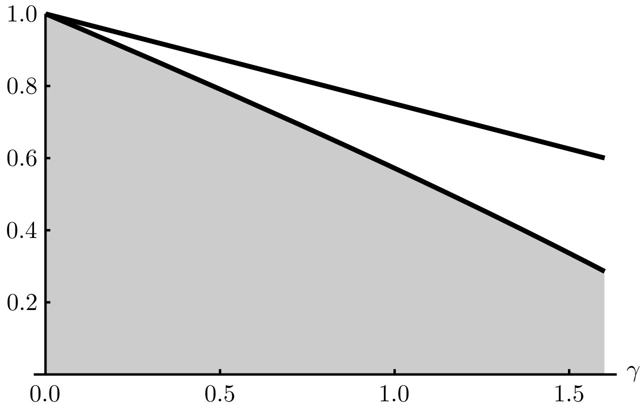

Figure 2: Set of feasible values of b.

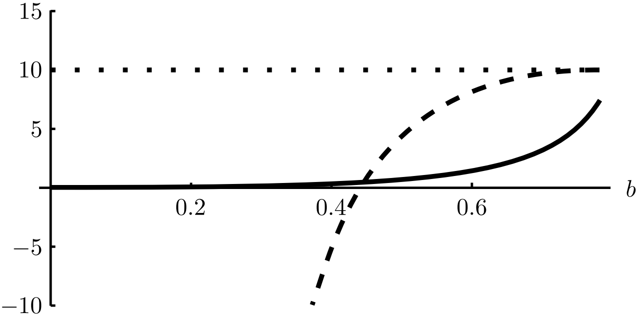

Figure 3: Difference in profit of leader.

Appendix D: Repeated Price Competition with Linear Demand and Quadratic Research Costs

In this appendix we show that in the special case of linear demand and quadratic research costs (that we adopted in section 2), the single deterring firm in a repeated price competition setting ('leader' of section 3) will spend more on R&D than in the symmetric equilibrium.

In order to make the models comparable we need to compute the R&D production function that leads to the quadratic costs. We have to do this because in section 2, x_i represents the amount of research (the fall in production costs) whereas in section 3, x_i refers to the R&D expenditure.

From section 2 the cost of decreasing the production marginal cost by x is x^2/γ. Inverting this to get a production function (and redefining x as *R&D expenditure* to fit section 3) we find that by spending x a firm will have marginal production cost of

$c - \sqrt{\gamma x}$.

Using this R&D technology and a linear demand, the symmetric firm in a market with n firms will maximize

$$\max_{x_i} \Pi^i = (a - p^m)[p^m - (c - \sqrt{\gamma x_i})]/n - x_i - F. \tag{21}$$

We set the monopoly price to $p^m = [a - (c - \sqrt{\gamma x_i})]/2$ and solve the first order condition to get the optimal expenditure

$$x^a = \frac{\gamma(a-c)^2}{(4n-\gamma)^2}.$$

In the case when one firm has an advantage in R&D technology, it may decide to keep every other firm out of the market. In our example we will assume these other firms (from here 'followers') have $c - \sqrt{\gamma_f x_i}$ production costs for x_i spent on research, where $\gamma_f < \gamma$.[18] When this deterrence is optimal, the leader will solve

$$\max_{x_L} \Pi^L = (a - p^d)[p^d - (c - \sqrt{\gamma x_L})] - x_L - F, \tag{22}$$

where $p^d < p^m$ is the deterrence price, that is the market price that makes $\Pi^i = 0$. Taking the first order condition and solving it we get

$$x^d = \frac{\gamma\{2(a-c)[a-c+\sqrt{(a-c)^2 - F(4n-\gamma_f)}] - F(4n-\gamma_f)\}n^2}{(4n-\gamma_f)^2}.$$

It is straightforward to check that $x^d > nx^a$.

Appendix E: Sufficient Condition for Higher R&D Expenditure by a Single Firm

For R&D to be higher under a single (leader) firm than under n identical collusive firms, we need $x^d > nx^a$. Furthermore, as already discussed in the paper, at optimum

$$n|c_L'(x^d)| \leq |c_L'(x^a)|.$$

To simplify our analysis, we ignore the difference in denominators between (13) and (16). The previous inequality in that case holds with equality. This condition is weaker than what we already have because a lower $|c_L'(x^d)|$ would imply an even bigger x^d. Thus, for the leader to be producing more, we would need that at least an n times higher x is necessary to produce an n times lower $|c_L'(x)|$. Formally

$$\frac{|c_L'(x_1)|}{|c_L'(x_2)|} \leq \frac{x_2}{x_1}$$

must hold for all $0 < x_1 < x_2$. Taking the log of both sides and rearranging,

$$-[\log|c_L'(x_2)| - \log|c_L'(x_1)|] \leq \log x_2 - \log x_1.$$

[18] Note that the leader has the same technology as the case with symmetric firms. We do this to show that the difference in research is only due to market structure and not higher R&D efficiency.

For infinitesimal differences between x_2 and x_1, we have

$$\epsilon_{c'_L} = \frac{d \log |c'_L(x)|}{d \log x} \geq -1. \tag{23}$$

One type of marginal cost function that yields this result is $c_L(x) = a - bx^{1+\epsilon}$ where $\epsilon \in (-1, 0)$ is the desired (constant) elasticity of $c'_L(x)$. For unit elasticity $c'_L(x)$, the function is $c_L(x) = a - b \ln x$. These marginal cost functions are not positive everywhere, but a and b can be set such that the marginal cost is positive for all the relevant levels of R&D.

Technological Leadership and Persistence of Monopoly under Endogenous Entry: Static versus Dynamic Analysis

We build a dynamic oligopoly model with endogenous entry in which a particular firm (leader) invests in an innovation process, facing the subsequent entry of other firms (followers). We identify conditions that make it optimal for the leader in the initial oligopoly situation to undertake pre-emptive R&D investment (strategic predation) eventually resulting in the elimination of all followers. Compared to a static model, the dynamic one provides new insights into the leader's intertemporal investment choice, its optimal decision making, and the dynamics of the market structure over time. We also contrast the leader's investment decisions with those of the social planner.

1 Introduction

Is monopoly an environment conducive to innovation? Is there persistence of monopoly, or is there a change in the identity of the innovating firm ('leapfrogging')? These questions are not new among economists, but recently they seem to have been rekindled. In an issue of The Economist (2004), the authors of the already-celebrated column 'Economics Focus' in their provocatively-entitled article 'Slackers or Pace-Setters: Monopolies may have more incentives to innovate than economists have thought' claimed that monopolies may have a far more prominent role in generating innovation than previously thought. The authors further expressed doubts about the prevailing economic theory according to which 'a monopolist should have far less incentives to invest in creating innovations than a firm in a competitive environment.' Apparently, there is some controversy regarding the role of market power and monopolies in creating innovations, and the key to its resolution lies in the understanding of the underlying incentives to engage in innovation.

Recent empirical evidence seems to support these Schumpeterian allegations from The Economist: There is a positive relationship between market power and the intensity of innovation (see, for instance, Blundell *et al.*, 1999; Carlin *et al.*, 2004; Aghion and Griffith, 2004). Commenting on this empirical evidence, Etro (2004) stated that it 'is consistent with pre-emptive R&D investment by the leaders' (p. 282). In other words, there will be only one firm at the end of the day, but this firm would display far more competitive behavior than the standard monopolist; it would generate a higher flow of R&D, charge a lower price, and produce more. As a consequence of such strategic behavior, the Chandlerian phenomenon of the persistence of monopoly can arise.[1]

There are many real-world examples of monopolistic or dominant firms that are technological leaders and that invest more in innovation and R&D than their rivals (see Etro, 2004), and that survive over a long period of time. AT&T, a giant American telecommunications company, is a good case in point. Founded in 1885, the company is one of the largest telephone companies and cable television operators in the world. AT&T provides voice, video, data, and Internet telecommunications services to businesses, consumers,

[1] See Sutton (2007) for the theoretical and empirical issues concerning the measurement of the persistence of market leaders.

and government agencies. After becoming the first long-distance telephone network in the US, AT&T made huge investments in research and development. As a result, the company obtained near-monopoly power on long-distance phone services. Heavy investments in R&D together with aggressive behavior on the market allowed AT&T to acquire crucial inventions and to spread its near monopoly power to other markets. The company both bought patents for significant innovations and undertook innovations itself.[2]

The above observations on the relations among innovation, technological leadership, and market power motivate our paper in that we aim to describe and analyze a particular setup in which a persistence of monopoly can arise in the long run. More specifically, we study the situation in which the technological leader facing endogenous entry may undertake pre-emptive R&D investment (or, in our words, may adopt strategic predation), that eventually leads to the exit of the follower firms and/or prevents or limits the entry of new firms. We contrast this situation with one in which the leader (within the same setup) accommodates the endogenous entry of followers, that is, co-exists with the followers in an oligopolistic market structure. This comparison will enable us to study both positive aspects of the two main strategies of accommodation and strategic predation (for instance, which strategy yields higher R&D intensity), and normative aspects (social welfare implications) of the two resulting market structures: oligopoly versus (constrained or unconstrained) monopoly and their respective performances *vis-à-vis* a social planner. The latter aspect, as we will see, carries important policy implications.

Our paper is related to a recent stream of industrial economics literature on endogenous entry (see, for instance, Etro, 2004, 2006 and 2007; Erkal and Piccinin, 2007; Davidson and Mukerjee, 2008; and Creane and Konishi, 2009). For instance, both Etro (2006, 2007) and Creane and Konishi (2009) examine, among other things, both positive and social welfare effects of strategic predation that a technological leader may exhibit when faced with endogenous entry and exit. In modelling those features they rely on a three- or two-stage version of the static Cournot oligopoly. The novel feature of our approach, however, is that we utilize an explicit dynamic model in tackling these issues and contrast it with its static (or quasi-dynamic) counterpart. This comparison can be considered as the topic *per se* of our paper. Since strategic innovations and entry are inherently dynamic phenomena, we argue that a suitable model aimed at capturing both accommodating and pre-emptive, or predatory, behavior of the dominant firm should be explicitly dynamic. Furthermore, to emphasize the role of the technological leader we assume that the leading firm is the only one that invests in innovation.

The concept of two-stage competition used to be a typical tool to tackle standard strategic interactions like the case when the incumbent firm undertakes a strategic investment in the first stage and then there is competition in quantities or prices in the last, second stage. This concept concentrates on identifying 'strategic effects' that influence first-period behavior and aims to characterize the resulting strategic rivalry. It has proven successful in that the same strategic principles (e.g., overinvestment or underinvestment) apply in many economic environments, and the comparative static results from static oligopoly theory can be used to provide information about strategic behavior

[2]For instance, during the early 1920s, AT&T bought Lee De Forest's patents on the 'audion', the first triode vacuum tube, which let it enter the radio business. On the other hand, the first commercial communications satellite, Telstar I, was commissioned by AT&T in 1962.

(see Fudenberg and Tirole, 1984; Tirole, 1990; Shapiro, 1989; and Etro, 2004 and 2006).[3]

Adding endogenous entry in the above two-stage framework, however, would require an in-between (second) stage of the game that allows the competitors to decide whether to enter the market or not after they observe the strategic move (R&D investment) on the side of incumbent (leader) firm in the first stage. Thus, our static benchmark game will be, in fact, a three-stage Cournot game in which one firm ('leader') has a strategic advantage in the form of a prior (first-stage) investment in R&D that leads to a unit cost decrease. In the last (third) stage the leader and followers compete in quantities.

The concept of a two-stage (or multi-stage) oligopoly game relies, however, on an artificial time structure and neglects potential intertemporal tradeoffs. From the perspective of a full-fledged dynamic model, it gives at best the steady state values of the true underlying dynamic game. Thus, it neglects the dynamic adjustment process and lacks the explicit motion of the strategic variables over time and their accompanying comparative dynamics. More importantly, the set of strategies available to firms may be richer than in the corresponding static model. In particular, the leader may go for early or late predation, and the attractiveness of the predation strategy crucially depends on the leader's ability to translate its investment into an advantage on the product market.

To concentrate on the strategic aspects within the dynamic model we push the output decision to the background and deal with the so-called reduced-form profit function, making the firms' flows of profits a function of unit costs. The unit costs of the firms and the number of entrants serve as so-called state variables that are governed through the control variable, namely R&D expenditures. Another important feature here is that passage from a three-stage model to a dynamic one requires the introduction of a specific adjustment parameter that captures the speed with which the R&D investments translate into the unit cost reduction (see, for example, Fersthman and Kamien, 1987; and Stenbacka and Tombak, 1997 for a utilization of a similar approach). This makes our model more realistic because now it mimics the unavoidable time delay between R&D investment and the corresponding R&D output. The dynamic approach also enables us to study the behavior of the strategic variable over time and some of its comparative dynamic effects, as well as the adjustment process, all of which are missing in the simple three-stage framework.

Finally and most importantly, in an explicit dynamic model we can analyze how the optimal strategy of a firm that possesses a strategic advantage may lead to a change in market structure over time and thus create a persistence of monopoly. This phenomenon cannot be modelled within a static three-stage game. In other words, the strategic advantage of the leader may enable it to exhibit pre-emptive behavior (or strategic predation) on its rivals, eventually turning the initially oligopolistic market structure into a monopoly. In that case, the persistence of monopoly occurs endogenously due to continuous investments that do not disappear once the monopoly position has been achieved. The underlying dynamic optimization problem then involves an additional component compared to the case when the leader chooses the accommodation strategy. Namely, via its R&D investments the leader also determines how quickly predation takes place, i.e., at which point in time all rivals are eliminated.

[3] Etro (2006) however demonstrated that allowing for endogenous entry dramatically simplifies the taxonomy of business strategies since all that matters is whether strategic investment hurts the incumbent.

Overview of main results

Our analysis provides the following new insights:

(a) The technological leader adopts the accommodation strategy only when its R&D efficiency is 'low' or/and the size of the market is relatively large (more precisely, when fixed costs are small relative to the size of the market). In all other cases, the leader opts for strategic predation aiming to achieve the monopoly position after a certain time T.

(b) During the predation period (up to a certain time T), the leader might even be willing to incur losses in order to enjoy a monopoly profit from time T onward. Thus, unlike in the static game, in a fully dynamic model the costs of predation last for a certain period of time and have to be contrasted to the infinite stream of monopoly profit earned afterwards. As these costs depend on the speed of the adoption of new technology, strategic predation becomes a more attractive strategy to pursue when the adoption of new technology accelerates. In the limit case, when the adoption is instantaneous, the dynamic model essentially reduces to the static one.

(c) The time pattern of R&D investments crucially depends on the equilibrium strategy: If accommodation is the optimal strategy, then the leader chooses an R&D path which steadily increases over time towards a unique steady-state value. If, on the other hand, the strategic predation strategy becomes optimal, then the leader first invests significantly in R&D in order to achieve the monopoly position at time T. The shorter the target time T, by which all other follower firms are forced to exit, the higher the 'predatory' R&D investment has to be. In other words, the level of optimal R&D investment decreases with an increase in target time. (Note that it is not viable by assumption to force an immediate exit of all other firms, since it would then require an infinite amount of R&D, when the speed of adjustment is finite.)

(d) Once all rivals are eliminated, the leader may continue to further increase its R&D investment and become a so-called unconstrained monopolist. Alternatively, the leader may behave as a constrained monopolist that keeps its investment at a low level just high enough to prevent rivals from re-entering the market. Nevertheless, such an investment level is still higher than the one observed in the case of accommodation.

(e) Regarding social welfare considerations, we show that the social planner choosing the flow of R&D investment to maximize the sum of profit and consumer surplus while keeping the market structure unchanged also prefers strategic predation to accommodation when its R&D efficiency is 'large' and/or the size of the setup costs relative to the size of the market is large. Moreover, the social planner would prefer a longer predation time than the profit-maximizing leader if the combination of R&D efficiency and the relative size of fixed costs is below a certain threshold curve. On the other hand, the social planner can be more aggressive than the leader in the sense that the planner prefers a shorter predation time if another threshold curve is surpassed (this threshold corresponds to the situation when both R&D efficiency and the relative size of fixed costs are large).

The remainder of the paper proceeds as follows. The static model is analyzed in Section 2. Section 3 introduces the dynamic model. In the subsequent sections we study the leader's strategies of accommodation (Section 4) and strategic predation (Section 5). Section 6 provides a comparison of these strategies and determines the leader's optimal behavior in the long run. Section 7 presents the welfare analysis, where we contrast the leader's investment decision with that of the social planner. Section 8 concludes and discusses the potential policy implications of our results.

2 Static Model

2.1 Equilibrium with Endogenous Entry

In this section we describe the market game with endogenous entry that has been recently brought into attention by Etro (2004, 2006, 2007). We consider a market for a single homogeneous good. The good is produced by one leader firm (indexed by 0) and potentially also by several identical follower firms (indexed by $i = 1, 2, \dots$). Following Etro (2007), we assume that firms compete in quantities with endogenous entry. The game involves two stages so far. In the first stage all firms simultaneously decide whether to be active in the market or not. By being active, a firm incurs fixed setup costs F that are sunk later; not being active does not involve any costs. In the second stage, all active firms compete in quantities *à la* Cournot (see Etro, 2007 for details). The equilibrium of such a game is sometimes called *Marshall equilibrium* (see Etro, 2007) and is characterized by the number of followers that become active, their optimal outputs and the optimal output of the leader. The equilibrium number of active followers is the maximal one yet delivering non-negative profits in the subsequent Cournot competition. If even only one follower is not able to earn a positive profit, the leader is the only firm active and becomes a monopolist (we assume that the leader is able to earn a non-negative profit).

Production in the second stage involves unit variable costs: all followers produce the good at constant unit (variable) costs $\bar{c}$, whereas the leader produces the good at constant unit (variable) costs c_0, where $c_0 \leq \bar{c}$. The leader's unit costs may be lower than $\bar{c}$ due to previous R&D investments.[4] Note that the leadership in our setup implies the existence of an incumbent firm rather than the firm having a standard first-mover advantage. That incumbent firm is the only one assumed to be capable of investing in innovation. Thus, in a sense, our leader firm acts as a technological rather than Stackelberg leader.

In the following sections we embed this model into a static model (Section 2.2) and a dynamic model (Section 3) that specifically describe the leader's R&D investments decisions. Via R&D investment, the leader firm can affect its unit costs and thus — indirectly — the number of followers. Therefore, we first extend the model to a three-stage (static) setup by introducing an initial stage in which the leader decides on an R&D investment that lowers its unit costs. Later on we consider a dynamic model where the

[4]For simplicity, we refer to these costs as 'unit costs', instead of the more appropriate term 'unit variable costs'.

number of active followers as well as their outputs adjust instantaneously to the change in the leader's unit costs so that the market is in Marshall equilibrium at every point in time. The leader solves a dynamic optimization problem with its unit costs being a state variable following a certain law of motion and with investment being a control variable.

We consider a linear inverse demand function: $p = A - Q$, where Q denotes the market demand and $A - \bar{c}$ captures the size of the market (where $A > \bar{c}$). If n is the number of followers active in the second stage, then in the Cournot equilibrium the output of the leader q_0 and the output of each follower q_i (for $i = 1, \ldots, n$) appear to be

$$q_0 = \frac{A - \bar{c} + (n+1)(\bar{c} - c_0)}{n+2} \qquad \text{and} \qquad q_i = \frac{A - \bar{c} - (\bar{c} - c_0)}{n+2}.$$

The leader's and the followers' (gross) profits are then $\Pi_0 = q_0^2$ and $\Pi_i = q_i^2$, respectively.

In equilibrium, the number of active followers satisfies the zero-profit condition $\Pi_i = F$, where F are fixed costs incurred in the first stage and sunk later. Thus each follower's equilibrium output is equal to $q_i = \sqrt{F}$ and the equilibrium number of followers is

$$n = \frac{A - 2\bar{c} + c_0}{\sqrt{F}} - 2. \tag{1}$$

Similar results can also be found in Etro (2007). For the case of symmetric unit costs (i.e., $c_0 = \bar{c}$), equation (1) collapses to the expression obtained also by Mankiw and Whinston (1986), where they compute the number of firms in the symmetric free-entry equilibrium with linear demand and Cournot setup (p. 52).

For simplicity and tractability purposes, we use a continuous variable to approximate the number of followers. More specifically, we assume that n can take values from the interval $[1, \infty)$ or be equal to 0, where the latter means that all followers are crowded out from the market and the leader is a monopolist.[5]

Taking the zero-profit condition into account, a direct computation then yields the following equilibrium quantities and price (in the case of entry):

$$q_0 = \bar{c} + \sqrt{F} - c_0, \qquad q_i = \sqrt{F}, \qquad p = \bar{c} + \sqrt{F}. \tag{2}$$

In the case of no entry, the leader becomes a monopolist, setting the monopoly quantity $q_M = \frac{1}{2}(A - c_0)$ that results in the monopoly price $p_M = \frac{1}{2}(A + c_0)$ and generates the monopoly profit of $\Pi_M = q_M^2$.

Now, entry occurs when $n \geq 1$ in equilibrium. As follows from (1), the latter condition is equivalent to

$$c_0 >, \qquad \text{where} \qquad = -A + 2\bar{c} + 3\sqrt{F}. \tag{3}$$

If the reverse inequality strictly holds, the leader becomes a monopolist.[6] The value $= -A + 2\bar{c} + 3\sqrt{F}$ thus represents a critical value of the leader's unit costs that determines

[5]When n is defined as in (1) and $n \geq 1$, then the 'actual' number of active followers is equal to the (unique) integer that lies in the interval $(n-1, n]$.

[6]If $c_0 =$, there is only one active follower who is actually indifferent between being active or not. At this point, both the leader's quantity and profit (as functions of c_0) have a jump downwards. More precisely, the limits of the leader's quantity (when c_0 approaches) from the left and from the right are $\hat{q}_0 = A - \bar{c} - 2\sqrt{F}$ and $\hat{q}_M = A - \bar{c} - \frac{3}{2}\sqrt{F}$, respectively. Thus, when c_0 is the outcome of a preceding R&D investment, in equilibrium the leader also becomes a monopolist for $c_0 =$. In other words, the leader's equilibrium profit is continuous in c_0 from the right.

the resulting market structure. If the leader's costs are sufficiently high, i.e., the gap between the leader and the followers is sufficiently small, entry occurs with the number of entrants increasing in the leader's costs. On the other hand, if the leader's costs fall below this critical value, the leader becomes a monopolist.

Note also that in the symmetric case when $c_0 = \bar{c}$ (without any prior investment), entry occurs if and only if $\Phi \leq \frac{1}{3}$, where

$$\Phi = \frac{\sqrt{F}}{A - \bar{c}}.$$

In other words, to allow entry, fixed costs need to be sufficiently small relative to the size of the market. Otherwise, entry never occurs in equilibrium. Thus, in what follows, we will restrict our analysis to the case $\Phi \leq \frac{1}{3}$.

2.2 Leader's Investment Decision

In this section we add an initial stage to the game and consider a game where the (Marshall) equilibrium with endogenous entry is preceded by an investment stage. We further assume that the leader has *ex-ante* identical unit (variable) costs with the followers. Thus, without any investment, its unit costs are $c_0 = \bar{c}$. In other words, initially all firms have access to the old technology, implying that the initial level of both fixed and unit costs are the same for all firms. We, however, assume that the R&D investments of the leader do not affect its fixed costs but only its unit costs.

In order to describe the effects of R&D investments, we employ a simple *R&D production function* where the leader lowers its unit costs by $\sqrt{gx}$ if it invests an amount of x (see Chin and Grossman, 1990, or Žigić, 1998 for the use of such a function). The variable x represents the level of R&D expenditures that are incurred in the investment stage and sunk later. The parameter g describes the efficiency of the R&D process; we assume that $g \in (0, 4)$ where the upper bound is determined by the positivity requirement imposed on the monopoly output and investments in the equilibrium. For convenience we introduce the transformation $x = z^2$ and in what follows use x and z interchangeably to refer to investment size or investment level. In this notation, after investing the amount of z^2, the leader's unit costs become

$$c_0(z) = \bar{c} - \sqrt{g}\, z \tag{4}$$

for $z \in [0,\, \bar{c}/\sqrt{g}]$.

The resulting market structure depends on the size of the leader's investments. Combining (3) and (4), we find that if the leader's investment level z is below the threshold $\hat{z}$, i.e.,

$$z < \hat{z}, \qquad \text{where} \qquad \hat{z} = \frac{\bar{c} - \hat{c}}{\sqrt{g}} = \frac{A - \bar{c} - 3\sqrt{F}}{\sqrt{g}},$$

then $c_0 >$ and entry occurs, where the equilibrium values are given by (1) and (2). In such a case, we say that the leader chooses an *accommodation* strategy. Alternatively, the leader may choose an investment level $z \geq \hat{z}$ (or, equivalently, $c_0 \leq$) that leads to a monopoly. In such a case, we say that the leader chooses a *strategic predation* strategy.

The leader maximizes its net profit $q^2 - z^2 - F$, where $q = q_0$ for $c_0 >$, $q = q_M$ for $c_0 \leq$, and the relation between investments and unit costs is given by (4). In the case of accommodation, the optimal level of investment and the resulting equilibrium output of the leader are

$$z_A^* = \frac{\sqrt{g}}{1-g}\sqrt{F} \qquad \text{and} \qquad q_A^* = \frac{1}{1-g}\sqrt{F},$$

which allows for the entry of $n^* = \frac{1}{\Phi} - \frac{2-g}{1-g}$ followers. Entry occurs if and only if z_A does not exceed $\hat{z}$ (or $n^* \geq 1$). We may rewrite this condition as $\Phi \leq \phi_A(g)$, where $\phi_A(g) = \frac{1-g}{3-2g}$. Note that the necessary condition for accommodation is $g < 1$. If $g \geq 1$, then the leader's accommodation profit is increasing in z on $[0, \hat{z})$. In this case, accommodation is not optimal; the leader chooses $z \geq \hat{z}$ and becomes a monopolist.

Analogously, in the case of strategic predation, the optimal level of investment and the leader's output are

$$z_M^* = \frac{\sqrt{g}}{4-g}(A - \bar{c}) \qquad \text{and} \qquad q_M^* = \frac{2}{4-g}(A - \bar{c}).$$

Reasoning as above, we conclude that the leader becomes a monopolist if and only if z_M^* (weakly) exceeds $\hat{z}$, which is equivalent to $\Phi \geq \phi_M(g)$, where $\phi_M(g) = \frac{2(2-g)}{3(4-g)}$.[7] In such a case, the leader's profit is decreasing in z. Because the profit has a jump upwards in $z = \hat{z}$, the leader's profit may also be maximized at this point, leading to a monopoly with output $\hat{q}_M = A - \bar{c} - \frac{3}{2}\sqrt{F}$ (see footnote 6). In this case the leader actually chooses a minimal investment level that prevents the followers from entering (i.e., $z = \hat{z}$) and becomes in some sense a constrained monopolist.

A comparison of the resulting profit with the profit from accommodation reveals that accommodation is optimal if and only if

$$\Big(1 - \frac{3-2g}{1-g}\Phi\Big)\sqrt{\frac{1-g}{g}} > \sqrt{\Phi\Big(1 - \frac{7}{4}\Phi\Big)}. \tag{5}$$

Note that inequality (5) holds for $\Phi = 0$, whereas for $\Phi = \phi_A(g)$ its sign is reversed because the left-hand side of (5) vanishes. Direct computation yields that for any $g \in (0, 1)$ there is a critical value of Φ, namely $\phi_0(g) = 2(1-g)(6-\sqrt{5g}-3g)/(36-41g+9g^2)$, such that the leader chooses accommodation if and only if Φ lies below this critical value.

Figure 2.2 shows the regions of parameters g and Φ, where accommodation (region A) and strategic predation (the union of regions CM_1, CM_2, and UM) are chosen by the leader.[8] For Φ close to $\frac{1}{3}$, the leader chooses strategic predation with the optimal monopoly investment. When the fixed costs decrease (Φ surpasses the threshold $\phi_M(g)$), then the optimal monopoly investment leads to entry. In this case the leader becomes a constrained monopolist choosing the minimal investment level $z = \hat{z}$ that still prevents

[7] Note that for $g < 4$ (assumed above), the maximum exists and the monopoly output is positive. On the other hand, if $g \geq 4$, the leader's profit is increasing in z and unbounded when $z > \hat{z}$. Moreover, economic relevance requires that the unit costs remain positive, i.e., $c_M^* > 0$ or equivalently $g < 4\bar{c}/A$ (where $4\bar{c}/A < 4$). As all our results will actually be formulated only in terms of the size of the market $A - \bar{c}$ and not in terms of A and $\bar{c}$, we omit this (stronger) condition from further elaborations and just assume that $g < 4$. This is without loss of generality, as for any size of the market and any $g \in (0, 4)$, we can find values of A, $\bar{c}$ that yield such a size of the market and satisfy the inequality $g < 4\bar{c}/A < 4$.

[8] Recall that the feasible parameter values are $(g, \Phi) \in (0, 4) \times (0, \frac{1}{3}]$.

the followers from entering. For even lower fixed costs (when $\Phi \leq \phi_0(g)$), the leader chooses the accommodation strategy.

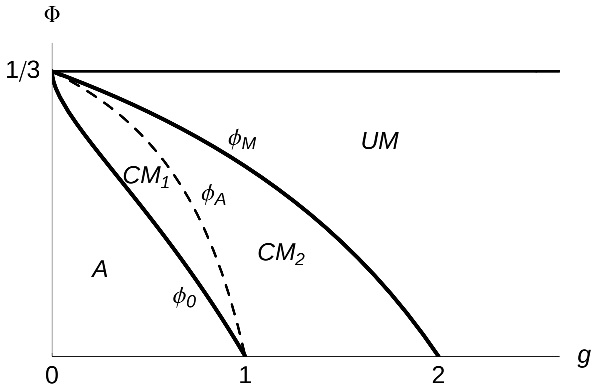

Figure 1: Leader's optimal strategies in the static model (parameter values $A = 5$, $c = 4$)

3 Dynamic Model

Building upon the static model, we consider a setup in which all firms may operate over an infinite time horizon (in continuous time). Much like in the static setup, we assume that there is one leader firm (indexed by 0), and several potential follower firms indexed by $i = 1, 2, \ldots$. Note that now each active firm needs to incur the production costs at each moment of time. These costs comprise of instantaneous fixed costs F and unit (variable) costs c. We assume that initially (at time $t = 0$), all firms are identical and have unit costs $c_0(0) = c_i(0) = \bar{c}$. The leader makes an investment that affects its unit costs; the followers make no investment and their unit costs are constant over time, i.e., $c_i(t) = \bar{c}$ for all $t \geq 0$. The fixed costs are flow costs that need to be incurred perpetually. Note that in the dynamic setup these fixed costs should not be interpreted as entry costs, but rather as standard production costs, like, for instance, a rent on capital that firms incur just before the production phase. By the same token, our parameter Φ (which is a function of F), has to be interpreted accordingly. We believe that this is a reasonable way to model the production costs in the dynamic setup.[9]

In order to build a genuine dynamic model, we now consider a law of motion that drives the change in the leader's unit costs, depending on its investment. Denoting the time path of the leader's investment as $x(t) = z^2(t)$ (where $z(t) \geq 0$), we assume that its unit costs change according to the following law of motion

$$\dot{c}_0(t) = \mu[\bar{c} - c_0(t) - \sqrt{g}\, z(t)], \tag{6}$$

[9]Flow costs have been used frequently in the innovation literature; see for instance, Lee and Wilde (1980) or Reinganum (1982).

that resembles specification (4) of the static model in Section 2.2. In particular, we assume that it takes time for the R&D investment to transform into a decrease in unit costs and we introduce the *speed of adjustment* parameter $\mu > 0$ designed to capture this time lag (more precisely, the inverse of it). In this respect our model closely follows that of Stenbacka and Tombak (1997); see also Fershtman and Kamien (1987) for a similar approach.[10] The parameter g characterizes the efficiency of the R&D process; we assume that $g \in (0, 4\rho)$ where $\rho = 1 + r/\mu \geq 1$, due to the requirement for monopoly output and investment to be positive in the dynamic context (see Section 5.3). The expression $\rho - 1$ can then be viewed as a so-called 'generalized discount rate', that is, the interest rate r corrected by the speed-of-adjustment coefficient: Given r, the higher the level of μ, the faster R&D investment materializes, and the more important the future becomes. The parameter ρ will turn out as particularly relevant for the leader's intertemporal decisions.

Note that the above law of motion requires sufficient perpetual investments in order to prevent the unit costs from increasing. If the investment is not sufficient, the costs tend to revert back to their initial value $\bar{c}$. In particular, in the absence of R&D investment, the costs will converge to $\bar{c}$ when $t \to \infty$. The latter can be interpreted as some kind of depreciation of knowledge or skills.[11]

Given the leader's unit costs $c_0(t)$ as a state variable, at each point in time the market follows the equilibrium with endogenous entry (see Section 2.1), where the number of active followers as well as the leader's output adjust instantaneously. Note that only the leader's investment decision involves intertemporal trade-offs. In this respect, the explicit dynamics in the model comes from the leader's intertemporal R&D investment decision and not from the competition in quantities. The latter is myopic in the sense that both the leader and the followers determine their outputs via Cournot-Nash equilibrium at each instant of time rather than committing in advance to a particular output path. These instantaneous equilibria are however critically determined by the R&D flow that the leader has under its control. Our approach is thus in a sense a generalization of the related static models at which the R&D of the leader at an initial stage of the game affects the output and number of firms at subsequent stages of the game.

As for the number of followers, $n = n(t)$ is now a time-specific variable and it is determined by the law of motion of the unit costs. The intuition for it is that a change in production technology and the speed of its adoption are key factors governing the change in the efficiency of the technological leader, which affects the dynamics of new firms' entry into the market. Consistent with this, the change of unit costs and its speed (aimed to capture the change and dynamics of technology improvement) fully determines the number of firms and their dynamics in our model. The dynamics (law of motion) for the number of firms and the leader's output can be derived from the equilibrium relations (1) and (2) by taking their time derivatives, $\dot{n}(t) = \frac{1}{\sqrt{F}}\dot{c}_0(t)$ and $\dot{q}_0(t) = -\dot{c}_0(t)$.

[10]Kobayashi (2001) made a differential game version of the D'Aspremont and Jacquemin (1988) two-stage game, where the dynamics of the model stems from a depreciation of R&D stock rather than from the speed of adjustment.

[11]The expression $\mu[\bar{c} - c_0(t)]$ then corresponds to the instantaneous depreciation rate.

After substituting for c_0 and $\dot{c}_0$ into the law of motion (6) we obtain:

$$\dot{n}(t) = \mu\Big[\frac{A - \bar{c} - 2\sqrt{F}}{\sqrt{F}} - n(t) - \frac{\sqrt{g}}{\sqrt{F}}\, z(t)\Big], \tag{7}$$

$$\dot{q}_0(t) = \mu[\sqrt{F} - q_0(t) + \sqrt{g}\, z(t)], \tag{8}$$

whenever entry occurs, that is, $n(t) > 1$. Since all firms are identical at time $t = 0$ (i.e., $c_0(0) = c_i(0) = \bar{c}$ for all i), it follows from (1) and (2) that the initial leader's equilibrium output is evaluated as $q_0(0) = \sqrt{F}$, and the initial number of followers equals $n(0) = \frac{1}{\Phi} - 2$.

3.1 Leader's Optimization Problem

The leader maximizes the present value of its (net) profit and solves the following infinite horizon optimal control problem with one state variable c_0 and one control variable z:

$$\max_{z(\cdot)} \int_0^\infty [q^2(t) - z^2(t) - F]e^{-rt}dt \tag{L}$$

$$\text{subject to}$$

$$\dot{c}_0(t) = \mu[\bar{c} - c_0(t) - \sqrt{g}\, z(t)],$$

$$q(t) = \begin{cases} q_0(t), & \text{if } c_0(t) >, \\ q_M(t), & \text{if } c_0(t) \leq, \end{cases}$$

$$c_0(0) = \bar{c}.$$

This problem involves a 'regime change' that occurs when the leader's costs attain the critical value $= -A + 2\bar{c} + 3\sqrt{F}$. If the leader's costs are above $\hat{c}$, at least one follower is active, and the leader's output equals $q_0(t) = \bar{c} + \sqrt{F} - c_0(t)$ as in the equilibrium with endogenous entry. If the leader's costs fall below the critical value, it becomes a monopolist producing output $q_M(t) = \frac{1}{2}[A - c_0(t)]$.

There are several points worth noting. First, the leader's optimization problem does not explicitly contain the number of followers, which is, however, endogenous and follows the law of motion (7). Second, fixed costs F in the leader's objective function are incurred over the whole time span (and integrate up to F/r) independently from the leader's investment decision, and thus can be in principle omitted. However, for the sake of completeness we will always include them in the objective function. Third, the leader always has the option not to invest at all, in which case it will be identical to the followers and earn zero profit. Finally, initially there is always at least one active entrant, because $\bar{c} >$ (or, equivalently, $\Phi < \frac{1}{3}$). However, the current number of active followers is neither bounded from above nor assumed to be strictly positive, and depends on the exogenously given parameters A, $\bar{c}$, F and g, and on the endogenously determined investment strategy $z(t)$ (in particular, $n(t)$ does not change if $n(t) = \frac{1}{\Phi} - 2 - \frac{\sqrt{g}}{\sqrt{F}}\, z(t)$).

Depending on whether the leader eventually becomes a monopolist, we classify its strategies into the following two categories:

1. *Accommodation:* The leader invests only moderately in R&D so that at least one active follower exists at any point in time, i.e., $n(t) > 1$ for all $t \geq 0$. In this case, the leader's costs always lie above the threshold .

2. *Strategic predation:* The leader invests significantly in R&D in order to eventually eliminate all followers and achieve a monopoly position, i.e., $n(T) = 1$ at a finite point in time T. In this case, the leader's costs attain the critical value at time T.

Note that accommodation may also involve the elimination of some (but not all) followers. According to our classification, in accommodation there is at least one active follower at any point in time.

It is important to recognize that in the case of strategic predation, insufficient R&D investment may in principle result in the eventual reversal of the leader's costs to the critical level and even above it, allowing some of the followers to re-enter the market. However, such a pattern is never optimal because the problem involves an unbounded time interval, and, therefore, the problem is 'shift invariant', i.e., the optimal value of control z depends directly only on the state c_0 and not on the physical time t.[12] Thus, if the leader's unit costs attain the same value at two distinct points in time, the subsequent investment patterns in both cases should be identical. The latter excludes the possibility that (under optimal investment) the leader's costs revert back to the value once they are lower than .[13] Of course, the same argument holds for any value of costs, which means that the leader's costs are non-increasing in optimum. Moreover, if the leader's costs stay constant over a certain time interval, then they also remain unchanged afterwards. The above argument also implies that in optimum, the leader's output is non-decreasing and its R&D investment is always positive.

Compared to the static model, the time dimension enriches the set of strategies available to the leader. In particular, in the case of strategic predation, the leader's investment decision determines the predation time T when all followers are eliminated. Similarly to the static model, we solve the problem by separately considering the case of accommodation and the case of strategic predation. Under each strategy we find an optimal investment pattern. Further, we find conditions under which these patterns are sustainable and compare the leader's profits in cases when more strategies are sustainable.

4 Accommodation

Let us first consider the leader's optimization problem under the accommodation strategy. In that case, $q(t) = q_0(t) = \bar{c} + \sqrt{F} - c_0(t)$ for all $t \geq 0$. Thus, we may rewrite the problem (L) in terms of the leader's quantity q as a state variable following the law of motion (8):

$$I_A = \max_{z(\cdot)} \int_0^{+\infty} [q^2(t) - z^2(t) - F]e^{-rt}\, dt, \qquad (A)$$

$$\text{subject to}$$

$$\dot{q}(t) = \mu[\sqrt{F} - q(t) + \sqrt{g}\, z(t)],$$

$$q(0) = \sqrt{F}.$$

[12] Note that our problem is indeed shift-invariant despite the objective function being time dependent. This follows from linearity and from the specific time dependence in the form of discounting.

[13] Reverting would mean that for some ε, the value $-\varepsilon$ is also attained at two points in time, followed one time by a decrease and the other time by an increase in the leader's costs.

In order to solve this problem, we form the Hamiltonian function

$$\mathcal{H} = (q^2 - z^2 - F)e^{-rt} + \eta\mu(\sqrt{F} - q + \sqrt{g}\,z), \tag{9}$$

where η is a Lagrange multiplier. The joint dynamics of the state and control variables is derived from the first-order conditions (see the Appendix for details)[14]

$$\dot{z} = (r + \mu)z - \mu\sqrt{g}\,q, \tag{10}$$

$$\dot{q} = \mu(\sqrt{F} + \sqrt{g}\,z - q). \tag{11}$$

System (10)–(11) has a unique equilibrium (steady-state):

$$z_A^* = \frac{\mu\sqrt{gF}}{r + \mu(1-g)} = \frac{\sqrt{g}}{\rho - g}\sqrt{F}, \qquad q_A^* = \frac{(r+\mu)\sqrt{F}}{r + \mu(1-g)} = \frac{\rho}{\rho - g}\sqrt{F}, \tag{12}$$

with the steady-state number of followers and the leader's unit costs

$$n^* = \frac{1}{\Phi} - \frac{2\rho - g}{\rho - g} \qquad \text{and} \qquad c_A^* = \bar{c} - \frac{g}{\rho - g}\sqrt{F}.$$

Since $z(t)$ must be non-negative, the equilibrium may arise only in the first quadrant (i.e., $z_A^* \geq 0$, $q_A^* \geq 0$). Therefore, the equilibrium exists if and only if $r + \mu(1-g) > 0$, or $g < \rho$. The above method solves the leader's optimization problem in accommodation as an unconstrained optimization problem. We, however, also need to verify that the leader's unit costs indeed always remain above the critical value , or equivalently that its output does not fall below $\hat{q}_0 = A - \bar{c} - 2\sqrt{F}$. In such a case we say that accommodation is *sustainable*. By the same argument as in the previous section, the leader's unit costs are non-increasing over time under the optimal investment path. Thus, the condition for sustainability reduces to a simple check of whether the steady-state is sustainable; formally, $c_A^* \geq$ (or $q_A^* \leq \hat{q}_0$). To this end, the sustainability condition for accommodation becomes

$$g < \rho \qquad \text{and} \qquad \Phi \leq \phi_A(g) = \frac{\rho - g}{3\rho - 2g}. \tag{13}$$

Much like in the static model, the function ϕ_A is decreasing and, thus, inequality (13) is satisfied when g is sufficiently low. In other words, accommodation is sustainable only if R&D efficiency is not very high.

It is worthwhile to note that the steady-state value of investment monotonically increases, and the steady-state number of followers monotonically decreases in μ. Moreover, when the adjustment becomes instantaneous ($\mu \to \infty$), the steady-state values of all variables coincide with their static counterparts. Also, condition (13) reduces to the sustainability condition in the static model. Thus, the static model serves as a good long-run approximation of the dynamic one for industries that are subject to rapid technological change. However, when the speed of adjustment becomes smaller, we may expect lower investments as well as a higher number of firms in the long run.

[14]Alternatively, the solution can be obtained by making a transformation of (A) as $\tilde{q} = e^{-\frac{1}{2}rt}q_0$, $\tilde{z} = e^{-\frac{1}{2}rt}z$ that brings the problem into a standard linear quadratic form, which can be solved using Theorem 5.16 in Engwerda (2005).

If $g < \rho$, then the eigenvalues of the system (10)–(11) are real and of opposite sign (i.e., the equilibrium is a saddle). The existence of a unique equilibrium then implies the existence and uniqueness of an optimal path of R&D and output converging to this equilibrium. Using the initial condition together with the transversality condition, it is straightforward to obtain the following closed-form solution for the joint dynamics of R&D investment and output (see the Appendix for technical details and Figure 4 for an illustration):

$$z_A(t) = z_A^* - \frac{g}{\rho - g}\sqrt{F} \cdot \frac{\rho + 1 - \sqrt{(\rho+1)^2 - 4g}}{2\sqrt{g}}\, e^{\lambda_A t}, \tag{14}$$

$$q_A(t) = q_A^* - \frac{g}{\rho - g}\sqrt{F}\, e^{\lambda_A t}, \tag{15}$$

where $\lambda_A = \frac{1}{2}\mu\big[\rho - 1 - \sqrt{(\rho+1)^2 - 4g}\big]$ is the negative eigenvalue of the system (10)–(11). The price is constant over time and equals $\bar{c} + \sqrt{F}$, which is the equilibrium price (see Section 2.1), independent on the leader's unit costs. Note that the optimal R&D investment (14) as well as the leader's output monotonically increase over time towards its steady-state value. Higher values of μ are associated with a higher steady-state value of investments and faster convergence towards the steady-state (i.e., higher absolute value of λ_A).[15] The intuition is that a higher rate of transformation of R&D inputs into lower unit costs (higher μ) decreases the time gap between the R&D investment and its benefits expressed in terms of future profits. If adjustment takes place instantaneously ($\mu \to \infty$), then $q(t) \equiv q_A^*$ and $z(t) \equiv z_A^*$, as predicted by the static model.

Now it is technically possible to evaluate the leader's maximal profit in closed form as $I_A = \int_0^\infty [q_A^2(t) - z_A^2(t) - F]e^{-rt}\,dt$. The resulting expression is, however, rather complicated and will not be provided here. As a special case note that if the adjustment is instantaneous, the leader's maximal profit becomes $\int_0^\infty [(q_A^*)^2 - (z_A^*)^2 - F]e^{-rt}\,dt = \frac{1}{r}[(q_A^*)^2 - (z_A^*)^2 - F] = \frac{g}{(1-g)r}F$. Note also that, unlike in the case of an exogenously given number of followers, the leader's profit increases in the fixed costs F, because larger F leads to less entry and thus enables the leader to enjoy a higher profit.

5 Strategic Predation

Strategic predation involves two phases. In the first phase, the *predation* phase, the leader invests in R&D in order to gradually decrease the number of followers. If it aims to eliminate the followers rather early, it may even incur temporary losses. When the leader's costs eventually fall to the level at time T, it becomes a monopolist. In the second phase, the *monopoly* phase, the leader enjoys the monopoly position. At time T, the leader faces two options. First, it may decide to keep its unit costs at the level that will just prevent the follower(s) from entering the market.[16] In such a case, the leader is

[15]Note that due to the condition $g < \rho = 1 + \frac{r}{\mu}$, the inequality $g < 1$ is necessary in order to have the set of feasible values of μ unbounded.

[16]When $c_0(t) =$, there is actually only one active follower. However, as we argued in footnote 6, by slightly increasing investment, the leader gains a monopolistic position, which raises its profit significantly (due to the jump upwards). Thus, in the equilibrium, the leader will become a monopolist even with $c_0(t) =$.

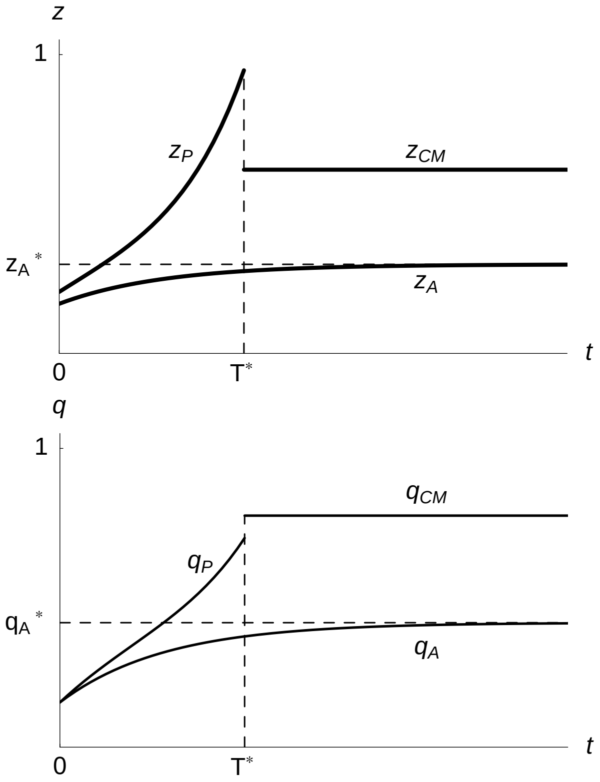

Figure 2: Patterns of z and q in accommodation and strategic predation (example for $A = 5$, $c = 4$, $r = 0.05$, $g = 0.8$, $F = 0.0225$, $\mu = 0.2$; which implies $\Phi = 0.15$, $\rho = 1.25$ and optimal the predation time $T^* = 15.7883$)

constrained by the presence of potential followers and we call the resulting arrangement a *constrained monopoly*. Second, the leader may continue to lower its costs further. In this case the leader won't be constrained by the presence of potential followers anymore; we call this arrangement an *unconstrained monopoly*. Recall that in Section 3.1 we argued that the leader's unit costs are non-increasing in optimum. Thus, it is not optimal for the leader to allow the re-entry of followers after having achieved the monopoly position. This way persistence of monopoly arises endogenously, due to enduring investments in R&D that do not vanish once the leader has achieved the monopoly position. Note also that in both the constrained and the unconstrained monopoly, the leader indeed chooses the monopoly output given its current costs. Thus, the concept of 'constrained' rather applies to whether its investment decision is affected by the presence of potential followers.

We find the optimal investment path under strategic predation in three steps:

1. We solve the predation phase. Given the predation time T, we find the optimal path of R&D on the interval $[0, T]$ that leads to the elimination of all followers by time T. Let $I_P(T)$ denote the corresponding present value of the leader's profit.

2. We solve the monopoly phase. Given that all followers are eliminated at time T, we find the optimal path of R&D on the interval $[T, \infty)$ under unconstrained as well as constrained monopoly. Let $I_M(T)$ and $I_{CM}(T)$ denote the corresponding present values of profits (evaluated at time T).

3. We maximize profits $I_P(T) + e^{-rT} I_M(T)$ and $I_P(T) + e^{-rT} I_{CM}(T)$ with respect to the predation time T.

5.1 Predation Phase

In this section we solve for the first step of the optimization problem listed above. If the leader firm sets the objective to eliminate all its rivals at time T, its output should attain the critical value $\hat{q}_0 = A - \bar{c} - 2\sqrt{F}$ at time T, whereas the market is in equilibrium with endogenous entry before time T. This imposes an additional terminal condition on the leader's output. The leader thus solves the following optimization problem:

$$I_P(T) = \max_{z(\cdot)} \int_0^T [q^2(t) - z^2(t) - F] e^{-rt} \, dt, \tag{P}$$

$$\text{subject to}$$

$$\dot{q}(t) = \mu[\sqrt{F} - q(t) + \sqrt{g}\, z(t)],$$

$$q(0) = \sqrt{F}, \qquad q(T) = A - \bar{c} - 2\sqrt{F}.$$

The problem (P) is indeed very similar to (A); it differs only in the additional terminal condition $q(T) = \hat{q}_0 = A - \bar{c} - 2\sqrt{F}$ at time T, that is equivalent to $c_0(T) =$, or $n(T) = 1$. Thus, we again obtain Hamiltonian (9) and equations (10)–(11) that drive the joint dynamics of R&D and output. However, instead of applying the transversality condition, we use the terminal condition to solve these equations; see the Appendix for details as well as the closed-form solution. Figure 4 illustrates the optimal dynamics of z

and q in predation. Note that Figure 4 presents the case when the leader indeed makes instantaneous losses during the predation phase, because its gross profit does not cover the R&D investments whenever $q_P(t) < z_P(t)$.

Similarly to the accommodation case, we can then evaluate the optimal profit $I_P(T)$ associated with the predation phase that lasts up to a given time T, as $I_P(T) = \int_0^T [q_P^2(t) - z_P^2(t) - F]e^{-rt}\,dt$. Again, we will not provide the explicit formula; it can be easily computed from the solution in the Appendix. Note, however, that with instantaneous adjustment ($\mu \to \infty$), the optimal predation profit becomes similar to the one from the accommodation case $\int_0^T [(q_A^*)^2 - (z_A^*)^2 - F]e^{-rt}\,dt = \frac{1}{r}(1 - e^{-rT})[(q_A^*)^2 - (z_A^*)^2 - F] = \frac{g}{(1-g)r}(1 - e^{-rT})F$.

Let us now study comparative dynamics of the leader's optimal investment path. In addition to the comparisons with respect to μ, as in the preceding section, we are interested in the comparative results with respect to predation time T. Such results then help us to assess properties of the overall profit with respect to T.

Intuitively, if the speed of adjustment μ increases, predation becomes easier and requires lower investment. Thus, we might expect the profit from predation to be increasing in μ. Similarly, an increase in predation time T should lead to a lower investment and a lower output, which consequently increases profit. When the predation time becomes very long, the leader's behavior in predation should be close to that in accommodation. This, in particular, means that in the predation phase the leader indeed invests more than in accommodation.

The above intuition as well as the additional comparative dynamics results are summarized in the two lemmas below.

Lemma 1 *Assume that accommodation is sustainable, i.e.,* $\Phi < \phi_A(g)$*. Then,* $z_P(t)$ *and* $q_P(t)$ *are increasing over time, but are decreasing in the predation time* T *and converge pointwise to* $z_A(t)$ *and* $q_A(t)$ *as* $T \to \infty$*.*

Proof See the Appendix.

In the following lemma we provide comparative dynamics results for the optimal predation profit $I_P(T)$. In order to compute its derivative with respect to the predation time T, we use the dynamic version of the *Envelope theorem* (see Theorem 10 in Seierstad and Sydsaeter, 1987, p. 213) which claims that:

$$\frac{d}{dT} I_P(T) = \mathcal{H}^*(T), \tag{16}$$

where $\mathcal{H}^*(T)$ is the Hamiltonian of the accommodation problem with predation time T, evaluated under optimal q and z, and for $t = T$. This property turns out to be very handy in several places where we address the optimal predation time.

Lemma 2 *Assume that accommodation is sustainable, i.e.,* $\Phi < \phi_A(g)$*. Then the optimal profit from the predation phase* $I_P(T)$ *is increasing and concave in* T*, and converges to* I_A *as* $T \to \infty$*. Moreover,* $I_P(T)$ *is increasing in the speed of adjustment* μ*.*

Proof See the Appendix.

5.2 Constrained Monopoly

In this section we search for the optimal investment path under a constrained monopoly. Assume that the leader's unit costs reach value at time T (i.e., all followers are eliminated by T) and the leader chooses to behave as a constrained monopolist. Thus, at time T, after the elimination of all followers the leader increases its output by $\frac{1}{2}\sqrt{F}$ to the monopoly quantity $q_M(T) = \hat{q}_M = A - \bar{c} - \frac{3}{2}\sqrt{F}$. At the same time the total output decreases by $\frac{1}{2}\sqrt{F}$ and the price increases by $\frac{1}{2}\sqrt{F}$ to the monopoly price $p_M(T) = \frac{1}{2}(A + \bar{c}) = \bar{c} + \frac{3}{2}\sqrt{F}$.

After time T, the leader does not lower its costs below , but rather invests just as much as to keep its costs constant in order to prevent the followers from re-entering the market. As an outcome, the monopoly will persist over time. Setting $\dot{c}_0 = 0$ and $c_0 =$ in the law of motion (6) we find that the investment and output are constant over time on $[T, \infty)$ and are equal to

$$z_{CM} = \frac{A - \bar{c} - 3\sqrt{F}}{\sqrt{g}}, \tag{17}$$

$$q_{CM} = \hat{q}_M = A - \bar{c} - \tfrac{3}{2}\sqrt{F}. \tag{18}$$

The equations above represent a corner solution and are analogous to those in the static model case with $z = \hat{z}$. They indeed yield the same investment and output levels. Also note that the above path of z and q depends neither on the predation time T, nor on the speed of adjustment μ. It is straightforward to verify that $z_{CM} > z_A^*$, which implies that in strategic predation with constrained monopoly the leader invests more than in accommodation, not only in the predation phase, but also after all rivals are eliminated.

The leader's profit $I_{CM}(T)$, evaluated at time T, also does not depend on the predation time T and is equal to

$$I_{CM} = \frac{q_{CM}^2 - z_{CM}^2 - F}{r}.$$

Finally, let us find the optimal predation time T that maximizes the overall profit $I_P(T) + e^{-rT} I_{CM}$. This problem represents the trade-off between incurring high costs in order to eliminate all followers early, or delaying high constrained monopoly profits when the followers are eliminated later. Recall that according to Lemma 2, the optimal profit from the predation phase is increasing in T. Early elimination (i.e., low T) leads to instantaneous losses (that is, negativity of instantaneous net profit) caused by high R&D investments in the predation phase. These losses are compensated in the monopoly phase when all rivals are eliminated. On the other hand, when elimination is delayed (i.e., T is high), the leader postpones the high profits earned in the constrained monopoly phase, but also invests only moderately in R&D during the predation phase.

The optimal value of T can be computed from the first order condition. Using (16), we obtain the derivative of the leader's overall profit

$$\tfrac{d}{dT}[I_P(T) + e^{-rT} I_{CM}] = \mathcal{H}^*(T) - re^{-rT} I_{CM}.$$

However, the resulting first order condition (with T as unknown) is not solvable analytically (unless $\mu \to \infty$). Nevertheless, we are not directly interested in the magnitude of the leader's profit or the precise value of the predation time T, but in its choice between accommodation and strategic predation. Recall that when accommodation is sustainable, then $I_P(T) \to I_A$ as $T \to \infty$. Thus, also $I_P(T) + e^{-rT} I_{CM} \to I_A$ as $T \to \infty$. Thus, the leader chooses strategic predation over accommodation, if and only if $I_P(T) + e^{-rT} I_{CM}$ attains its maximum at a finite time T.

As an illustration, we analyze first the case of $\mu \to \infty$ (instantaneous adjustment). Then, the leader's profit from the predation strategy equals $\frac{1}{r}(1 - e^{-rT})[(q_A^*)^2 - (z_A^*)^2 - F] + \frac{1}{r} e^{-rT}[(q_{CM}^*)^2 - (z_{CM}^*)^2 - F]$. It increases in T if $(q_A^*)^2 - (z_A^*)^2 > (q_{CM}^*)^2 - (z_{CM}^*)^2$, and decreases in T when the opposite inequality holds. In the former case, the leader's profit does not attain its maximum and the leader chooses accommodation. In the latter case, the optimal predation time is 0; the leader takes advantage of the instantaneous adjustment and eliminates all rivals immediately at $T = 0$. In both cases, its profit then becomes identical to the static profit, except for the factor $\frac{1}{r}$, and the above inequality is actually equivalent to (5) in the static model.

In the general case of a finite μ we obtain the following proposition:

Proposition 3 *The leader chooses accommodation over strategic predation with constrained monopoly, if and only if*

$$\Big(1 - \frac{3\rho - 2g}{\rho - g}\Phi\Big)\psi(g) > \sqrt{\Phi\Big(1 - \frac{7}{4}\Phi\Big)}, \tag{19}$$

where $\psi(g) = \frac{1}{2\sqrt{g}}[\rho - 1 + \sqrt{(\rho + 1)^2 - 4g}] > 0$.

Proof See the Appendix.

Inequality (19) holds if $\Phi = 0$, and the opposite inequality is true if $\Phi = \phi_A(g)$. Similarly to the static case, we find that for any $g \in (0, \rho)$, there is a critical value of Φ, denoted $\phi_0(g)$, such that the leader chooses accommodation if and only if $\Phi < \phi_0(g)$. This critical value is such that (19) holds with equality and satisfies the inequality $\phi_0(g) < \phi_A(g)$ for all $g \in (0, \rho)$.

Consistently with the above analysis, (19) reduces to (5) when $\mu \to \infty$. In addition, the left-hand side of (19) is decreasing in μ. Therefore, the size of the region where accommodation is chosen increases as μ decreases. This result is intuitive since lower values of μ make predation slower and more expensive.

5.3 Unconstrained Monopoly

Again, assume that the leader's unit costs become equal to the value at time T, and the leader chooses to behave as an unconstrained monopolist by lowering its unit costs below . In that case, the leader can again set the monopoly quantity $q_M(t) = \frac{1}{2}[A - c_0(t)]$ after time T. Equation (6) implies that after time T, the leader's output follows the law of motion

$$\dot{q}_M(t) = \mu[\tfrac{1}{2}(A - \bar{c}) - q_M(t) + \tfrac{1}{2}\sqrt{g}\, z(t)],$$

with the initial condition $q_M(T) = \hat{q}_M$. This initial condition is identical to that in the constrained monopoly case, and does not depend on time T. The law of motion and the leader's net (instantaneous) profit do not depend on T, either. Thus, the optimal path of investment after time T does not depend on time T itself. In other words, the leader's profit from unconstrained monopoly $I_M(T)$, evaluated at time T, also does not depend on T and can be written as

$$I_M = \max_{z(\cdot)} \int_0^\infty [q^2(t) - z^2(t) - F]e^{-rt}\,dt, \tag{M}$$

$$\text{subject to}$$
$$\dot{q}(t) = \mu[\tfrac{1}{2}(A - \bar{c}) - q(t) + \tfrac{1}{2}\sqrt{g}\,z(t)],$$
$$q(0) = A - \bar{c} - \tfrac{3}{2}\sqrt{F}.$$

Using a similar procedure as developed in Section 4 (see the Appendix for clarifications), we obtain a system of two differential equations analogous to (10)–(11). The equilibrium values of this system are derived as

$$z_M^* = \frac{\sqrt{g}}{4\rho - g}(A - \bar{c}), \qquad q_M^* = \frac{2\rho}{4\rho - g}(A - \bar{c}).$$

Thus, we obtain the steady-state value of the leader's unit costs as

$$c_M^* = \bar{c} - \frac{g}{4\rho - g}(A - \bar{c}).$$

Recall that the set of values of g has been restricted earlier to the interval $(0, 4\rho)$. The expression for c_M^* provides a justification for such a restriction: It requires the monopoly output to be positive.[17] Similarly to the accommodation problem, we also need to verify whether under the optimal investment path, the leader's costs do not exceed the critical value , which would lead to the re-entry of followers. In such a case, we again say that unconstrained monopoly is *sustainable*. The condition for sustainability thus becomes $c_M^* \leq$, or equivalently

$$g < 4\rho \qquad \text{and} \qquad \Phi \geq \phi_M(g) = \frac{2(2\rho - g)}{3(4\rho - g)}.$$

Clearly, the function $\phi_M(g)$ is decreasing for $g \in (0, 2\rho)$, implying that unconstrained monopoly is sustainable only when the R&D efficiency g is sufficiently high. Moreover, as $\phi_M(g) > \phi_A(g)$ for all $g > 0$, there are no values of parameters for which both accommodation and unconstrained monopoly are sustainable. In addition, as the investment path of constrained monopoly is available in the optimization problem (M), the leader's profit from constrained monopoly cannot exceed the profit from unconstrained monopoly, whenever the latter is sustainable. It follows that unconstrained monopoly is optimal whenever it is sustainable. Last but not least, note that much like in the case of constrained monopoly, persistence of monopoly occurs here and is caused by the leader's R&D investment that persist even in the monopoly phase.

[17] At this point we again need to mention that economic interpretation requires $c_M^* > 0$, or equivalently $g < 4\rho\,\bar{c}/A$. By the same argument as in footnote 7 we again omit this condition from further elaborations.

Finally, as in Section 4, we derive the joint dynamics of the leader's investments and output:

$$z_M(t) = z_M^* + \left[\frac{2\rho - g}{4\rho - g}(A - \bar{c}) - \frac{3}{2}\sqrt{F}\right] \frac{\rho + 1 - \sqrt{(\rho+1)^2 - g}}{\sqrt{g}} e^{\lambda_M t}, \tag{20}$$

$$q_M(t) = q_M^* + \left[\frac{2\rho - g}{4\rho - g}(A - \bar{c}) - \frac{3}{2}\sqrt{F}\right] e^{\lambda_M t}, \tag{21}$$

where $\lambda_M = \frac{1}{2}\mu\left[\rho - 1 - \sqrt{(\rho+1)^2 - g}\right]$. Note that the condition $g < 4\rho$ implies that $g < (\rho+1)^2$ and $\lambda_M < 0$. The resulting price can then be computed as $p_M(t) = A - q_M(t)$. It follows from the sustainability condition that the R&D investment as well as the leader's output are increasing over time, whereas the price is decreasing. Interestingly, when the R&D efficiency is sufficiently high, namely when $\Phi > \frac{3}{2}\phi_M(g)$, the leader keeps investing significantly in R&D so that the monopoly price eventually drops below the accommodation price, and in the steady-state $p_M^* < p_A$.

We can now evaluate the leader's profit $I_M = \int_0^\infty [q_M^2(t) - z_M^2(t) - F]e^{-rt}\,dt$. The optimal predation time T can then be found as a maximum of the overall profit $I_P(T) + e^{-rT} I_M$. Again, this optimization problem is solvable analytically only if $\mu \to \infty$. We omit further elaboration on the optimal predation time and the comparison to accommodation, because as shown above, the sustainability of unconstrained monopoly excludes the sustainability of accommodation.

6 Accommodation vs. Strategic Predation

In this section, we sum up on the leader's long-run strategies of accommodation and strategic predation. First, as argued above (see the preceding section), unconstrained monopoly is chosen by the leader whenever it is sustainable. Second, constrained monopoly is chosen when neither accommodation nor unconstrained monopoly are sustainable. Third, in some subsets of the region of parameters (g, Φ) where accommodation is sustainable, the leader prefers strategic predation with constrained monopoly in the second phase. More precisely, the set $(0, 4\rho) \times (0, \frac{1}{3}]$ of admissible values of (g, Φ) can be divided into four regions with the following market structures (see Figure 6 for an illustration):

- Region UM, where $\phi_M(g) < \Phi$: Accommodation is not sustainable, but unconstrained monopoly is. Thus, strategic predation with unconstrained monopoly is optimal.

- Region CM_2, where $\phi_A(g) < \Phi < \phi_M(g)$: Neither accommodation nor strategic predation with unconstrained monopoly are sustainable. Thus, strategic predation with constrained monopoly is optimal.

- Region CM_1, where $\phi_0(g) < \Phi < \phi_A(g)$: Unconstrained monopoly is not sustainable, but accommodation is. It, however, yields a lower profit than strategic predation with constrained monopoly.

- Region A, where $\Phi < \phi_0(g)$: Accommodation is sustainable and also optimal.

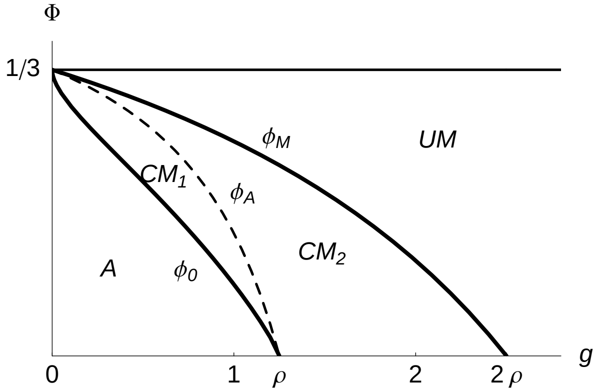

Figure 3: Leader's strategies in the dynamic model (for parameter values $A = 5$**,** $c = 4$**,** $r = 0.05$**,** $\mu = 0.2$)

As we have already mentioned, when the adjustment becomes instantaneous, these regions are identical to the ones found in the static model. On the contrary, when μ decreases (and, thus, ρ increases) the curves $\Phi = \phi_0(g)$, $\Phi = \phi_A(g)$ and $\Phi = \phi_M(g)$ rescale to the right (see Figure 6). This in particular means that region A expands and accommodation becomes more likely when the rate of the adoption of new technologies is slower, whereas we might expect more predatory behavior in industries with rapid technological change. In our interpretation of $\rho - 1$ as a generalized discount factor, the future becomes less important when ρ increases. In turn, a heavily discounted future invites accommodation as a sustainable and also optimal long-run strategy. Thus, accommodation is more likely to become an optimal strategy in the equilibrium. The same effect arises when the discount rate r increases which again implies that ρ increases. In the limit case $r \to \infty$ we obtain that only accommodation is chosen by the leader (as the left-hand side of (19) diverges to $+\infty$).

At this point it is important to note that in all cases the equilibrium values of q, z, as well as prices are homogeneous of degree 1 in $(A - \bar{c}, \sqrt{F})$. Therefore, in all cases the equilibrium profits as well as consumer surplus, social welfare, and the present value of R&D investment are homogeneous of degree 2 in $(A - \bar{c}, \sqrt{F})$ and can be written as a product of $(A - \bar{c})^2$ and some function of Φ (that is independent on both A and $\bar{c}$). Hence, any comparison of those variables does not depend on A and $\bar{c}$; it can depend only on the parameters g, Φ, μ, and r.

7 Welfare analysis

In this section we analyze the normative aspects of the leader's strategies. That is, we compare the social welfare effects of strategic predation *vis-à-vis* accommodation and contrast them to an appropriate benchmark that involves the maximization of social welfare. An obvious benchmark would be the first-best situation, but this is not an overly interesting or insightful ground for comparison: in this case the government or social planner would clearly ban the entry of any followers in order to avoid the duplication of fixed costs, leaving the leader the only active firm.[18] As our main interest is the comparison of accommodation and strategic predation, we will not elaborate on the first-best further. In addition, the first-best situation is in general not realistic and not achievable.

An alternative and, as we claim, more insightful benchmark would be a setup in which a social planner controls the leader's R&D investments (and indirectly also the time of the elimination of the last follower, T) in order to maximize the social welfare, and does not interfere with the markets in any other way. In other words, the stage of the game in which the firms select quantities as well as the entry stage remain unaltered. We are particularly interested in the comparison of the choice of strategy (accommodation vs. strategic predation) by the leader as opposed to the corresponding choice of social planner. In the case of predation, we also compare the corresponding predation times.

Social welfare consists of firms' net profits and consumer surplus. In the case of linear demand considered here, the instantaneous consumer surplus has the simple form $CS = \frac{1}{2}(A - p)^2$, whereby the price p depends on the market structure. Recall that accommodation as well as the predation phase of strategic predation exhibit (in equilibrium) the following two properties: (i) the price is constant and equal to $p_A = \bar{c} + \sqrt{F}$; (ii) all firms except the leader earn zero profit. Thus, the optimization problems of the leader and the social planner differ only by an additive constant, namely $CS_A = \frac{1}{2r}(A - p_A)^2$, in the objective function. This implies that the leader's investment choice in accommodation coincides with the choice of social planner and is, therefore, socially efficient. Consequently, the output path is the same in both setups (given accommodation).

Now consider strategic predation with constrained monopoly after time T. If we fix the predation time T, by the same argument as above, the leader's investment choice in the predation phase is socially efficient. Moreover, in the second phase after time T, the investment path is uniquely determined (so that the unit costs remain equal to $\hat{c}$) and, therefore, the R&D expenditures are also socially efficient (given a constrained monopoly). The price is constant and equal to $p_{CM} = \bar{c} + \frac{3}{2}\sqrt{F}$, which is higher than p_A. Thus, the instantaneous consumer surplus in constrained monopoly is lower than in accommodation. Summing up, in both phases the objective function of the social planner differs from the leader's only in an additive constant and (given that predation is followed by constrained monopoly after time T) the social planner would undertake exactly the same R&D investment over time, and consequently have the same output as the leader.

This efficiency argument, however, holds only for an exogenously given market structure (accommodation or constrained monopoly) and an exogenous (fixed) predation time T. Both market structures and predation time are part of the leader's decision process and are determined endogenously. Thus, for instance, the social planner may indeed prefer a different predation time than the leader as their maximization problems with

[18] The planner would also set the price equal to marginal costs if the leader is not required to break even, that is, if its overall (net) profit can be negative. Alternatively, the planner would choose a price and investment pattern (with price above marginal costs) so that the leader breaks even, if the leader's overall profit is required to be non-negative. A Supplementary Appendix analyzing the first-best situation may be obtained from the authors upon request.

respect to T differ. The socially optimal predation time maximizes

$$I_P(T) + e^{-rT} I_{CM} + (1 - e^{-rT}) CS_A + e^{-rT} CS_{CM}, \tag{22}$$

where $CS_{CM} = \frac{1}{2r}(A - p_{CM})^2 = \frac{1}{2r} q_{CM}^2$, whereas the leader's objective function is merely $I_P(T) + e^{-rT} I_{CM}$.

Alike to the leader's problem, we can analyze the social planner's choice between accommodation and strategic predation with constrained monopoly by comparing the limiting behavior of her objective function (22) as $T \to \infty$. We obtain the following proposition that is an analogue of Proposition 3.

Proposition 4 *The social planner chooses accommodation over strategic predation with constrained monopoly, if and only if*

$$\Big(1 - \frac{3\rho - 2g}{\rho - g}\Phi\Big)\psi(g) > \sqrt{\frac{1}{2}\Phi\Big(1 - \frac{9}{4}\Phi\Big)}. \tag{23}$$

Moreover, in constrained monopoly, when $\Phi < \phi_A(g)$, the social planner chooses a longer predation time than the leader.

The above condition resembles very much the condition for the leader's choice in Proposition 3. They only differ in the right-hand sides, which is smaller in (23), meaning that the social planner chooses accommodation for a larger set of parameters. This, in turn, implies that there is a region where the leader's choice is socially inefficient, that is, (19) holds but (23) does not. This range of parameters represents a rather small region and is illustrated in Figure 7 by shading. Moreover, we again find that there exists a critical value of Φ, denoted $\phi_{0S}(g)$, such that the social planner chooses accommodation if and only if $\Phi < \phi_{0S}(g)$. This critical value makes (23) an equality and satisfies $\phi_0(g) < \phi_{0S}(g) < \phi_A(g)$ for all $g \in (0, \rho)$.

In other words, predation starts to become optimal when either R&D efficiency gets larger (g rises), or the fixed costs increase relative to the size of the market (measured by Φ).[19] Thus, these two factors make both the leader and the social planner more aggressive, tipping in favor of predation, and, hence, aimed for a larger profit and social welfare, respectively. The leader, however, ignores the impact of R&D investment on consumer surplus and thus adopts predation for a bit lower combination of g and Φ (see Figure 7). Regarding the social planner, the social gains from consumer surplus that comes from the followers' production still exceed the forgiven future profits from predation in the shaded region. So the social planner sticks to the accommodation strategy in this marginal range of parameters.

In the second part of Proposition 4, we claim that the leader would like to eliminate the followers earlier than is socially optimal. Thus, the leader overinvests in R&D in order to achieve such a predation time. This also implies that during the predation period, the number of followers is smaller than would be socially optimal. Again, this is a consequence of the leader's ignorance of consumer surplus, making the leader more aggressive than is socially optimal.

[19] A shift toward predation as an optimal strategy also occurs when, *ceteris paribus*, the rate of technology adoption μ increases, causing ρ to fall.

Consider now predation with unconstrained monopoly. Recall that we keep the output choice unchanged, therefore the monopolist's output still satisfies $q(t) = A - p(t) = \frac{1}{2}[A - c(t)]$. The corresponding consumer surplus then equals $CS(t) = \frac{1}{2}q^2(t)$. It is not constant over time and causes a distortion in the optimization problem (compared to the leader's problem). As a consequence, the leader's R&D investment would be socially suboptimal. The social planner solves a problem similar to (M) but with the objective function being $\int_0^\infty [\frac{3}{2}q^2(t) - z^2(t) - F]e^{-rt}dt$. Solving the optimization problem (see the Appendix for details) we obtain the following sustainability condition:

$$g < \frac{8}{3}\rho \qquad \text{and} \qquad \Phi > \phi_{MS}(g) = \frac{2(4\rho - 3g)}{3(8\rho - 3g)}.$$

Comparing the sustainability of unconstrained monopoly under the leader's and the social planner's optimal investments, we obtain that $\phi_{MS}(g) < \phi_M(g)$ for all $g \in (0, \frac{8}{3}\rho)$. Therefore, compared to the leader, the social planner is now more aggressive and chooses unconstrained monopoly for a larger set of parameters than the leader; see Figure 7 for an illustration.[20] As before, the intuition behind this statement is that the social planner takes into account the positive impact of R&D on consumer surplus and, therefore, chooses a larger flow of R&D than the profit-maximizing leader. For high enough g and Φ, this larger flow of R&D prevents the followers to even control the firm's pricing policy via the threat of entry, enabling the social planner an unconstrained monopoly position. Consequently, the region of parameters where unconstrained monopoly is socially optimal becomes significantly larger compared to the respective set of parameters for the profit-maximizing leader. Moreover, the social planner's optimal choice implies higher steady-state output and a lower price (see the Appendix for details).

As for the optimal predation time when the predation phase is followed by an unconstrained monopoly, it appears that the social planner is again more aggressive and chooses a shorter T, provided that the R&D efficiency g and the relative size of the market Φ are large enough (see the Appendix for more details). In this case, the larger flow of R&D by the social planner that acts as unconstrained monopolist generates both a bigger consumer surplus and a higher profit than any other market structure under consideration.

8 Conclusion

The empirical findings and stylized facts on the relations among innovation, technological leadership, and market power have motivated our paper to describe and analyze a particular setup with a technological leader and endogenous entry, where the persistence of monopoly is likely to arise in the long run. On the positive side, we study the leader's choice between two main strategies of accommodation and strategic predation. On the normative side, we analyze the welfare aspects of the resulting market structures: oligopoly versus (constrained or unconstrained) monopoly. We show that

[20]It appears that there is now a tiny region (not illustrated in the figure) where both accommodation and unconstrained monopoly are sustainable, that is $\phi_{MS}(g) < \phi_A(g)$ when $g \in (0, \frac{1}{3}\rho)$. However, in this region accommodation is inferior even to constrained monopoly. Thus, there is no point in making a cross-profit comparison of accommodation and strategic predation with unconstrained monopoly.

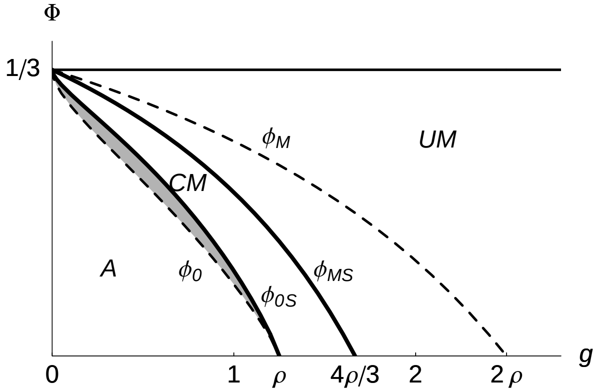

Figure 4: Socially efficient strategies in the dynamic model (for parameter values $A = 5$**,** $c = 4$**,** $r = 0.05$**,** $\mu = 0.2$)

strategic predation, when chosen by the leader, is in most cases also a socially efficient strategy.

Our analysis thus bears several important competition policy implications. First, the size of market share *per se* might not be a sufficient condition for a legal offence and, second, abuse of a dominant position may not even be an issue in dynamic markets where the size and the intensity of innovation are crucial for the subsequent market positioning, and where the very presence of actual or potential competitors constrains the behavior of market leaders. The challenge for the design of antitrust policy against predation is related to the ability of the antitrust authority to discriminate a price that is low for other predatory purposes from a price that might be set very low as a part of an efficiency-enhancing process, resulting, in turn, in enhanced competition and eventually leading not only to the exit of competitors but also to the enhancement of social welfare and, possibly, consumer surplus. For instance, in the presence of network effects or learning effects it would be legitimate and consistent with vigorous competition that firms set very low prices when they are introducing new products, targeting new customer segments or rivals, installed bases, or when they are in the first phase of the learning curve. Thus, a competition authority with limited knowledge of industry- and firm-specific data faces a complex problem when attempting to identify those circumstances under which loss-inducing predatory prices cause harm to the competition. For that reason the antitrust authorities have to be fully aware of the risks of misclassification when approaching a predation case.

In order to qualify our results and findings, it is important to stress that we assume the technological leadership as given and study under which conditions this leadership transfers into the market dominance (monopoly) and how such factors like technological efficiency, speed of the adoption of new technology, and the (relative) size of the market contributes to this market dominance. A more elaborated model of monopoly persistence could also account for competition in R&D from which the technological leadership may arise. For instance, one can allow for different speeds of technological adoption among the competing firms, that in turn may result in technological leadership in the long-run. In this light, our current model would be the special case of that more elaborated model in which all firms but one have zero adoption rate of the new technology.

Another natural way to generalize our model would be to consider other effects of investment. Despite the assumption of cost reducing investment, our results are not bound to this setup only. Our intuition is actually driven by the property that investment increases the gap between the leader and the followers and results in less entry. Although the qualitative features may be different, our intuition translates to other setups where this property holds. Regarding the speed of adjustment, it could be 'endogenized', for instance, as a function of the R&D intensity or R&D stock. But then, such endogenization may appear to make the leader even more aggressive — reinforcing our findings about the persistence of monopoly and strategic predation. Furthermore, we could model the last, quantity competition stage between the leader and follower explicitly by relying on the concepts of state-dependent strategies and Markov perfect equilibria. This approach could make the game even more 'dynamic' and possibly provide further insights.

Moreover, our results are obtained under special modelling assumptions such as product homogeneity, endogenous entry, and a specific form of cost-reducing investment with exogenous speed of the adoption of new technology. Thus these results have to be taken with the necessary caveats. As we may know (e.g., from Dixit, 1979), product differentiation makes strategic predation more difficult and more costly for the leader. Moreover, strategic predation in this case leads to fewer product varieties in the market, and this in turn harms consumers. However, by the continuity argument, it is pretty safe to claim that our findings would also hold in the situation when the degree of product differentiation is not 'large', that is, when the goods are 'close' substitutes. We also assume an absence of entry barriers. If this is not the case then policy makers may worry about having only one firm in the market — recall, for instance, the relatively recent case of the banned merger of the General Electric and Honeywell. In the light of our analysis, however, the message would be that one should target barriers to entry rather than market leaders (see also Etro, 2006 in this respect). Another, possibly interesting, extension would be to allow for an exogenous exit rate of the followers in the spirit of Melitz (see, for instance, Ghironi and Melitz, 2005 and 2007, Melitz and Ottaviano, 2007, Bilbiie, Ghironi, and Melitz, 2008 or Etro and Colciago, 2010). Adding this feature to the model is likely to make strategic predation less costly and thus more attractive. In this case the leader would attain the monopoly position and display the persistence more often.

Although all of the modifications discussed above might result in rather complicated model(s), they seem as challenging directions for future research.

Appendix A: Proofs and Derivations

Solution to the optimal control problem (A) The first-order conditions for the Hamiltonian (9) are:

$$\begin{aligned} \mathcal{H}_z &= -2ze^{-rt} + \mu\sqrt{g}\,\eta = 0, \\ \mathcal{H}_q &= \quad 2qe^{-rt} - \mu\eta \quad = -\dot{\eta}. \end{aligned}$$

From the first condition, $\eta = \frac{2}{\mu\sqrt{g}} z e^{-rt}$, which after substitution into the second condition directly yields (10). Equation (11) is the law of motion.

The eigenvalues and eigenvectors of the matrix associated with system (10)–(11) are

$$\lambda_{1,2} = \frac{\mu}{2}[\rho - 1 \pm \sqrt{(\rho+1)^2 - 4g}], \quad V_{1,2} = (v_{1,2}, 1)^T = \left(\frac{\rho + 1 \pm \sqrt{(\rho+1)^2 - 4g}}{2\sqrt{g}}, 1 \right)^T.$$

If $g < \rho$, then the eigenvalues are real and of opposite sign and the equilibrium is a saddle;[21] let $\lambda_1 > 0 > \lambda_2$. Moreover, the system has a constant particular solution (z_A^*, q_A^*). Thus, its general solution can be written as

$$(z, q)^T = (z_A^*, q_A^*)^T + k_1 V_1 e^{\lambda_1 t} + k_2 V_2 e^{\lambda_2 t}, \tag{24}$$

where k_1 and k_2 are arbitrary constants.

The transversality condition demands $k_1 = 0$ (in other words, the optimal solution must be bounded). The constant k_2 is determined from the initial condition $q(0) = \sqrt{F}$, which implies $k_2 = -\frac{g}{\rho - g}\sqrt{F}$. This gives the optimal path (14)–(15).

Solution to the optimal control problem (P) As argued in Section 5.1, the solution is again of the form (24). Using the initial condition and the terminal conditions for the leader's output we solve for constants k_1 and k_2.

$$k_1(T) = \frac{A - \bar{c}}{e^{\lambda_1 T} - e^{\lambda_2 T}} \left[\left(1 - \frac{3\rho - 2g}{\rho - g} \Phi \right) + \frac{g}{\rho - g} e^{\lambda_2 T} \Phi \right], \tag{25}$$

$$k_2(T) = \frac{A - \bar{c}}{e^{\lambda_2 T} - e^{\lambda_1 T}} \left[\left(1 - \frac{3\rho - 2g}{\rho - g} \Phi \right) + \frac{g}{\rho - g} e^{\lambda_1 T} \Phi \right]. \tag{26}$$

Recall that k_1 and k_2 are constant with respect to t, but depend on the predation time T. In further proofs we also use the argument T, and denote $z_P(t, T)$ and $q_P(t, T)$ the optimal paths of z and q in order to highlight their dependency on T.

Proof of Lemma 1 The monotonicity of z and q (with respect to t) can be established easily, when we recall that $\lambda_1 > 0 > \lambda_2$. Then also $k_1 > 0 > k_2$, whenever $\Phi < \phi_A(g) = \frac{\rho - g}{3\rho - 2g}$. Thus, both $k_1(T)e^{\lambda_1 t}$ and $k_2(T)e^{\lambda_2 t}$ are increasing in t. The monotonicity of z and q follows from the fact that eigenvectors V_1 and V_2 have positive coordinates.

Now we are in a position to study the comparative statics results with respect to the predation time T. The initial condition at time $t = 0$ implies that $k_1(T) + k_2(T) = \sqrt{F} - q_A^*$, which is constant. Taking the derivative, we obtain $k_1'(T) + k_2'(T) = 0$. A direct computation gives

$$k_1'(T) = -\frac{A - \bar{c}}{(e^{\lambda_1 T} - e^{\lambda_2 T})^2} \left[(\lambda_1 e^{\lambda_1 T} - \lambda_2 e^{\lambda_1 T}) \left(1 - \frac{3\rho - 2g}{\rho - g} \Phi \right) + \frac{g}{\rho - g} (\lambda_1 - \lambda_2) e^{(\lambda_1 + \lambda_2)T} \Phi \right],$$

[21] If $\rho < g < \frac{1}{4}(\rho+1)^2$, the equilibrium is an unstable node. If $\frac{1}{4}(\rho+1)^2 < g$, the equilibrium is an unstable focus.

which is negative, given $\lambda_1 > 0 > \lambda_2$. Therefore, $\frac{\partial}{\partial T} q_P(t,T) = (e^{\lambda_1 t} - e^{\lambda_2 t}) k_1'(T)$ and $\frac{\partial}{\partial T} z_P(t,T) = (v_1 e^{\lambda_1 t} - v_2 e^{\lambda_2 t}) k_1'(T)$. Since $\lambda_1 > 0 > \lambda_2$ and $v_1 > v_2$, both partial derivatives are clearly negative.

Taking the limit $T \to \infty$, we obtain $k_1(T) \to 0$ and $k_2(T) \to -\frac{g}{\rho - g}\sqrt{F}$, which are the same constants as in accommodation. Thus, $z_P(t,T)$ and $q_P(t,T)$ monotonically decrease and converge pointwise towards the values in accommodation $z_A(t)$ and $q_A(t)$ as $T \to \infty$.

Proof of Lemma 2 Assume $\Phi < \phi_A(g)$. The convergence with respect to T follows from the direct evaluation of profits and from the convergence of coefficients k_1 and k_2 established in the proof of Lemma 1 (note that the instantaneous profit is actually a linear combination of exponential functions).

Now we prove the monotonicity with respect to T. Consider the Hamiltonian for the problem in accommodation. Substituting for the Lagrange multiplier η, we obtain the (present value) Hamiltonian along the optimal path:

$$\mathcal{H} = \Big(q^2 + z^2 - F - \frac{2}{\sqrt{g}}\, qz + \frac{2}{\sqrt{g}}\sqrt{F}\, z\Big) e^{-rT}.$$

Recall that both q, z, and also $\mathcal{H}$ are in fact functions of t and T. In order to evaluate $\mathcal{H}^*(T)$ we need to substitute the terminal values of z and q at $t = T$. Recall that $q_P(T,T) = A - \bar{c} - 2\sqrt{F} = \hat{q}_0$ is constant, as given by the terminal condition for the predation phase. Let us now denote (the current value Hamiltonian)

$$h(T) = \mathcal{H}^*(T) e^{rT} = z_P^2(T,T) - \frac{2}{\sqrt{g}}\,(\hat{q}_0 - \sqrt{F})\, z_P(T,T) + \hat{q}_0^2 - F.$$

As shown in the text preceding Lemma 2, the derivative of the leader's profit from the predation phase then equals $\frac{d}{dT} I_P(T) = \mathcal{H}^*(T) = h(T) e^{-rT}$. Moreover, $\frac{d^2}{dT^2} I_P(T) = h'(T) e^{-rT} - r h(T) e^{-rT}$. In the following we establish some properties of $h(T)$:

$\lim_{T\to 0^+} h(T) = +\infty$.
Proof. Given $v_1 > v_2$ and $\lambda_1 > 0 > \lambda_2$, we find that $\lim_{T\to 0^+} z_P(T,T) = +\infty$. Because $h(T)$ is quadratic in $z(T,T)$, then also $\lim_{T\to 0^+} h(T) = +\infty$.

$\lim_{T\to\infty} h(T) = (A - \bar{c})^2 \big[\big(1 - \frac{3\rho - 2g}{\rho - g}\Phi\big)^2 \psi^2(g) + (1 - 3\Phi)(1 - \Phi) - \frac{1}{g}(1 - 3\Phi)^2\big] > 0$, where $\psi(g) = \frac{1}{2\sqrt{g}}[\rho - 1 + \sqrt{(\rho+1)^2 - 4g}] > 0$.
Proof. Denote Y the expression in square brackets. It follows from (24) and (25)–(26) that

$$\lim_{T\to\infty} z_P(T,T) = z_A^* + \Big[(A - \bar{c} - 3\sqrt{F}) - \frac{g}{\rho - g}\sqrt{F}\Big] \frac{\rho + 1 + \sqrt{(\rho+1)^2 - 4g}}{2\sqrt{g}}.$$

The identity $\lim_{T\to\infty} h(T) = (A - \bar{c})^2 Y$ is then obtained by a direct computation. To prove that $Y > 0$, we discuss two cases. First consider the case $g \geq \frac{1-3\Phi}{1-2\Phi}$. As the first term in Y is non-negative, then $Y \geq (1 - 3\Phi)(1 - \Phi) - \frac{1}{g}(1 - 3\Phi)^2$. Using the above inequality for g, we obtain $Y \geq (1 - 3\Phi)(1 - \Phi) - (1 - 3\Phi)(1 - 2\Phi) = \Phi(1 - 3\Phi)$, which is positive. Second, let $0 < g < \frac{1-3\Phi}{1-2\Phi}$. Observe that this implies $g < 1$. Now for any $\rho \geq 1$, we have $\rho > \frac{1-2\Phi}{1-3\Phi} g$, and thus $\Phi < \phi_A(g)$. For $\rho = 1$ we obtain by a direct computation that $Y = \frac{g}{1-g}\Phi^2$, which is positive. As the last step, we show that Y is increasing in ρ, when $\rho \geq 1$. This follows from the fact that both $\psi(g)$ as well as $1 - \frac{3\rho-2g}{\rho-g}\Phi$ are positive and increasing in ρ.

$h'(T) < 0$ for all $T > 0$.
Proof. Consider the derivative $h'(T) = \frac{2}{\sqrt{g}}[\sqrt{g}\, z_P(T,T) - \hat{q}_0 + \sqrt{F}]\, \frac{d}{dT} z_P(T,T)$. According to the law of motion, the term in brackets is actually the time derivative of the leader's output evaluated at time $t = T$, which is positive according to Lemma 1. Thus, it remains to prove that $\frac{d}{dT} z_P(T,T) < 0$. This derivative is equal to

$$\begin{aligned}
\frac{d}{dT} z_P(T,T) &= [k_1'(T) + \lambda_1 k_1(T)] v_1 e^{\lambda_1 T} + [k_2'(T) + \lambda_2 k_2(T)] v_2 e^{\lambda_2 T} = \\
&= [k_1'(T) + \lambda_1 k_1(T)]\,(v_1 - v_2) e^{\lambda_1 T} = \\
&= -\frac{e^{(\lambda_1+\lambda_2)T}(A - \bar{c})(v_1 - v_2)}{(e^{\lambda_1 T} - e^{\lambda_2 T})^2} \Big[(\lambda_1 - \lambda_2)\Big(1 - \frac{3\rho - 2g}{\rho - g}\Phi\Big) + \\
&\qquad + \frac{g}{\rho - g}\,(\lambda_1 e^{\lambda_2 T} - \lambda_2 e^{\lambda_1 T})\Phi\Big],
\end{aligned}$$

where the second line is obtained by differentiating the terminal condition $k_1(T)e^{\lambda_1 T} + k_2(T)e^{\lambda_2 T} = \hat{q}_0 - q_A^*$, which gives $[k_2'(T) + \lambda_2 k_2(T)]e^{\lambda_2 T} = -[k_1'(T) + \lambda_1 k_1(T)]e^{\lambda_1 T}$, and the third line comes by a direct computation. As $v_1 > v_2$, $\lambda_1 > 0 > \lambda_2$, and $\Phi < \phi_A(g)$, we indeed see that $\frac{d}{dT} z_P(T,T) < 0$.

$h(T) > 0$ for all $T > 0$.
Proof. This follows directly from properties (ii) and (iii). The monotonicity and concavity of $I_P(T)$ then follow from (iv) and (iii).

As the last part of the proof it remains to prove the monotonicity with respect to μ. Here we make use of the *Dynamic Envelope theorem* by Caputo (1990). Similarly to the static envelope theorem, it specifies the (total) derivative of the optimal value of the objective functional with respect to a parameter. In our case,

$$\frac{d}{d\mu} I_P(T) = \int_0^T \mathcal{L}_\mu \, dt,$$

where $\mathcal{L}$ is the Lagrangian of the problem. Note that in our problem the Lagrangian function coincides with the Hamiltonian.[22] Because the parameter μ appears only in the law of motion, we obtain

$$\frac{d}{d\mu} I_P(T) = \int_0^T \eta(t)[\sqrt{F} - q(t) - \sqrt{g}\, z(t)] e^{-rt}\, dt = \int_0^T \frac{2}{\mu\sqrt{g}} z(t)\dot{q}(t) e^{-rt}\, dt.$$

Since z is non-negative, and it was already shown that q is increasing, we conclude that $\frac{d}{d\mu} I_P(T) > 0$.

[22] Compared to the Hamiltonian, the Lagrangian contains additional terms for equality constraints multiplied by Lagrange multipliers.

Proof of Proposition 3 The derivative of the leader's overall profit takes the form

$$\mathcal{H}^*(T) - re^{-rT} I_{CM} = [h(T) - rI_{CM}]e^{-rT}.$$

As $h(T)$ is decreasing, the equation $h(T) = rI_{CM}$ may have at most one solution. Moreover, if such a solution exists (denote it as T^*), then the leader's profit is increasing on $(0, T^*)$ and decreasing on (T^*, ∞), and, therefore, the leader prefers strategic predation (with the optimal predation time T^*) over accommodation. On the other hand, if the solution does not exist, then $h(T) > rI_{CM}$ for all $T \in (0, \infty)$, because $h(T)$ is not bounded from above as shown in property (i) in the proof of Lemma 2. Thus, the leader's profit is increasing in T and the leader prefers accommodation over strategic predation.

In order to check whether the overall profit attains its maximum at finite T it suffices to evaluate the sign of $h(T) - rI_{CM}$ in the limit, as $T \to \infty$. Recall that $rI_{CM} = q_{CM}^2 - z_{CM}^2 - F$, where z_{CM} and q_{CM} are given by (17)–(18). This together with the property (iii) in the proof of Lemma 2 gives

$$\lim_{T\to\infty} h(T) - rI_{CM} = (A - \bar{c})^2 \Big[\Big(1 - \frac{3\rho - 2g}{\rho - g}\Phi\Big)^2 \psi^2(g) - \Phi\Big(1 - \frac{7}{4}\Phi\Big)\Big].$$

Since $\Phi < \frac{\rho - g}{3\rho - 2g} < \frac{1}{3}$, the above limit is positive if and only if the condition stated in the proposition holds. This completes the proof.

As a byproduct, we can also compute the value of (instantaneous) investments at the optimal predation time. More precisely, by solving the quadratic equation $h(T) = rI_{CM}$ we obtain $z(T,T) = (A - \bar{c})\Big[(1 - 3\Phi)/\sqrt{g} + \sqrt{\Phi(1 - \frac{4}{7}\Phi)}\Big]$.

Solution to the optimal control problem (M) The Hamiltonian for the problem becomes $\mathcal{H} = (q^2 - z^2 - F)e^{-rt} + \eta\mu[\frac{1}{2}(A - \bar{c}) - q + \frac{1}{2}\sqrt{g}\,z]$, which yields the following differential equation for the control variable $\dot{z} = (r + \mu)z - \frac{1}{2}\mu\sqrt{g}\,q$. The solution follows directly from the corresponding dynamic system by the same procedure as for the problem in accommodation.

Proof of Proposition 4 Similarly as in the proof of Proposition 3, we find that the derivative of social welfare with respect to T is $\mathcal{H}^*(T) - re^{-rT}(I_{CM} - CS_A + CS_{CM}) = [h(T) - rI_{CM} + r(CS_A - CS_{CM})]e^{-rT}$. Moreover, a straightforward computation gives

$$\lim_{T\to\infty} h(T) - rI_{CM} + r(CS_A - CS_{CM}) = (A - \bar{c})^2 \Big[\Big(1 - \frac{3\rho - 2g}{\rho - g}\Phi\Big)^2 \psi^2(g) - \frac{1}{2}\Phi\Big(1 - \frac{9}{4}\Phi\Big)\Big].$$

The condition stated in Proposition 4 now follows directly from this equality.

Furthermore, since $h(T)$ is decreasing and $CS_A > CS_{CM}$, the leader's first-order condition has a lower solution than the social planner's first-order condition.

Solution to the social planner's problem in unconstrained monopoly As in Problem (M), we obtain the Hamiltonian $(\frac{3}{2}q^2 - z^2 - F)e^{-rt} + \eta\mu[\frac{1}{2}(A-\bar{c}) - q + \frac{1}{2}\sqrt{g}\,z]$ and thus the following differential equation describing the dynamics of the control variable: $\dot{z} = (r+\mu)z - \frac{3}{4}\mu\sqrt{g}\,q$. The solution is again obtained directly from the corresponding dynamic system. In particular, the steady-state of the system is

$$z^*_{MS} = \frac{3\sqrt{g}}{8\rho - 3g}(A-\bar{c}), \qquad q^*_{MS} = \frac{4\rho}{8\rho - 3g}(A-\bar{c}).$$

Note that $z^*_M < z^*_{MS}$. Thus, in the steady-state, the leader underinvests, and also its output is lower than the social optimum.

The sustainability condition follows directly from the comparison of the steady-state value of the leader's costs $c^*_{MS} = \bar{c} - \frac{3g}{8\rho-3g}(A-\bar{c})$ with the critical value $\hat{c}$.[23]

To conclude, let us comment on the comparison of predation times. The social planner's optimal predation time maximizes the expression $I_P(T) + e^{-rT}I_{MS} + (1-e^{-rT})CS_A + e^{-rT}CS_{MS}$, where $I_{MS} = \int_0^\infty [q^2_{MS} - z^2_{MS} - F]e^{-rt}\,dt$ and $CS_{MS} = \frac{1}{2}\int_0^\infty q^2_{MS}e^{-rt}\,dt$ are the leader's profit and consumer surplus under the socially optimal investment, respectively. The derivative of social welfare is $[h(T) - r(I_{MS} - CS_A + CS_{MS})]e^{-rT}$. Now, it can be easily shown that $I_{MS} - CS_A + CS_{MS} < I_M$, and also $I_{MS} - CS_A + CS_{MS} < I_{CM}$ for sufficiently large g. For decreasing $h(T)$, our result implies that the social planner chooses a shorter predation time than the leader.[24]

Appendix B: Supplementary material

Supplementary material associated with this article can be found in the on line version at 10.1016/j.jedc.2010.03.011.

[23]Once more, an economic interpretation requires $c^*_{MS} > 0$, or equivalently $g < \frac{8}{3}\rho\,\bar{c}/A$. See footnotes 7 and 17 for more details.

[24]Note however that $h(T)$ may not necessarily be decreasing outside the region where $\Phi < \phi_A(g)$ when T is large. Thus, we have additionally verified the comparison of predation times in unconstrained monopoly numerically (using a grid of values of parameters g and Φ in the range when unconstrained monopoly is feasible, and computing the optimal predation times for the values of (g, Φ) from that grid).

References:

Acemoglu, D., Aghion, P. and Zilibotti, F., 2006. 'Distance to frontier, selection and economic growth', *Journal of the European Economic Association*, 4, pp. 37-74.

Aghion, P. and R. Griffith, 2004.*Competition and Growth*, Cambridge, MA: The MIT Press.

Bagwell, K., & Staiger, R. W., 1994 The sensitivity of strategic and corrective R&D policy in oligopolistic industries, *Journal of International Economics*, 36, pp. 133-150.

Bayoumi, T., Coe, D.T., Helpman, E., 1996. R&D spillovers and global growth. *CEPR Discussion Paper*, no. 1467.

Bester, H., & Petrakis, E., 1993. The incentives for cost reduction in a differentiated industry, *International Journal of Industrial Organization*, 11, pp. 519-534.

Bhagwatti, J.N., 1989. Is free trade passé after all? *Weltwirschaftliches Archive 1*, 17-44.

Bhattacharjea, A., 1995. Strategic tariffs and endogenous market structures: trade and industrial polices under imperfect competition. *Journal of Development Economics* 47, 287-312.

Bhattacharjea, A., 2002. Infant industry protection, revisited: entry-deterrence and entry promotion when a foreign monopolist has unknown costs, *International Economic Journal*, 16(3), pp. 115-133.

Bilbiie, F., F. Ghironi, and J. Melitz 2007. Endogenous Entry, Product Variety, and Business Cycles,*NBER Working Paper 13646.*
Available at: www.nber.org/papers/w13646.

Blundell, R., R. Griffin, and J. van Reenen 1999. Market Share, Market Value and Innovation in a Panel of British Manufacturing Firms,*Review of Economic Studies*, *66* (3), 529-554.

Bouet, A., 2001. Research and development, voluntary export restriction and tariffs, *European Economic Review*, 45, pp. 323-336.

Boone, J., 2002. Be nice, unless it pays to fight: A new theory of price determination with implications for competition policy. *WZB Discussion Paper* FS IV 02-18.

Boone, J., 2004. Balance of power. *CEPR Discussion Paper* 4733.

Braga, C.P., 1990. The developing country case for and against intellectual property protection. In: Siebeck, W.E. (Ed)., Strengthening Protection of Intellectual Property in Developing Countries: A Survey of the Literature. *World Bank Discussion Papers*, no. 112.

Braga, H.C., Willmore, L.N., 1991. Technological imports and technological effort: an analysis of their determinants ants in Brazilian firms. *The Journal of Industrial Economics*, pp. 421-433.

Brander, J. A., & Spencer, B. J., 1985. Export subsidies and market share rivalry, *Journal of International Economics*, 18, pp. 83-100.

Brander, J., 1995. Strategic trade policy. In: Grosmann, G.M., Rogoff, K. (Eds)., *The Handbook of International Economics*, Vol. 3. North-Holland.

Brander, J., Krugman, P., 1983. A 'reciprocal dumping' model of international trade. *Journal of International Economics* 15, 313-323.

Brander, J., Spencer, B., 1984. Tariff protection and imperfect competition. In: Kierzkowski, H. (Ed)., Monopolistic Competition and International Trade. *Clarendon Press, Oxford*, pp. 194-206.

Caputo, M., 1990. How to Do Comparative Dynamics on the Back of an Envelope in Optimal Control Theory,*Journal of Economic Dynamics and Control*, *14* (3), 655-638.

Carlin, W., M.E. Schaffer, and P. Seabright 2004. A Minimum of Rivalry: Evidence from Transition Economies on the Importance of Competition on Innovation and Growth,*CEPR Discussion Paper, No. 4343*.

Carmichael, C. 1987. 'The control of export credit subsidies and its welfare consequences', *Journal of International Economics*, 23, pp. 1-9.

Cheng, L.K., 1988. Assisting domestic industries under international oligopoly: the relevance of the nature of competition to optimal policies. *American Economic Review* 78, 764-768.

Chin, J.C., Grossman, G.M., 1990. Intellectual property rights and NorthSouth trade. In: Jones, R.W., Krueger, A.O. (Eds)., The Political Economy of International Trade: Essays in Honor of Robert E. *Baldwin. Blackwell, Cambridge, MA.*

Chin, J.C., Grossman, G.M., 1990. Intellectual property rights and North-South trade. In: Jones, R.W., Krueger, A.O. (Eds.), The Political Economy of International Trade: Essays in Honor of Robert E. Baldwin. *Blackwell*, (Basil), Cambridge, MA.

Cho, In-Koo & Kreps, David M. 1987. Signaling games and stable equilibria, *The Quarterly Journal of Economics*, 102 (2), pp. 179-221.

Creane, A. and H. Konishi 2009. The Unilateral Incentives for Technology Transfers: Predation (and Deterrence) by Proxy,*International Journal of Industrial Organization*, *27* (3), 379-389.

Czarnitzki, D., Etro, F., Kraft, K., 2008. The effect of entry on R&D investment of leaders: Theory and empirical evidence. *mimeo, INTERTIC.*

Das, S. P. 2002. Foreign direct investment and the relative wage in a developing economy, *Journal of Development Economics*, 67, pp. 55-77.

Dasgupta, P., 1986. The theory of technological competition. In: Stiglitz, J.E., Mathewson, G.F. (Eds)., New Developments in the Analysis of Market Structure. *MIT Press, Cambridge, MA*, pp. 519-547.

Davidson, C. and A. Mukherjee 2008. Horizontal mergers with free entry, *International Journal of Industrial Organization*, *25* (1), 157-172.

Deardorff, A.V., 1992. Welfare effects of global patent protection. *Economica* 59, 35-59.

De Bondt, R., Slaets, P., Cassiman, B., 1992. The degree of spillovers and the number of rivals for maximum effective R&D. *International Journal of Industrial Organization* 10, 35-54.

Deneckere, R. J., Kovenock, D., Lee, R., 1992. A model of price leadership based on consumer loyalty. *Journal of Industrial Economics* 40 (2), 147-56.

Diwan, I., Rodrik, D., 1991. Patents, appropriate technology, and NorthSouth trade. Journal of International Economics 30, 27-47.

Dollar, D., 1986. Technological innovation, capital mobility, and the product cycle in North-South trade. *American Economic Review* 76, 177-190.

D'Aspremont, C., Jacquemin, A., 1988. Cooperative and noncooperative R&D in duopoly with spillovers. *American Economic Review* 78, 113-137.

Dixit, A., 1979. A model of duopoly suggesting a theory of entry barriers. *Bell Journal of Economics* 10 (1), 20-32.

Dixit, A.K., 1984. International trade policy for oligopolistic industries. *Economic Journal* 94, *Supplement* 1-16.

Dixit, A.K., 1988. Anti-dumping and countervailing duties under oligopoly. European Economic Review 32, 55-68.

Eaton, J. and Grossman, G., 1986. Optimal trade and industrial policy under oligopoly, *Quarterly Journal of Economics*, 101, pp. 383-406.

Economic Focus, May 22 2004. Slackers or pace-setters? Monopolies may have more incentives to innovate than economists have thought. *The Economist*.

Economist, The 2004. Slackers or Pace-Setters: Monopolies May Have More Incentives to Innovate than Economists Have Thought,*The Economist*, May 20, 2004.

Engwerda, J.C. 2005. *LQ Dynamic Optimization and Differential Games*, Chichester, UK: Wiley & Sons.

Erkal, N. and D. Piccinin 2007. Welfare-Reducing Mergers in Differentiated Oligopolies with Free Entry, Mimeo, Intertic.
Available at: www.intertic.org/Theory%20Papers/Erkal-Piccinin.pdf

Etro, F., 2004. Innovation by leaders. *Economic Journal* 114 (495), 281-303.

Etro, F., 2007. Competition, Innovation and Antitrust: A Theory of Market Leaders and Its Policy Implications. *Springer Verlag*, Berlin & New York.

Etro, F. 2006. Aggressive Leaders, *The Rand Journal of Economics*, *37*, 1-10.

Etro, F., 2008. Stackelberg competition with endogenous entry. *Economic Journal* 118: 1670-1697.

Etro, F. and A. Colciago 2010. Endogenous Market Structure and the Business Cycle, *The Economic Journal*, 120: 1201-1233.

Evanson, R.E., 1990. Survey of empirical studies. In: Siebeck, W.E. (Ed)., Strengthening Protection of Intellectual Property in Developing Countries: A Survey of the Literature. *World Bank Discussion Papers*, No. 112.

Ferrantino, J.M., 1993. The effect of intellectual property rights on international trade and investment. *Weltwirschftilches Archive* 129, 300-331.

Fersthman, C. and M. Kamien 1987. Dynamic Duopolistic Competition with Sticky Prices, *Econometrica*, *55* (5), 1151-1164.

Fudenberg, D. and Tirole, J. 1984. The fat-cat effect, the puppy-dog ploy, and the lean and hungry look, *American Economic Review: Papers and Proceedings*, 74, pp. 361-366.

Ghironi, F. and M. Melitz 2005. International Trade and Macroeconomic Dynamics with Heterogeneous Firms, *Quarterly Journal of Economics*, *120* (3), 865-915.

Ghironi, F. and M. Melitz 2007. Trade Flow Dynamics with Heterogeneous Firms, *American Economic Review: Papers and Proceedings*, *97* (2), 356-361.

Gilbert, R., Katz, M., 2001. An economist's guide to U.S. vs Microsoft. *The Journal of Economic Perspectives* 15 (2), 25-44.

Goldberg, P. K. 1995. 'Strategic export promotion in the absence of government precommitment', *International Economic Review*, 36, pp. 407-426.

Gould, M.D., Gruben, W.C., 1996. The role of intellectual property rights in economic growth. *Journal of Development Economics* 48, 323-350.

Grossman, G.M., Helpman, E., 1995. Technology and trade. In: Grosmann, G.M., Rogoff, K. (Eds)., *The Handbook of International Economics, Vol.* 3. North-Holland.

Grossman, G.M., Maggi, G., 1998. Free trade versus strategic trade: a peek into Pandora's box. *CEPR Discussion Paper*, no. 1784.

Hamilton, J. H., Slutsky, S. M., 1990. Endogenous timing in duopoly games: Stackelberg or cournot equilibria. *Games and Economic Behavior* 2 (1), 29-46.

Helpman, E. and Krugman, P. R. 1989. Trade Policy and Market Structure, *Cambridge, MA and London: MIT Press*, pp. xii, 191.

Helpman, E., 1993. Innovation, imitation, and intellectual property rights. *Econometrica* 61 (6), 1247-1280.

Helpman, E., Grossman, M., 1995. Technology and trade. In: *The Handbook of International Economics*, vol. 3, North-Holland, Amsterdam.

Hinloopen, J., 1997. Subsidizing R&D-cooperatives. Discussion paper, no. 15. *Centre for Industrial Economics, University of Copenhagen.*

Hwang, Hae-Shin & Schulman, Craig T. 1992. Strategic non-intervention and the choice of trade policy for international oligopoly, *Journal of International Economics*, 34, pp. 73-93.

Ionaşcu, Delia & Žigić, Krešimir., 2001. Free trade versus strategic trade as a choice between two 'second-best' polices: a symmetric versus asymmetric information analysis, *CEPR Discussion Paper* 2928.

Jensen, R., Thursby, M., 1986. A strategic approach to the product life cycle. *Journal of International Economics* 21, 269-284.

Kamien, I.M., Muller, E., Zang, 1992. Research joint venture and R&D cartels. *American Economic Review* 82, 1293-1306.

Karp, L. S. and Perloff, J. M. 1995. 'The failure of strategic industrial policies due to manipulation by firms', *International Review of Economics and Finance*, 4, pp. 1-16.

Katz, M.I., 1986. An analysis of cooperative research and development. *Rand Journal of Economics* 4, 538-556.

Klein, B., 2001. The Microsoft case: What can a dominant firm do to defend its market position? *Journal of Economic Perspectives* 15 (2), 45-62.

Kobayashi, S. 2001. A Model of R and D in Oligopoly with Spillovers, Mimeo, Nihon University, Tokyo, Japan.

Konings, J. and Vandenbussche, H. 2007. Antidumping protection and productivity of domestic firms: A firm level analysis, *LICOS Discussion Paper No. 196, University of Leuven*, http://www.econ.kuleuven.ac.be/licos/DP/DP2007/DP196.pdf.

Krugman, P., 1979. A model of innovation, technology transfer, and the world distribution of income. *Journal of Political Economy* 87, 253-266.

Krugman, P.R., 1984. Import protection as export promotion. In: Kierzkowski, H. (Ed)., Monopolistic Competition and International Trade. *Clarendon Press, Oxford,* 1984, pp. 194-206.

Krugman, P.R., 1987. Is free trade passé? *Journal of Economic Perspectives* 2, 131-141.

Krugman, P. 1989. New trade theory and the less developed countries, in Calvo, C., Findlay, R., Kowi, P. and Braga de Macedo, J. (eds), *Debt, Stabilization and Development: Essays in Memory of Carlos Diaz-Alejandro, Oxford and Cambridge: Blackwell*, pp. 347-365.

Leahy, D., Neary, J.P., 1997. Public policy towards R&D in oligopolistic industries. *American Economic Review* 87, 642-662.

Leahy, D. and Neary, J. P. 1999. Learning by doing, precommitment and infant industry promotion, *Review of Economic Studies*, 66, pp. 447-474.

Lee, T. and L. Wilde 1980. Market Structure and Innovation: A Reformulation, *Quarterly Journal of Economics*, *94* (2), 429-436.

Levin, R.C., Klevorick, A.K., Nelson, R.R., Winter, S.G., 1987. Appropriating the returns from industrial research and development. *Brookings Pares on Economic Activity 3*, 783-831.

Levy, S., Nolan, S., 1992. Trade and foreign investment polices under imperfect competition. J*ournal of Development Economics 37*, 31-62.

Lin, Ping & Saggi, Kamal 2002. Product differentiation, process R&D, and the nature of market competition, *European Economic Review*, 46, pp. 201-211.

Maggi, Giovanni 1996. Strategic trade policies with endogenous mode of competition, *The American Economic Review*, 86(1), pp. 237-258.

Maggi, Giovanni 1999. Strategic trade policy under incomplete information, *International Economic Review*, 40(3), pp. 571-594.

Mankiw, G.N. and M.D. Whiston 1986. Free Entry and Social Inefficiency,*The Rand Journal of Economics*, *17* (1), 48-58.

Mansfield, E., Schwartz, M., Wagner, S., 1981. Imitation costs and patents: an empirical study. *Economic Journal 91*, 907-918.

Mansfield, E., 1985. How rapidly does new industrial technology leak out? *Journal of Industrial Economics (December)*, 217-223.

Mansfield, E., 1989. Protection of intellectual property rights in developing countries. *The World Bank*, Washington, DC.

Mansfield, E., 1994. Intellectual property protection, foreign direct investment, and technology transfer. IFC Discussion Paper, no. 19. *The World Bank, Washington*, DC.

Martin, S., 1993. Advanced Industrial Economics. *Blackwell, Oxford, UK.*

Matsuyama, K. 1990. Perfect equilibrium in a trade liberalization game, *American Economic Review*, 80, pp. 480-492.

Melitz, M. and M. Ottaviano 2008. Market Size, Trade, and Productivity,*Review of Economic Studies*, *75* (1), 295-316.

Miravete, J. E. 2003. Time-consistent protection with learning by doing, *European Economic Review*, 47, pp. 761-790.

Miyagiwa, K. and Ohno, Y. 1995. Closing the technological gap under protection, *American Economic Review*, 85, pp. 755-770.

Miyagiwa, K. and Ohno, Y. 1999. Credibility of protection and incentives to innovate, *International Economic Review*, 40, pp. 143-163.

Motta, M. 1992. Multinational firms and the tariff-jumping argument: A game theoretic analysis with some unconventional conclusions, *European Economic Review*, 36, pp. 1557-1571.

Motta, M., 2004. Competition Policy: Theory and Practice. *Cambridge University Press*, Cambridge.

Neary, J.P., 1994. Cost asymmetries in international subsidy games: should government help winners or losers. *Journal of International Economic 37*, 197-218.

Neary, J. P. and Leahy, D. 2000. Strategic trade and industrial policy towards dynamic oligopolies, *Economic Journal*, 110, pp. 484-508.

Neven, D., Siotis, G., 1996. Technology sourcing and FDI in the EC: an empirical evaluation. *International Journal of Industrial Organization 14 (5)*, 543-560.

Qiu, L. D. 1994. Optimal strategic trade policy under asymmetric information, *Journal of International Economics*, 36(34), pp. 333-354.

Qiu, L. D. and Lai, E. 2004.Protection of trade for innovation: The roles of Northern and Southern tariffs, *Japan and the World Economy*, 16, pp. 449-470.

Rapp, R., Rozek, R., 1990. Benefits and costs of intellectual property protection in developing countries. *Journal of World Trade 24 (2)*, 75-102.

Reinganum, J. 1982. A Dynamic Game of R&D: Patent Protection and Competitive Behavior,*Econometrica*, *50* (3), 671-688.

Reitzes, J. D. 1991. The impact of quotas and tariffs on strategic R&D behavior, *International Economic Review*, 32, pp. 985-1007.

Rodríguez, F. and Rodrik, D. 2000. Trade policy and economic growth: A skeptic's guide to the cross-national evidence, *in Bernanke, B. and Rogoff, K. S. (eds), Macroeconomics Annual 2000, Cambridge, MA: NBER.*

Rodrik, D. 2001. The global governance of trade: As if development really mattered, *New York: UNDP*,

Ronnen, U. 1991. Minimum quality standards, fixed costs, and competition, *RAND Journal of Economics*, 22, pp. 490-504.

Rotemberg, J. J., Saloner, G., 1990. Collusive price leadership. *Journal of Industrial Economics* 39 (1), 93-111.

Seierstad, A. and K. Sydsaeter 1987. *Optimal Control Theory with Economic Applications*, Amsterdam: North-Holland.

Shapiro, C. 1989. Theories of Oligopoly Behaviour, in R. Schmalensee and R. Willig (eds.), *Handbook of Industrial Organization*, pp.329-410, Amsterdam: North-Holland.

Singh, N. and Vives, X. 1984. Price and quantity competition in a differentiated duopoly, *Rand Journal of Economics*, 15, pp. 546-554.

Spence, M., 1976. Product differentiation and welfare. *American Economic Review* 66 (2), 407-14.

Spence, M., 1986. Cost reduction, competition and industry performance. In: Stiglitz, J.E., Mathewson, G.F. (Eds)., New Developments in the Analysis of Market Structure. *MIT Press, Cambridge, MA*, pp. 475-518.

Spencer, B.J., Brander, J.A., 1983. International R&D rivalry and industrial strategy. R*eview of Economic Studies 50*, 707-722.

Spencer, B.J., 1986. What should trade policy target? In: Krugman, P.R. (Ed)., Strategic Trade Policy and the New International Economics. *MIT Press, Cambridge, MA.*

Stenbacka, R. and M.M. Tombak 1997. Commitment and Efficiency in Research Joint Ventures, in J. Poyago-Theotoki (ed.), *Competition, Cooperation, Research and Development: The Economics of Research Joint Ventures*, pp.138-158, Macmillan Publ. Co.

Sutton, J., 1991. Sunk Cost and Market Structure. *MIT Press*, Massachusetts.

Sutton, J. 2007. Market Share Dynamics and the 'Persistence of Leadership' Debate,*American Economic Review*, *97* (1), 222-241.

Syropoulos, C., 1994. Endogenous timing in games of commercial policy. *Canadian Journal of Economics* 27 (4), 847-64.

Syropoulos, C., 1996. Nontariff trade controls and leader-follower relations in international competition. *Economica* 63 (252), 633-48.

Suzumura, N., 1992. Cooperative and noncooperative R&D in an oligopoly with spillovers. *American Economic Review 82*, 1307-1320.

Tirole, J. 1991. The Theory of Industrial Organization, *Cambridge, MA: MIT Press.*

Taylor, M.S., 1993. TRIPS, trade and technology transfer. *Canadian Journal of Economics* 26 (3), 625-637.

United States International Trade Commission, 1988. Foreign protection of intellectual property rights and the effect on US Industry and Trade, *USITC Publication 2065.*

van Damme, E., Hurkens, S., 1999. Endogenous stackelberg leadership. *Games and Economic Behavior* 28 (1), 105-129.

Venables, A.J., 1994. Trade policy under imperfect competition: a numerical assessment. In: Krugman, P.R., Smith, A. (Eds)., Empirical Studies of Strategic Trade Policy. *University of Chicago Press, Chicago.*

Vickers, J., 2009. Competition policy and property rights. *Economics series working papers*, University of Oxford, Department of Economics.

Vishwasrao, S., 1994. Intellectual property rights and the mode of technology transfer. *Journal of Development Economics* 44, 381-402.

Whinston, M. D., 2001. Exclusivity and tying in u.s. v. microsoft: What we know, and don't know. *Journal of Economic Perspectives* 15 (2), 63-80.

Wright, D. J. 1995. 'Incentives, protection, and time consistency', *Canadian Journal of Economics*, 28, pp. 929-938.

Zhou, D., Spencer, B. J. and Vertinsky, I. (2002). 'Strategic trade policy with endogenous choice of quality and asymmetric costs', *Journal of International Economics*, 56, pp. 205-232.

Žigić, K., 1996a. Intellectual property rights and the NorthSouth trade: the role of spillovers. *CERGE-EI, Working Paper, no. 92*.

Žigić, K., 1996b. Optimal tariff, spillovers and the NorthSouth trade. *CERGE-EI, Working Paper, no. 93.*

Žigić, K., 1998a. Intellectual property rights violations and spillovers in NorthSouth trade. *European Economic Review 42*, 1779-1799.

Žigić, K., 1998b. Strategic trade policy, spillovers, and uncertain mode of competition: Cournot versus Bertrand. *CERGE-EI, Working Paper, no. 123.*

Žigić, K. 2000. 'Strategic trade policy, intellectual property rights protection, and North South trade', *Journal of Development Economics*, 61, pp. 27-60.

Žigić, K. 2003. Does 'non-committed' government always generate lower social welfare than its 'committed' counterpart?' *CEPR Discussion Paper No. 3946, London: CEPR.* http://www.cepr.org/pubs/dps/DP3946.asp.

Strategic Interactions in Markets with Innovative Activity:
The Cases of Strategic Trade Policy and Market Leadership

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