Research Reports
Kansantaloustieteen laitoksen tutkimuksia, Nro 101 : 2004
Dissertationes Oeconomicae

Ville Mälkönen

Essays on Environmental Policy and Strategic Behavior in International Trade

ISBN 952-10-1539-X (nid.)
ISBN 952-10-1540-3 (pdf)

Acknowledgements

I am very grateful to my supervisors Professors Erkki Koskela and Markku Ollikainen who provided me with motivation and encouragement. Most of this thesis has been written in the Finnish Doctoral Programme in Economics at the Department of economics in the University of Helsinki. I wish to thank the FDPE for giving me this opportunity and the Department for its hospitality and excellent working conditions.

I would like to express my gratitude to the pre-examiners of my thesis, Dr. Matti Liski and Dr. Mikko Leppämäki, for their thoughtful advice and high standards of expertise which helped to improve the thesis during the final revisions. I had the privilege to enjoy the company of a very special group of colleagues with whom I shared the basement offices in the Faculty of Social Sciences in the University of Helsinki. Without their comments and the daily discussions during coffee breaks, finishing this thesis would have been a lot harder.

Part of the research was carried out in the Department of Agricultural and Resource Economics at UC Berkeley. I would like to thank the people at the ARE department for providing a stimulating environment in which to conduct research. I made the final revisions of the thesis when I was visiting the research department of the Bank of Finland. I thank the head of the department Dr. Juha Tarkka and research coordinator Dr. Tuomas Takalo for this unique opportunity to learn and widen the scope of my research.

Financial support by the Academy of Finland, the Finnish Cultural Foundation, and Yrjö Jahnsson Foundation is gratefully acknowledged.

Finally, I would like to thank those closest to me. I thank my friends who made me often turn off the computer to go out and play, no matter what the deadline was. I am forever grateful to my parents, Kristiina and Heikki Mälkönen, and Marita Laukkanen for their understanding, patience and encouragement when it was most required.

Helsinki, November 2004

Ville Mälkönen

Contents

Introduction

1 Background

In economic terms environment can be defined as a public good in its role as a provider of amenities and a natural living space for the mankind. As a provider of inputs of raw-materials and a receptor of wastes, environment is in most cases private good, although it has been used in the past as a common property resource with a free access. National environmental policy determines the quality of the public good and integrates the concept of environmental scarcity into economic decisions, defining the institutional framework for decentralized economic decisions that essentially determine the allocation of environmental resources. Since international trade constitutes a link between countries and their respective institutional frameworks, the liberalization of international trade has raised concerns that governments facing competitive pressures might be reluctant to raise the environmental standards they apply to domestic producers, and perhaps even lower these standards to enhance their competitiveness.

Tracing back to Pigou (1932), the consensus in the economic literature has been that in a closed economy with perfect competition, a benevolent central planner maximizes domestic welfare by designing the environmental standards to satisfy the usual first-best rule in environmental economics: the marginal costs of regulation equals the marginal environmental damage generated by the environmentally harmful activity. The concern about the link between trade and environment has induced a number of economists to focus on the circumstances under which the optimal policy in a trading economy should impose environmental standards laxer than this benchmark.

The first theoretical contributions to the trade and environment literature used perfectly competitive models of classical trade theory where the role of the environment is an additional factor of production or production related externality. The benchmark result in these models is that in a small open economy optimal environmental policy coincides with Pigovian first-best level. This can be understood intuitively in the following way: perfect competition in the export market does not constitute a market distortion, because the domestic producers' take prices as given in the world market. Since the market is undistorted, apart from the production related environmental externality, a welfare maximizing market environment can be implemented through the first-best environmental policy.

If one considers the international markets with multiple distortions, it becomes less clear that optimal policy entails Pigovian environmental standards. The reason is that the policy decision is made in a second-best situation as the policy maker addresses several distortions with just one policy instrument. Strategic environmental policy approach is perceived as a favorable framework in formalizing the hypothesis that policy makers might apply inefficiently low environmental standards to implicitly subsidize domestic firms with market power in the export markets. The key idea is that when a government has an incentive to establish export taxes or subsidies to enhance domestic competitiveness, but the access to these policy instruments is limited, the trade policy incentives carry over to the design of environmental standards. As a result, the policy outcome might exhibit inefficiently low environmental standards giving the producers an unfair competitive advantage and aggravating the environmental degradation, or even worse, the countries may end in a 'race to the bottom', where not only trade gains are lost, but furthermore, the environment is depleted.

Forest is a good example of a resource with several distinct economic functions and values. It has a private value as an investment to forest owners, and it provides public goods to the society in the form of amenities and biological diversity. Forest conservation requirements are designed to correct for the market failure that arises, when the provision of the public good is neglected in forest owners' decisions concerning the capitalization of the investment. In most wood producing countries, forest industries are highly export oriented and the international market for forest products is dominated by relatively few wood producing countries. Therefore, the predictions of the strategic trade theory are not implausible in the case of national forest conservation programs.

The first two essays of this dissertation examine the international markets for wood products and the domestic markets for timber inputs, and investigate the extent to which features specific to these markets influence the design of optimal forest conservation policies. By comparing the optimal policy outcomes with the first-best benchmark and the predictions derived in models of strategic environmental policy, the analyses derive the potential sources of strategic distortions in forest conservation policy. In particular, Essay I addresses the implications of competitive pressures in the design of forest conservation policies, when the consumers exhibit positive willingness to pay for products originating from sustainable sources. Essay II examines the implications of timber importation on the forest conservation policy in an economy where wood-processing industry buys timber from domestic forest owners and produces the final goods for the export-markets.

The third essay investigates the implications of national environmental policies on imperfectly competitive international markets with information asymmetries. As opposed to the first two essays, which examined mandatory environmental policy instruments, Essay III considers the effectiveness of voluntary policy instruments, namely, environmental labels aimed to induce the producers to improve the environmental quality of the products. The analysis formalizes the idea that credible environmental labeling is an important factor in correcting a market failure that emerges when the consumers are willing to pay for products' environmental quality, but cannot observe the actual environmental condition surrounding the production process. This mechanism is then employed to investigate the welfare consequences of the emergence multiple national environmental labeling schemes in the international markets where consumers cannot differentiate between different labels and labeling standards.

The remainder of this introductory chapter is organized as follows. Next section reviews the literature relevant to this thesis. The third section briefly describes the essays and summarizes the main results.

2 An Overview of the Literature

Essays I and II employ strategic trade framework to examine optimal forest conservation policies. The first part of this section therefore reviews economic literature on strategic trade and environmental policy with an attention on the relevant issues in essays I and II. Essay III is based on vertical product-differentiation framework with asymmetric information. Hence, the second part surveys the literature on vertical product-differentiation, asymmetric information, environment and trade.

2.1 Strategic Trade and Environmental Policy

Strategic-trade framework has been widely used to formalize the reasons why governments might impose inefficiently weak environmental standards.[1] The literature traces back to Spencer and Brander (1983); and Brander and Spencer (1985). These studies analyze optimal trade and industrial policies, when the world market is imperfectly competitive. Brander and Spencer (1985) developed a basic model involving two exporting countries and one importing country. In each exporting country there is a single firm that produces for a third country export-market. The game is in two stages. At the first stage, the government imposes an export tax, or - subsidy, and then firms compete on the basis of Cournot competition.

Brander and Spencer showed that if the domestic country chooses the policy unilaterally, an export subsidy raises domestic welfare. The reason is that export subsidies for domestic firm induce the rival firm to contract output. Hence, an appropriate subsidy allows domestic firm to credibly establish a commitment to a higher output level, replacing some of the foreign output in the export market. Among others, Barrett (1994) and Conrad (1993) employed strategic-trade framework to illustrate how these trade policy incentives carry over to the design of environmental policies. By a similar line of reasoning these studies showed that policy makers are induced to impose weaker standards than the first-best so as to improve domestic competitiveness.

The strategic trade framework has attracted much attention among trade and en-

[1] Term 'inefficiently weak regulation' refers to policy decision that entails lower standards than indicated by the usual first-best rule in environmental economics: marginal social cost of regulation is equal to marginal social benefit induced by higher environmental quality.

vironmental economists for it provides a convenient framework for analyzing the circumstances under which policy makers have an incentive to apply inefficiently low environmental standards for the reasons of competitiveness. A number of analysts have elaborated the basic-model. In particular, firms' potential to use investments to alleviate the cost-effects associated with environmental regulation has led analysts to examine the so-called Porter-hypothesis (Porter 1991). Porter-hypothesis argues that tight environmental regulation may spur innovation and thereby improve firms' competitiveness in the long-run. However, this argument has found little support in rigorous economic studies. For instance, Simpson and Bradford (1996) examined the Porter-hypothesis in strategic trade framework, and show that the argument holds only under specific assumptions about firms' cost function.

Essay I examines whether these basic results apply to forest conservation. The model is similar to Simpson and Bradford (1996) and Ulph (1996a) in that the firms can reduce their production costs through investments. The novelty is that cost associated with environmental regulation is determined by a specific vertical-market structure as the price of timber inputs is determined endogenously in national timber markets. Furthermore, the conservation policy influences the products' positioning in quality space, because the consumers in the importing country exhibit positive willingness to pay for final-goods originating from sustainable sources.[2]

Several authors have addressed the theoretical and empirical weaknesses of the strategic trade theory. Eaton and Grossman (1986) established that the result derived by Brander and Spencer (1985) is reversed, if one presumed Bertrand conjectures instead of Cournot. More specifically, under price competition the optimal policy calls for an export tax rather than subsidies. Tax makes credible the domestic firm's promise not to cut prices, and thereby relaxes the price competition and increases national income. In the case of models of strategic environmental policy, the findings are similar. For instance, Barrett (1994) showed that under Bertrand competition, optimal policy entails higher environmental standard than the first-best. In a model with cost-reducing investments Ulph (1996b) showed that policy result that obtains in Ulph (1996a) is

[2] A more detailed discussion about the literature on vertical product differentiation and environmental policy is in the next subsection.

reversed under Bertrand-assumption.

Maggi (1996) re-examined the sensitivity of the results to assumptions about the mode of competition, and considered a strategic trade policy model under endogenous mode of competition. The model involves a two-stage game, in which firms first choose output capacities and then compete on the basis of capacity-constrained price competition where the firms have the option to produce in excess of the predetermined output capacity. In line with Kreps and Scheinkman (1983), Maggi showed that the mode of competition approaches to Cournot benchmark, when the cost of producing in excess of the predetermined capacity level is high. However, when this cost is lower, the capacity constraint becomes more flexible. Consequently, the market equilibrium coincides with that of pure Bertrand competition. The policy results provide a qualification to the results in strategic trade theory by showing that a capacity subsidy is weakly welfare-improving, regardless of the particularities of the market studied.

Essay II extends the literature on strategic environmental policy and forest conservation by considering the optimal conservation policy under endogenous mode of competition. The model follows Maggi (1996) with the exception that the cost of capacity is endogenously determined in the domestic timber market that is modeled as a bargaining process between the forest owners and the exporting firm. This framework is then employed to analyze the impact of timber importation on the national timber markets and the optimal design of forest conservation policies.

There are several empirical studies estimating the mark-ups of price over marginal cost in international market. For instance, in case of the international market for forest products, Goldberg and Knetter (1999), and Yerger (1996) studied US exports of linerboard paper and wood pulp, respectively. The studies provide evidence that export markets in several industries are imperfectly competitive. However, the empirical evidence on the policy makers' rent-shifting incentives is clearly lagging behind the theoretical developments. An exception is Hamilton and Stiegert (2002). Hamilton and Stiegert employed real data and constructed a theory-based empirical test to examine rent-shifting hypothesis in the case of a payment system associated with Canadian durum wheat exports. The results did not reject the rent-shifting hypothesis, hence, the authors argued that the established payment system was consistent with theoretical findings.

2.2 Environmental Certification, Asymmetric Information and Trade

When the victims of polluting firms can signal their environmental preferences to firms through reduced demand for products, they can influence firms' profitability and create incentives for the firms to improve the environmental quality of the products. This is the stylized fact driving the results in vertical product-differentiation models applied to production related environmental problems. For instance, Arora and Gangopadhyay (1995) and Cremer and Thisse (1999) have used a vertical product differentiation approach to provide an explanation for voluntary self-regulation. Consumers derive utility from buying from a firm that uses a less pollution-intensive technology generating a price premium for goods with higher environmental quality. Differences in the consumers' valuation for goods' environmental attributes segment the market by consumer types, and price competition between the firms induces a market outcome that entails different environmental qualities.[3]

One of the underlying principles of vertical product-differentiation framework is that perfect information among market participants is critical for the efficient operation of the markets. However, often the sellers are better informed about quality attributes than the consumers, who may have misperceptions of the environmental hazards associated with the use or the production of a certain product. The supply of green products thus depends on the producers' ability to signal improvements in their environmental performance to the consumers. Akerlof (1970) formalized the market failure generated by the information problem associated with differences between product qualities. Akerlof showed that the markets are ineffective in providing quality and only goods with the lowest quality survive the competition in the market. The reason is an adverse selection problem: if the seller cannot signal the quality of the product he is selling, the high quality goods do not get the desired price-premium, hence, only the low-quality goods are offered for sale.

[3] More recent literature involves Bansal and Gangopadhyay (2003).

Several analysts have examined the signaling problem in markets with asymmetric information in a perfectly competitive and monopoly environment.[4] However, the literature on asymmetric information between buyers and sellers in a vertically differentiated industry has deserved less attention. The exceptions are Fluet and Garella (2002); and, Hertzendorf and Overgaard (2001) who used a duopoly model to examine how firms can signal qualities through prices and advertising. The results imply that absent advertising, price-signaling is not a sufficient mechanism to implement a separating equilibrium in terms of product qualities. The reason is that standard equilibrium refinements such as "intuitive criterion", to prune the set of pooling equilibria (Cho and Kreps (1987)), are inapplicable in an oligopoly framework.

One suggested solution to the signaling problem in terms of products environmental characteristics is environmental labeling. Kirchhoff (2000) examined a monopolist's incentives to invest in environmental quality in an asymmetric information framework and showed that if the labeling requirements were randomly monitored by an independent third-party, the monopolist finds it more profitable to invest in quality. Cason and Gangadharan (2002) studied the buyers' perceptions of goods' environmental attributes in a laboratory setting. The results establish that a certificate awarded by a third-party labeling organization, induced a positive mark-up on the goods' price, whereas "cheap-talk" and reputation building were insufficient mechanisms to generate a high enough price premium.

These studies suggest that credible national labeling programs might constitute an efficient environmental policy instrument, especially in the presence of information asymmetries between the producers and the consumers in the international markets.[5] The intuition is that credible information about the condition surrounding the production process will differentiate the products from other products on the market helping the domestic producers to capitalize on the price premium. The idea of government

[4] For instance, Milgrom Roberts (1986) and Schmalensee (1978) examined the quality provision and firms' pricing and advertising behavior under monopoly and perfect competition, respectively.

[5] Gabszewicz et al. (1981) examines the implications of international trade on quality distribution on markets, showing that trade diminishes the number of product varieties offered at the market, but tougher price competition drives the goods with lowest quality out of the market. Motta (1992) extends the analysis by allowing for sunk costs that the producers incur before production stage. Motta (1992) establishes that the welfare implications of free trade depend crucially on the sunk cost.

involvement in eco-labeling schemes under asymmetric information was put forward by Rege (2000). Rege showed that in an asymmetric environment framework, a government has an incentive to establish a penalty system, inducing the domestic producers to produce under the environmental standards they claim to produce. This increases the credibility of the domestic producers and thereby improves their competitiveness in the international markets.[6]

Essay III considers the role of environmental labeling as a mechanism to mitigate the problem of asymmetric information and the effect of labeling requirements on the international trade patterns in products that exhibit production-related environmental externalities. The essay extends the existing literature by introducing imperfect competition, asymmetric information and signaling into a model of international trade with vertically differentiated industries. The analysis formalizes a welfare comparison between two international labeling schemes: harmonization and mutual recognition of labeling standards. Under mutual recognition of national eco-labels consumers cannot observe the differences between the existing labels. This generates an information-rent in the export market inducing more producers to apply for the labeling program. Under harmonization, the premium on the export market will be lost indicating lower participation in the labeling programs. The welfare analysis compares these effects and describes the circumstances when mutual recognition of environmental labels is welfare superior to harmonization.

[6]Moeltner and van Kooten (2003) test empirically the argument that European buyers exhibit greater concern for forest management practices, and hence, firms that serve mostly European markets are more eager to certify their products. The results indicate that consumer preferences in the export market constitute an important factor explaining why firms seek to apply for a label. Furthermore, the results support the argument that producing countries may benefit from export-driven certification through improvement in domestic environmental quality.

3 Contents of the Dissertation

3.1 Essay I: Optimal Forest Conservation: The Role of Green-Image Demand and Investments

Essay I considers three relevant factors in forest industry that might influence the design of the socioeconomically optimal forest conservation policy. First, raising conservation requirements the government applies to domestic forest owners increases timber prices. Higher timber prices, in turn, increase the production costs and thereby diminish the competitiveness of the forest industry. Second, the forest industry can use investments to reduce the cost of using timber in production, indicating that the industry might have an incentive to increase the level of investments to alleviate the negative cost effect in terms of higher timber prices. Finally, if raising conservation requirements increases the consumers' willingness to pay for products originating from sustainable sources, higher requirements can improve the competitiveness of the industry through the green-image effect which differentiates its product from other products on the market. The analysis solves for an optimal conservation level when governments recognize how these effects influence the competitiveness of the domestic industry. The optimal solution is then compared with the first-best outcome to identify the potential distortions generated by the strategic behavior on the behalf of the governments.

The model builds on Simpson and Bradford (1996), Ulph (1996a) and Ulph (1996b), except that the government's intervention affects the products' positioning in quality space. The results demonstrate that raising conservation requirements reduces domestic industry's competitiveness through reductions in investments and higher timber price. However, when the demand effect generated by the products' green-image is high, tighter conservation level improves domestic competitiveness. Optimal conservation level is thus higher than the first-best, because it gives the government an incentive to increase the consumers' willingness to pay for domestic products by raising the conservation requirements.

The results also establish that the equilibrium might not exhibit the usual Prisoners Dilemma outcome in strategic trade models.[7] The reason is that a raise in conservation requirements in both exporting countries increases both production costs and consumers' willingness to pay. The demand effect gives the governments an ex-ante incentive to impose higher conservation requirements. When both governments have the same conjecture, the unintended consequence of the policy game is that the product differentiation effect is weaker than anticipated. It then follows that the cost effects are more likely to dominate the demand effects, indicating an increase in prices and profits of both industries, because the aggregate output supplied to the export market decreases.

3.2 Essay II: Optimal Forest Conservation Under Endogenous Mode of Competition: The Role of Timber Imports

Essay II is an investigation into a forest sector where firms producing processed wood products for export markets can either buy domestic timber from the domestic forest owners or acquire timber inputs from the world markets. Within this framework the study examines the implications of timber importation on the international markets for processed wood products and on the national timber markets. Furthermore, the model will be employed to address the question whether the potential to use imported timber provides new opportunities for forest conservation in wood-producing countries?

The model considers the domestic timber market as a bargaining process where the exporting firm bargains with domestic forest owners over timber prices. The firm then competes on the export market on the basis of capacity-constrained price competition. Following Maggi (1996), the key feature of the game is that the firms can mitigate the price competition on the market for final goods through a precommitment to a certain output level determined by timber inputs acquired from domestic timber market. This capacity level has its full commitment value when the unit cost of timber importation is above a critical level for which the combined production costs become high enough

[7] That is, when both governments engage in strategic design of environmental policies, the equilibrium of the policy game involves inefficiently low environmental standards and negative trade gains. See e.g. Barrett (1994) and Spencer and Barret (1983).

so that the firm will be priced out of the market. In this case, the outcome of the game coincides with the Cournot benchmark. The lower the unit cost of timber imports, the closer the price to the more competitive Bertrand benchmark.

The analysis contributes to the existing literature on strategic environmental policy and forest economics in the following way. First, a lower cost of timber importation leads to more competitive pricing on the export-market and in domestic timber market reducing the aggregate profit in the forest sector. Second, the results entail a qualification to the usual results in strategic environmental policy models in the sense that the optimal policy is less sensitive to assumptions about the mode of competition, because the option to use timber imports makes the export market less sensitive to asymmetric changes in domestic timber prices.

3.3 Essay III: Harmonization Versus Mutual Recognition of National Eco-labels

A national eco-labeling program is an efficient instrument to certify that certain producers comply with a set of particular environmental standards guaranteeing sustainable conditions surrounding the production process. A market-based reason for the existence of eco-labels is their role as a signal of higher environmental quality, when the consumers with willingness to pay for this information cannot fully assess whether producers actually produce at the standards they claim to produce. In international markets, eco-labels have become an important factor in the market access, generating pressures for the producers to apply for a label. Some national eco-labeling schemes are thus often considered either discriminating against producers with different labeling requirements or imposing too lax standards that might not coincide with the social priorities of other countries. These arguments have fueled public debate about appropriate level of differentiation between region-specific labeling standards in the global markets.

There are two suggested remedies for the problem of multiple country-specific labels. Harmonizing labeling standards means that the exporters can sell their products without having to comply with different regulations in each country and ensures the consumers that imported products comply with the same standards. A fundamental problem inherent to harmonization is that different regions have different environmental and social priorities, indicating that harmonized standards are not always appropriate for the environmental or economic conditions in exporting countries. Furthermore, under harmonized labeling standards the price-cost mark-up generated by the labels might be insufficient for some producers to participate the labeling schemes.

The second remedy is mutual recognition of existing labeling schemes. This means that if a product is eligible for a label granted by a national labeling program, it would automatically receive an equal treatment with any other label in the importing countries. Mutual recognition arguably allows for more leverage to consider the national characteristics in the design of labeling standards, and therefore, it should induce higher participation in the labeling programs. The adverse effect of mutual recognition is that when consumers cannot observe the actual differences between the product qualities, goods with higher labeling standards may not survive the competition.

Essay III examines the role of asymmetric information in the producers' endogenous quality decision in a closed economy and provides a welfare comparison between the regimes of mutual recognition and harmonization of eco-labels in international trade. In particular, the aim of the study is not to examine the design optimal labeling programs. Instead, it formalizes the market-based reasons for the emergence of eco-labeling programs and illustrates the market failures generated by the mutual recognition and harmonization of eco-labels in international markets. By comparing the welfare implications of these market failures, the study might be of help in understanding the trade-offs associated with the international coordination of eco-labeling programs.

The study extends the existing literature on quality signaling and environmental quality differentiation in the following respects. First, the model illustrates the implications of asymmetric information and signaling on the firms' endogenous quality decision. Second, it formalizes the reasoning and the welfare implications of third-party eco-labeling schemes in a vertically differentiated oligopoly under asymmetric information. Finally, unlike Jansen and Lincé de Faria (2002) the study considers the welfare implications of harmonization and mutual recognition, when the producers can use price signaling to influence consumers' beliefs about the labeling requirements in different countries.

The main contributions of the last essay are as follows. First, although the existing qualities and the associated costs are common knowledge, the market for goods with high environmental quality collapses, because the firms cannot implement equilibrium in which the consumers observe the quality differences between the firms. Second, a third-party eco-labeling program can be used to implement equilibrium with different environmental qualities, but the market outcome fails to satisfy the criteria for Pareto efficiency. Finally, if the producing countries are opened for trade, mutual recognition of country-specific eco-labels Pareto dominates harmonization of labeling standards, provided that the difference between the labeling standards is low.

References

Akerlof, G.: 1970, The market for lemons, *Quarterly Journal of Economics* **LXXXIV**, 488–500.

Arora, S. and Cason, T. N.: 1995, An experiment in voluntary environmental regulation: Participation in EPA's 33/50 program, *Journal of Environmental Economics and Management* **28**(3), 271–286.

Arora, S. and Gangopadhyay, S.: 1995, Toward a theoretical model of voluntary overcompliance, *Journal of Economic Behavior and Organization* **28**.

Bansal, S. and Gangopadhyay, S.: 2003, Tax/subsidy policies in the presence of environmentally aware consumers, *Journal of Environmental Economics and Management* **45**(2), 333–355.

Barrett, S.: 1994, Strategic environmental policy and international trade, *Journal of Public Economics* **54**.

Boom, A.: 1995, Asymmetric international minimum quality standards and vertical differentiation, *The Journal of Industrial Economics* **43**(1), 101–119.

Brander, J. and Spencer, B.: 1985, Export subsidies and international market share rivalry, *Journal of International Economics* **18**.

Cason, T. N. and Gangadharan, L.: 2002, Environmental labeling and incomplete consumer information in laboratory markets, *Journal of Environmental Economics and Management* **43**(1), 113–134.

Conrad, K.: 1993, Taxes and subsidies for pollution-intensive industries as trade policy, *Journal of Environmental Economics and Management* **25**(2), 121–135.

Cremer, H. and Thisse, J.-F.: 1999, On the taxation of polluting products in a differentiated industry, *European Economic Review* **43**(3), 575–594.

Eaton, J. and Grossman, G. M.: 1986, Optimal trade and industrial policy under oligopoly, *Quarterly Journal of Economics* **101**(2), 383–406.

Fluet, C. and Garella, P. G.: 2002, Advertising and prices as signals of quality in a regime of price rivalry, *International Journal of Industrial Organization* **20**(7), 907–930.

Gabszewicz, J. J., Shaked, A., Sutton, J. and Thisse, J. F.: 1981, International trade in differentiated products, *International Economic Review* **22**(3), 27–534.

Goldberg, P. K. and Knetter, M. M.: 1999, Measuring the intensity of competition in export markets, *Journal of International Economics* **47**(1), 27–60.

Hamilton, S. F. and Stiegert, K. W.: 2002, An empirical test of the rent-shifting hypothesis: The case of state trading enterprises, *Journal of International Economics* **58**(1), 135–157.

Hertzendorf, M. N. and Overgaard, P. B.: 2001, Price competition and advertising signals - signaling by competing senders, *Journal of Economics and Management Strategy* **10**, 621–662.

Jansen, M. and Lincé de Faria, A.: 2002, Product labeling, quality and international trade, *CEPR Discussion Paper* (3552).

Khanna, M. and Damon, L. A.: 1999, EPA's voluntary 33/50 program: Impact on toxic releases and economic performance of firms, *Journal of Environmental Economics and Management* **37**(1), 1–25.

Kirchhoff, S.: 2000, Green business and blue angels, *Environmental and Resource Economics* **15**, 403–420.

Koskela, E. and Ollikainen, M.: 2001, Optimal forest conservation: Competitiveness versus green image effects, *Forest Science* **47**, 178–187.

Kreps, D. and Scheinkman, J.: 1983, Quantity precommitment and bertrand competition yield cournot outcomes, *Bell Journal of Economics* **14**, 326–337.

Maggi, G.: 1996, Strategic trade policies with endogenous mode of competition, *American Economic Review* **86**, 237–258.

Milgrom, P. and Roberts, J.: 1986, Price and advertising signals of product quality, *Journal of Political Economy* **94**(4), 796–821.

Moeltner, K. and Van Kooten, G. C.: 2003, Voluntary environmental action and export destinations: The case of fores certification, *Journal of Agricultural and Resource Economics* **28**(2), 302–315.

Pigou, A. C.: 1932, *The Economics of Welfare*.

Porter, M.: 1991, America's green strategy, *Scientific American* **264**(4), 96.

Rege, M.: 2000, Strategic policy and environmental quality, *Environmental and Resource Economics* **15**, 279–296.

Schmalensee, R.: 1978, A model of advertising and product quality, *Journal of Political Economy* **86**(3), 485–503.

Shapiro, C.: 1983, Premiums for high quality products as returns to reputations, *The Quarterly Journal of Economics* **98**(4), 659–680.

Simpson, R. D. and Bradford, Robert L., I.: 1996, Taxing variable cost: Environmental regulation as industrial policy, *Journal of Environmental Economics and Management* **30**, 282–300.

Spencer, B. and Brander, J.: 1983, International r&d rivalry and industrial strategy, *Review of Economic Studies* **50**, 707–722.

Ulph, A.: 1996a, Environmental policy and international trade when governments and producers act strategically, *Journal of Environmental Economics and Management* **30**, 265–281.

Ulph, A.: 1996b, Strategic environmental policy and international trade - the role of market conduct, *in* Y. K. C. Carraro and A. Xepapadeas (eds), *Environmental Policy and Market Structure*, Kluwer Academic Publishers.

Yerger, D. B.: 1996, Testing for market power in multi-product industries across multiple export markets, *Southern Economic Journal* **62**(4), 938–56.

Essay I: Optimal Forest Conservation: The Role of Green-Image Demand and Investments

Abstract

This paper investigates optimal forest conservation in a strategic-trade framework. Exporting firms produce processed wood products with domestic timber supplied by forest owners, and use investments to reduce their production costs. Conservation influences the industry-equilibrium through higher timber prices and a price-premium generated by customers' willingness to pay for the products' green-image. The results demonstrate that tight conservation requirement increases timber prices, inducing a reduction in the firm's investments and output. A strong demand-effect reverses the result as the price premium leads to an expansion in domestic output. Finally, the optimal conservation level is lower than the Pigouvian one, unless the demand-effect is sufficiently strong. Under a strong demand effect, the equilibrium of a multilateral policy-game involves higher industry profit and higher conservation requirements in both producing countries.

Keywords: forest conservation, investments, timber market, wood-product exports, product-differentiation

JEL Classification: F12, Q28, L15

1 Introduction

Most wood-producing countries are modifying their forest policies to reflect international concerns with environmental damages associated with commercial forestry. Included among these are efforts to reduce logging on ecologically valuable natural habitats and change forestry practices to sustain not only timber yields, but also other forest outputs such as biodiversity. In countries where forests are privately owned the forest sector is, however, concerned that mandatory conservation requirement might reduce forest owners' welfare and the competitiveness of domestic industry. These concerns have raised a policy debate as some argue that the competitive pressures might diminish governments' incentives to raise conservation requirements they apply to the forest owners. The present study might be of use in formalizing these arguments and in describing the factors in international forest industry affecting the socioeconomically optimal design of conservation policies.

In the recent decades economists have examined the trade-off between environmental policy and competitiveness. In particular, several authors have adopted a strategic trade approach which provides a useful framework in examining the idea that environmental policies can be used as an indirect trade policy instrument to improve domestic competitiveness. Conrad (1993) and Barrett (1994) were the first to follow the lead of the model of imperfect competition on a third-country export market put forward by Brander and Spencer (1985). These studies demonstrate that when an increase in environmental standards affect the industry equilibrium in an imperfectly competitive export market, the optimal policy-design entails a distortion from the first-best, Pigovian level.

The intuition is that governments have diminished incentives to fully internalize the domestic environmental damages as lower standards can be used to shift rents from the export market. These analysis, however, neglect the idea that in response to environmental regulation the targeted industry might have an incentive to invest in a cost-reducing R&D to alleviate the cost effects associated with environmental regulation. This presumption and its implications to the optimal design of environmental policy were first introduced by Porter (1991). The so-called Porter-hypothesis assumes that tight regulatory framework may spur innovation investments in novel technologies and thereby improve the domestic competitiveness in the long-run. This, in turn, implies that an optimal environmental policy calls for tighter environmental standards to promote domestic competitiveness. The Porter-hypothesis has been addressed by several economists. For instance, Simpson and Bradford (1996) examine the so-called Porter-hypothesis in a strategic trade framework which arguably constitutes a plausible environment for the analysis. The results, however, indicate that the hypothesis holds only in limited circumstances.[1]

Trade and environmental policy has deserved considerable attention in economic literature, but relatively few authors have examined the link between competitiveness of the forest sector and forest conservation policy. An exception is Koskela and Ollikainen (2001) which develops a model analyzing the welfare implications of mandatory forest conservation in an economy with private forest owners and domestic industry which competes with an outside industry in domestic markets for processed wood products. The authors suggest that the optimal forest conservation policy depends on the following factors. First, conservation requirements tend to decrease the welfare of forest owners, and consequently, impose upward pressure on timber prices. Second, the increase in timber price reduces the competitiveness and hence the market share of the domestic industry through higher production costs. Finally, reflecting a recent trend in international markets for wood products, the study establishes that when consumers exhibit willingness to pay for products' environmental attributes, a positive 'green-image' demand effect may well offset the negative welfare effects associated with the loss of competitiveness on the supply side.

While the arguments put forward by Koskela and Ollikainen (2001) are intuitively clear, they do not analyze the potential policy-distortions generated by the imperfect competition in the downstream market for the final goods or the consumers' preferences toward goods originating from sustainable sources. Hence, there are compelling reasons to reconsider the design for optimal forest conservation policy in an open economy. The first reason is that no one has yet studied forest conservation policies in a strategic trade framework to illustrate the governments' rent-shifting incentives. Another reason is that the cost of wood-extraction and processing has decreased over the past decades due to increased investments in cost-saving technologies.[2] This suggests that to gain

[1] In a similar framework, Ulph (1996a) establishes that tighter environmental regulation induces firms to do more cost reducing R&D, but this effect is not enough to prevent governments from imposing inefficiently low environmental requirements.

[2] Stier and Bengston (1992) review empirical literature on technical change to forest industry in U.S. and summarize the results. The results suggest that technological change in forest wood processing industry is capital-using and labor-saving. Sedjo (1997) discusses the recent developments in logging technology and reports that technological change has also been capital-using. Sedjo (1997) also reports mostly anecdotal evidence that the development has been driven, among other things, by tighter environmental requirements on forest management practices.

broader understanding on the issue we should also consider the industries' incentives to use investments to alleviate the cost effects of higher timber prices. Finally, in the literature on strategic environmental policy, the results are driven by supply-side effects of environmental regulation which reflect the producers' strategic responses to changes in the rival's cost structure. All these analyses, however, reject the potential demand-side effects which can be a significant factor in the design of environmental policies, especially in the forest industry where the international market involves several international forest certification programs.[3]

Extending Koskela and Ollikainen (2001), the present paper considers how the trade-off between the competitiveness of forest sector and the social benefits generated by non-timber output of forests affects the design for optimal forest conservation policy. The analysis builds on Spencer and Brander (1983), and Ulph (1996a) with the exception that it captures the following features specific to the forest industry. The first feature is that the public intervention into the markets involves a mandatory forest conservation requirement which imposes a cost on the targeted industry that is realized through domestic timber markets.[4] The second feature is that the conservation requirements affect the consumers' perception of the products' positioning in quality-space as there is a 'green-image' effect increasing the consumers' willingness to pay for goods originating from a country where the logging practices have been modified to reduce the area eligible for harvest and leave more standing trees on harvested areas.[5]

The analysis demonstrates the usual trade-off in the design of environmental policy as the forest conservation affects domestic income by reducing the industry's competitiveness through reductions in investments and higher timber prices. However, the analysis formalizes the intuitive result that a green-image effect can improve the firms'

[3] The emergence of various industry-led forest certification programs indicates that the green image effect might be an important factor in the design of conservation policies. For instance, Ozanne and Vlosky (1997) report that 63 percent of consumer would be willing to pay more for wood-products originating from sustainable sources, and Ozanne and Smith (1998) identify market segment for certified wood products. Murray and Abt (2001) show that the required price-compensation that would induce forest owners to adopt sustainable management practices is relatively small. Furthermore, Moeltner and van Kooten (2003) establish that producing for the export market is an important factor explaining why producers improve their forest management practices.

[4] This is in line with Linden and Uusivuori (2002) who establish forest conservation policies increase timber prices on the market where forests are privately owned.

[5] For example, the new forest law in Finland which came into effect 1997 imposes such limitations on the commercial harvesting of timber in privately and publicly owned forests.

competitiveness through a green-image effect realized on the demand side of the market. Optimal conservation policy thus depends on the relative magnitude of the cost and demand effects and entails a conservation level which is lower than the first-best, unless the demand effect is sufficiently strong.

The nature of the optimal forest conservation policies indicates that the usual Prisoners Dilemma outcome in strategic trade models with non-cooperative policy decisions emerges as equilibrium under limited circumstances, when the green-image demand is strong enough.[6] A symmetric raise in forest conservation requirements in the exporting countries increases both production costs and consumers' willingness to pay for *any* wood-product on the market. Hence, the degree of product differentiation is less than the governments had anticipated. The immediate consequence is that the cost effect of conservation is more likely to dominate the green-image demand effect, indicating an increase in prices and profits of both industries due to a contraction in the aggregate supply on the export market.

The remainder of this paper is organized as follows. The following section describes the firms' production technology and the demand system representing customers' preferences in the presence of green-image demand. Section 3 describes the firms' behavior in the export market and domestic timber market. Section 4 investigates the impact on conservation policy on the equilibrium outcomes on the export market. Finally, section 5 analyses the optimal conservation policy, and the bilateral policy game between the governments. Section 6 concludes.

2 Preliminaries: Production Costs and Green-image Demand

The model is a game in threes stages involving two exporting countries and a third importing country. In each exporting country there is a firm producing processed wood

[6]The Prisoners Dilemma outcome emerges in strategic trade models, because each government has an incentive to relax the environmental policies for the reasons of competitiveness. Hence, the welfare in both countries is reduced as the aggregate output on the export market increases and lower environmental requirements exacerbate the production-related environmental externalities. See e.g. Barrett (1994).

products for a third-country export market.[7] At stage one, the firms invest in cost-reducing technology, which reduces the unit cost of using timber in production. At the second stage, the firms buy timber from domestic forest owners and, finally, compete on the basis a Cournot competition in a third-country export market. Prior the game played by the firms, the governments of the exporting countries choose the conservation requirements they apply to domestic forest owners. We consider both unilateral policy decision and non-cooperative policy game. A unilateral policy decision involves one government choosing the conservation level and the non-cooperative policy game refers to a simultaneous policy choice in both producing countries.

The producing countries are denoted by i and j, and superscripts are used to indicate country specific variables. Firm i produces final products, q^i, with domestic timber inputs, x^i. To save on notation, we consider a linear production technology in terms of timber inputs and normalize the input coefficient to unity. Letting t^i denote the timber price, the cost function can be formulated as

$$C^i(k^i, t^i, q^i) = [t^i + c^i(k^i)]q^i,$$

where $c^i(k^i)$ is a unit cost function describing the production costs net of timber price. We assume that the unit cost function is decreasing in investments:

$$C^i_{k^i}(k^i, t^i, q^i) < 0$$

The cost-reducing effect, however, declines as the level of investments increases, i.e. $C^i_{k^i k^i}(k^i, t^i, q^i) > 0$.

In modeling the green-image demand we adopt a formulation widely used in the industrial organization literature on vertical product differentiation.[8] Consumer n's utility of consuming one unit of product q^i is denoted by the following indirect utility

[7] The assumption that there is only one firm in each country arguably simplifies the analysis, but it is not implausible as the firm can rather be interpreted as a representative firm of the forest industry in each country. The implications of this assumption on the structure of the domestic timber market will be discussed below.

[8] The terminology "green-image" is borrowed from Koskela and Ollikainen (2001).

function[9]

$$U(\bar{h}^i, p^i) = \theta(\bar{h}^i)\alpha^n - p^i,$$

where p^i denotes the price of product q^i and $\theta(\bar{h}^i)$ is a parameter reflecting the consumers' perception on the impact of mandatory harvesting constraints on the ecological conditions in the forests of country i. This parameter is uniform to each consumer and an increasing function of the mandatory conservation requirement, $\bar{h}^i$, in country i. Letting $\underline{h}_0^i < \bar{h}^i$ denote the *laissez faire* conservation level, the quality factor satisfies the following properties: $\theta(\underline{h}_0^i) = 1$; $\theta'(\bar{h}^i) > 0$ and $\theta''(\bar{h}^i) < 0$.[10] In line with the literature on vertical product differentiation we assume that consumers differ in their taste for environmental characteristics of the good, described by parameter $\alpha^n \in [\underline{\alpha}, \overline{\alpha}]$ which is uniformly distributed with unit density.[11]

Assuming that the initial mandatory harvesting constraint is zero in both countries, we can formulate the demand functions for the two cases relevant to this study as follows. The first case is the unilateral design of conservation policy. This means that country i chooses the conservation level and the country j applies no harvesting constraints to the domestic forest owners. This implies that that the goods are environmentally differentiated, and thus, by assuming partial market coverage, the inverse demand function can be written as:

$$P^i(q^i, q^j; \bar{h}^i, \bar{h}^j) = \theta(\bar{h}^i)(\overline{\alpha} - q^i) - q^j,$$
$$P^j(q^i, q^j; \bar{h}^i, \bar{h}^j) = \overline{\alpha} - q^j - q^i.$$

when $\theta(\bar{h}^i) > 1$.[12] The demand functions imply that higher $\theta(\bar{h}^i)$ represents an advantage for the firm i: when $\theta(\bar{h}^i) > \theta(\bar{h}^j)$ it can charge a higher price than its rival for any given output quantity. Higher parameter α readily captures the property that for

[9] This is a usual formulation of consumers' indirect utility in the literature on vertical product differentiation, see e.g. Motta (1993). Arora and Gangopadhyay (1995) examine environmental quality competition under Bertrand conjectures.

[10] The determination of *laissez faire* conservation level will be discussed in section 3.2.

[11] The taste parameter can be interpreted as a parameter which links the marginal utility of income to the taste for environmental quality. For more information, see e.g. Arora and Gangopadhyay (1995)

[12] Assuming partial market coverage allows us to invert the demand function (see e.g. Motta 1993). Observe that although the demand functions express the demand for the goods when $\theta(\bar{h}^j) = 1$, the model could readily be extended to the case when $\theta(\bar{h}^i) > \theta(\bar{h}^j) > 1$.

the same physical quality, a consumer is willing to pay a higher price if the product originates from sustainable sources.[13] Formally:

$$\begin{aligned} \frac{dP^i(q^i, q^j; \bar{h}^i, \bar{h}^j)}{d\bar{h}^i} &= \theta'(\bar{h}^i)(\overline{\alpha} - q^i) > 0 \\ \frac{dP^j(q^i, q^j; \bar{h}^i, \bar{h}^j)}{d\bar{h}^i} &= 0 \end{aligned} \tag{2.1}$$

In the case of a symmetric conservation levels $\theta(\bar{h}^i) = \theta(\bar{h}^j)$ the aggregate demand for the homogeneous goods is given by $\theta(\bar{h}^i)(\overline{\alpha} - q^i - q^j)$. A symmetric increase in the conservation requirements implies that both firms can charge higher price for their output

$$\frac{dP^i(q^i, q^j; \bar{h}^i, \bar{h}^j)}{d\bar{h}^i} = \frac{dP^j(q^i, q^j; \bar{h}^i, \bar{h}^j)}{d\bar{h}^j} = \theta'(\bar{h}^i)(\overline{\alpha} - q^i - q^j) > 0 \tag{2.2}$$

Properties (2.1) and (2.2) characterize the *price effect* associated with the customer's perception of the products' green-image. An increase in conservation requirement generates a relative demand advantage for the firm i as the consumers willingness to pay for the good originating from country i increase as she perceives it being of higher environmental quality than wood products from country j. An increase in both conservation levels induces a similar effect on the prices of each firm. The latter effect is, however, weaker as the goods are perceived homogenous by the consumers. This means that neither firm can capitalize on the product-differentiation component of the green-image demand induced, but the increased willingness to pay for *any* good on the market relaxes the price competition in the importing country.

3 Industry Equilibrium and Domestic Timber Market

In this section, we describe the competition between the firms and analyze the upstream markets for timber. As is usual, we work our way backwards starting from the output stage. The second step involves the analysis of the timber markets. Finally, we examine

[13] For empirical evidence on the existence of such price premium, see Ozanne and Vlosky (1997) and Ozanne and Smith (1998).

the firms' investment behavior.

3.1 Output Choice

At the output stage the firms choose output quantities, taking the rival's quantity, timber price and investment level as given. The profits are written as

$$\begin{aligned} \pi^i(q^i, q^j; k^i) &= P^i(q^i, q^j; \bar{h}^i, \bar{h}^j)q^i - C^i(k^i, t^i, q^i) - rk^i, \\ \pi^j(q^i, q^j; k^j) &= P^j(q^i, q^j; \bar{h}^i, \bar{h}^j)q^j - C^j(k^j, t^j, q^j) - rk^j, \end{aligned}$$

where r denotes the sunk cost of investments.[14] Nash-equilibrium in quantities is characterized by the first-order conditions:

$$\pi^i_{q^i}(q^i, q^j; k^i) = \theta(\bar{h}^i)\overline{\alpha} - q^j - 2\theta(\bar{h}^i)q^i - C^i_{q^i}(k^i, t^i, q^i) = 0, \tag{3.1}$$

$$\pi^j_{q^j}(q^i, q^j; k^j) = \overline{\alpha} - 2q^j - q^i - C^j_{q^j}(k^j, t^j, q^j) = 0, \tag{3.2}$$

where the second-order and stability conditions are satisfied.[15]

Solving the first-order conditions for q^i and q^j, we obtain the following closed-form solutions

$$q^{i*}(k^i, k^j) = \Psi\left[\left(2\theta(\bar{h}^i) - 1\right)\overline{\alpha} - 2C^i_{q^i}(k^i, t^i, q^i) + C^j_{q^j}(k^j, t^j, q^j))\right] \tag{3.3}$$

$$q^{j*}(k^i, k^j) = \frac{\Psi}{\theta(\bar{h}^i)}\left[\overline{\alpha} - 2C^j_{q^j}(k^j, t^j, q^j) + \frac{1}{\theta(\bar{h}^i)}C^i_{q^i}(k^i, t^i, q^i)\right], \tag{3.4}$$

where $\Psi = \frac{1}{4\theta(\bar{h}^i)-1}$. Keeping in mind that $C^i_{q^iq^i} = 0$ and $C^j_{q^jq^j} = 0$, it is straightforward to see that the output levels are decreasing in domestic timber prices. Furthermore, the

[14] The parameter r is assumed to be identical in both countries. This simplification reflects the property that the cost of financing the investments is determined in the international capital markets. Therefore, it is not implausible to think that the cost of capital is indeed identical for both firms.

[15] That is,

$$\begin{aligned} \pi^i_{q^iq^i}(q^i, q^j; k^i) &= -2\theta(\bar{h}^i) < 0 \\ \pi^i_{q^iq^j}(q^i, q^j; k^i) &= -1 < 0, \end{aligned}$$

Hence, $D = \pi^i_{q^iq^i}(\cdot)\pi^j_{q^jq^j}(\cdot) - \pi^i_{q^iq^j}\pi^j_{q^jq^i} = 4\theta(\bar{h}^i) - 1 > 0$. This ensures that the subgame perfect equilibrium is stable and unique.

properties of the cost function indicate that output is increasing in own investments and decreasing in that of the rival's:

$$q_{t^i}^{i*}(k^i, k^j) < 0 \quad and \quad q_{t^i}^{j*}(k^i, k^j) > 0$$
$$q_{k^i}^{i*}(k^i, k^j) > 0 \quad and \quad q_{k^i}^{j*}(k^i, k^j) < 0$$

This result describes the strategic importance of investment decisions and timber prices. The equilibrium quantities are determined by the properties of the cost function. An increase in marginal cost of production reduces the competitiveness of the firm i. When the firm j observes an increase in timber price or a reduction in investments in firm i's costs, it infers that the resulting reduction in aggregate will increase prices on the export market. Anticipating this, the firm j is induced to expand its output to capture a higher market share in the export market.

3.2 Timber price Determination

Domestic timber market consists of a single buyer and a number of potential sellers. Although this assumption is rather extreme, it captures the stylized fact that producers of processed wood products have considerable market power in the roundwood markets in most wood-producing countries.[16] In theory, the approach can also be justified by that the extent to which forest conservation influences the timber prices does not qualitatively depend on the degree of competition on the domestic market (Koskela and Ollikainen 2001). Hence, different assumptions about the degree of competition provide little additional insight to the policy analysis which tries to explain the trade-policy implications of forest conservation.

Consider then a representative forest owner who derives revenue from selling timber and amenity benefits from the share of forest set aside from commercial forestry.[17] We assume that a quasi-linear utility function of the timber harvest describes forest owner's

[16] Murray (1995); and; Bergman and Brannlund (1995) provide empirical evidence that firms indeed employ oligopsony power on timber markets in USA and Sweden, respectively. Finnish timber market has a long tradition of periodical timber price negotiations between the forest owners' association and the forest industry. For more information see Koskela and Ollikainen (1998).

[17] This assumption is in keeping with several studies in forest economics. For instance, Hartman (1976) argues that forest owners maximize utility over timber revenues and recreational services.

utility:

$$
\begin{aligned}
V(x) &= t^i x + v(h) - G(x), \\
s.t. \quad h &= X - x
\end{aligned}
$$

where x denotes the harvesting of forest owner and t^i denotes the timber price.[18] The function $v(h)$ describes the forest owner's valuation of the non-timber output of the forest stock left standing, h, and satisfies $v'(h) > 0$; $v''(h) < 0$. Parameter $G(x)$ is a dummy-variable taking values $G(0) = 0$, and $G(x) = G > 0$ for $x > 0$, denoting a fixed cost of harvesting. The utility function thus captures the property that a corner solution in the form of clear-cutting the entire forest stock is unfeasible for the forest insofar as the timber price satisfies $t^i \leq v'(0)$.

The sale of timber is modeled as a contractual agreement between the representative forest owner and the domestic firm. An implicit assumption is that the buyer proposes a take-it-or-leave-it offer to the forest owner. To fix ideas, consider the outside option for the forest owner. Given the firm's offer, t^i, this option involves leaving the entire stock standing and receive $V(0) = v(X)$. It then follows that the optimal offer, which takes this constraint into account, can be defined as

$$t^{i*} = \arg\min_{t^i} C^i(k^i, t^i, q^i), \tag{3.5}$$

$$s.t. \quad t^i x + v(h) - G \geq v(X). \tag{3.6}$$

Constraint (3.6) states that a feasible price t^i ensures a timber revenue no less than $V(X)$. An optimal offer thus involves a minimum unit price which satisfies (3.6) for any given x. This can be written as

$$t^i(h^i) \geq \frac{v(X) - v(h^i) + G}{X - h^i}. \tag{3.7}$$

Expression (3.7) defines a reservation price which implicitly determines the quantity of timber traded between a representative forest owner and firm i.

[18] For a similar treatment of the forest owners' utility, see Hartman (1976) and Koskela and Ollikainen (2001).

The solution for the price contract is driven by the properties of the harvesting problem and the market power of the firm i. First, the harvesting problem has a non-convex component, indicating that a feasible offer ensures timber revenue that exceeds the fixed cost.[19] Second, consider the role of harvesting constraints. Absent binding constraints, the solution for $t^{i*} = \underline{t}^i$ is found at the point of tangency between $v(X)-v(\underline{h}_0^i)+G$ and $\underline{t}^i x$, which implicitly defines the harvest quantity $\underline{x} = (X-\underline{h}_0^i) > 0$, where $\underline{h}_0^i$ is the *laissez faire* level of forest stock left standing by the representative forest owner. For a given price, a binding constraint, $\bar{h}^i = \underline{h}_0^i + h_m^i$, implies a one-to-one reduction in timber harvest. Since the forest owners' outside option is fixed at $V(X)$, the timber revenue with price $\underline{t}^i$ and harvest $x = (X - \bar{h}^i)$ is too low to induce harvesting.[20] It then follows that the firm i is must increase its offer to ensure timber supply in domestic market.

The following result characterizes the optimal price offer for the firm i:

Result 1 *Equilibrium timber price is such that:*

(i) *Timber price equals the reservation price*

$$t^i(\bar{h}^i) = \frac{v(X) - v(\bar{h}^i) + G}{X - \bar{h}^i}$$

(ii) *Forest owners harvest up to constrained level i.e.* $x^i = X - \bar{h}^i$.

(iii) *Tighter harvesting constraint increases timber price*

$$\frac{dt^i(\bar{h}^i)}{d\bar{h}^i} = \frac{t^i(\bar{h}^i) - v'(\bar{h}^i)}{X - \bar{h}^i} > 0.$$

Proof. See the Appendix ■

The result just derived implies that forest conservation increases the rate of the linear price contract between the forest owners and the domestic buyer through a reduced supply potential of timber. Essentially, this result captures the price effect reported in Linden and Uusivuori (2002) who estimated the impact of a new forest law, which

[19] If there were no fixed cost the firm could, in principle, set a price $t^{i*} \to 0$ inducing forest owners to harvest an arbitrary small fraction of their forest stock, $x_0 = (X - h^i) \to 0$ such that $v'(h^i) = 0$.

[20] In section 5 we will show that the forest owners' optimal allocation of h does not coincide with that of non-forest owners who have no timber revenue. Hence, the optimal conservation policy involves a binding harvesting constraint.

came into effect 1997, imposing limitations on the commercial harvesting of timber in Finland. The law was designed to promote biodiversity in forests modified logging practices, by reducing the area eligible for harvest and required the forest owners to leave more standing trees on harvested areas. Linden and Uusivuori established that conservation requirements in the form of supply constraints induced the forest owners to increase the price levels to compensate the reduced supply.[21]

Before turning to the analysis of the green-image demand and industry competition, we should consider the role of government in imposing mandatory harvesting constraints. Harvesting constraints are an important component in promoting biological diversity and they are employed in most forest certification programs aimed to inform the consumers about the environmental characteristics of wood products. This immediately raises the question whether a government intervention is necessary, because the industry and the forest owners could voluntary engage in improving forest management practices. In the present model, this means that the firm could condition the price of timber also on the forest owners' forest management practices. The information requirements for such program are, however, high as the consumers find it virtually impossible to identify a wood product originating from sustainable sources. This generates a problem of asymmetric information between each link in the product chain, and thus, industry-led programs might not induce a desired green-image effect.[22]

A government intervention is therefore justified insofar as it serves as an instrument providing credible information about the minimum quality standard which the domestic wood products have to meet. We should also note that the target of the conservation requirements does not need to be the forest owners, as the same result obtains if the government applied a minimum quality standard on exported wood products. This could be seen as a public certification scheme, in which the government would play the role of a third-party accredidation body.

[21] A similar forest conservation program has also been launched in Sweden.

[22] As an example of credibility problems in forest certification see Greenpeace and The Finnish Natural League (2001), which claims that the Finnish certification program does not ensure sustainable forest management. Arora and Gangopadhyay (1995) provide theoretical background in a vertical differentiation framework for self-regulation. For detailed description of information problems in industry-led product certification see Janssen and de Faria (2002); Kirchhoff (2000); and Cason and Gangadharan (2002).

3.3 Investment Stage

At the first stage of the game, the firms choose the level of investments. Letting $\pi^i[q^i(\cdot), q^j(\cdot)] \equiv \Pi^i(k^i, k^j)$, we can write the firm i's program as

$$\max_{\{k^i\}} \Pi^i(k^i, k^j) = P^i(q^i, q^j; \bar{h}^i, \bar{h}^j)q^i - C^i(k^i, t^i, q^i) - rk^i,$$
$$s.t. \quad q^i = q^{i*}(k^i, k^j); \quad q^j = q^{j*}(k^i, k^j) \quad and$$
$$t^i = t^i(\bar{h}^i)$$

The firm chooses its level of investments given the effect of additional investments on output and timber demand assuming the rival keeps its investments fixed. Using the envelope theorem, we obtain a first-order condition characterizing the Nash-equilibrium in investments for the firm i

$$\Pi^i_{k^i}(k^i, k^j) = -q^j_{k^i}(k^i, k^j)q^i(k^i, k^j) - C^i_{k^i}(k^i, t^i, q^i) - r = 0,$$

where the second-order condition holds for each firm. Under mild assumptions about the properties of the cost function, the following condition holds

$$A = \Pi^i_{k^i k^i}(k^i, k^j)\Pi^j_{k^j k^j}(k^i, k^j) - \Pi^i_{k^i k^j}(k^i, k^j)\Pi^j_{k^j k^i}(k^i, k^j) > 0. \tag{3.8}$$

This ensures that the equilibrium is stable and unique.[23] The sign of $\Pi^i_{k^i k^j}(k^i, k^j) < 0$, implies that investments are strategic substitutes.[24]

The first-order condition restates the usual property in oligopoly-games with Cournot conjectures that the firms tend to over-invest in cost-reducing technologies so as to establish a credible pre-commitment to higher output level at the final stage of the game. However, since both producers have the same conjecture, the equilibrium involves higher aggregate output levels, which is conducive to more competitive prices in the output market and thereby lower profits than in the case of cost-minimizing investment levels.[25]

---

[23] The second-order conditions and (3.8) hold, provided that effect of investments on timber productivity declines sharply (i.e. $C^i_{k^i k^i}$ is sufficiently large).

[24] See Bulow et al. (1985).

[25] The cost minimizing level k^i_m is given by $\Pi^i_{k^i}(k^i, k^j) = C^i_{k^i}(k^i_m, t^i, q^i) - r = 0$.

The analysis of the firms' investment behavior indicates that investments do not influence the equilibrium outcomes in domestic timber markets or the consumers' perception of the goods green-image. This is because the vertical separation of the production of the final goods implies that timber prices are determined between the atomistic forest owners and the firm, whose investment behavior does influence the contractual environment in the domestic timber market. Furthermore, we assume that the green–image demand reflects the perceived forest management practices of the forest owners and there are no environmental externalities associated with production of processed wood products. This simplification arguably neglects the importance of the chain-of-custody issues in many forest certification programs, but it allows us to focus on forest conservation in more detail.

4 Industry Equilibrium and Forest Conservation

Section 2 established that conservation affects the firms' revenue through higher prices of the final good. The analysis of the firms' output decision and the timber price determination revealed that conservation, however, increases timber prices and therefore the firms' production costs. This section analyzes how these effects combined affect the industry equilibrium in terms of the firms' output and the investment decisions.

The equilibrium analysis is a comparative static exercise around the equilibrium. The results will be obtained with the help of the following lemma:

Lemma 1 (**i**) *The effect of a unilateral change in the conservation level $\bar{h}^i$ on the industry equilibrium is determined by the following single-crossing property which holds for any equilibrium output q^{i*} :*

$$\exists\ \underline{h} \in [\underline{h}_0^i, 1) \quad s.t. \qquad \left.\frac{\partial^2 \Pi^i(k^i, k^j)}{\partial q^i \partial \bar{h}^i}\right|_{q(k^i,k^j)=q^{i*}} \begin{cases} \geq 0 & for \quad \bar{h}^i \leq \underline{h} \\ < 0 & for \quad \bar{h}^i > \underline{h}, \end{cases} \tag{SC1}$$

where $\frac{\partial^2 \Pi^i(k^i,k^j)}{\partial q^i \partial \bar{h}^i} = \theta'(\bar{h}^i)(\overline{\alpha} - 2q^i) - t^{i\prime}(\bar{h}^i)$.

(**ii**) *In the case of symmetric change in the conservation policies, i.e.* $d\bar{h} = d\bar{h}^i =$

$d\bar{h}^j$, the single-crossing property becomes

$$\exists\ \underline{\underline{h}} < \underline{h} \quad s.t. \qquad \left.\frac{\partial^2 \Pi^i(k^i,k^j)}{\partial q^i \partial \bar{h}}\right|_{q(k^i,k^j)=q^{i*}} \begin{cases} \geq 0 & for \quad \bar{h}^i \leq \underline{\underline{h}} \\ < 0 & for \quad \bar{h}^i > \underline{\underline{h}}, \end{cases} \tag{SC2}$$

where $\frac{\partial^2 \Pi^i(k^i,k^j)}{\partial q^i \partial \bar{h}^i} = \theta'(\bar{h}^i)(\overline{\alpha} - q^j - 2q^i) - t^{i\prime}(\bar{h}^i)$.

Proof. See the Appendix ■

The expressions (SC1) and (SC2) illustrate the effects of higher conservation requirements on the firms' marginal revenue of additional units of output. On the demand side, a higher mandatory conservation requirement increases the consumers' willingness to pay for the firm's output which increases the marginal revenue of additional units of output. On the supply side, however, conservation requirements increase the production cost as the timber prices increase in the domestic markets.[26] The combined effect on the marginal revenue is determined by a unique critical parameter level which is lower when both governments modify their conservation requirements.

The intuition for the result is simple: a unilateral change in $\bar{h}^i$ differentiates firm i's product from other products on the market. This allows the firm i to charge higher price for its output, because the green-image effect reflecting the consumers' perception that the product has a higher environmental quality. In the case of bilateral change in conservation requirements, the firms cannot capitalize on this differentiation effect as the consumers consider the products homogeneous. It follows immediately that the increase in timber price is more likely to dominate the green-image demand effect.

The following result further examines the implications of Lemma 1 on the firms' output decisions:

Result 2 (**i**) *In the presence of green-image demand, the impact of marginal increase*

[26]Since the unit price of timber in convex in $\bar{h}^i$, the positive effect on firm's marginal revenue decreases with higher conservation levels and turns negative for parameters values $\bar{h}^i > \underline{h}$.

in conservation level $\bar{h}^i$ *is given by:*

$$\frac{dq^i}{d\bar{h}^i} = \begin{cases} >0 & for \quad \underline{h} > \bar{h}^i \\ <0 & for \quad \underline{h} < \bar{h}^i \end{cases} \quad and \quad \frac{dk^i}{d\bar{h}^i} = \begin{cases} >0 & for \quad \underline{h} > \bar{h}^i \\ <0 & for \quad \underline{h} < \bar{h}^i \end{cases}$$

$$\frac{dq^j}{d\bar{h}^i} = \begin{cases} <0 & for \quad \underline{h} > \bar{h}^i \\ >0 & for \quad \underline{h} < \bar{h}^i \end{cases} \quad and \quad \frac{dk^j}{d\bar{h}^i} = \begin{cases} <0 & for \quad \underline{h} > \bar{h}^i \\ >0 & for \quad \underline{h} < \bar{h}^i \end{cases}$$

(**ii**) *The effect of a symmetric change in the conservation policies is identical to both firms, i.e.*

$$\frac{dq^f}{d\bar{h}} = \begin{cases} >0 & for \quad \underline{\underline{h}} > \bar{h} \\ <0 & for \quad \underline{\underline{h}} < \bar{h} \end{cases} \quad and \quad \frac{dk^f}{d\bar{h}} = \begin{cases} >0 & for \quad \underline{\underline{h}} > \bar{h} \\ <0 & for \quad \underline{\underline{h}} < \bar{h}, \end{cases}$$

where $f = i, j$.

Proof. *See the Appendix* ■

The first result can be understood intuitively in the following way: a unilateral increase in the conservation requirement increases the consumers' willingness to pay for firm i's output, and consequently, the firm i expands its output and investments in order to capitalize on the price premium generated by the green-image effect. The rival anticipates the increase in the aggregate output and reduces its output to alleviate the downward pressure on the prices. This effect is reversed if the premium is lower than the marginal increase in timber prices, because the firm i is induced to contract its output and investments. Anticipating the increase in the prices of the final good, the firm j increases its output in order to capture a higher share of the export market.

Result (**ii**) examines the equilibrium implications when both countries modify their conservation policies. A bilateral increase in $\bar{h}$ has a similar effect on the firms' output and investment decision, but when the raise is symmetric, the consumers' willingness to pay is higher for *any* good on the market. As a result, the product differentiation component of green-image demand does not show up in demand. This means that each firm is less likely to increase its output and investments as a response to higher conservation requirement than in the case of unilateral policy scheme.

5 Policy Stage: Optimal Conservation Level

The policy analysis considers two cases. In the case of a unilateral policy decision, the government j keeps its conservation policy fixed and the government of country i assumes the role of first-mover of the game. In a non-cooperative policy game both countries simultaneously and independently impose conservation requirements.

The analysis is in three steps. First, we characterize the governments' problem. Second, we solve for the first-best policy. The first-best policy refers to an outcome which obtains under the assumption that government does not recognize the effects of the policy on the export market. Second, we determine the optimal policy schedule when the government designs the policy with an attention to the responses of the agents located in the foreign countries. Finally, we compare the policy outcomes and discuss the welfare implications.

5.1 Unilateral Policy Decision

Suppose that the government of country i sets the forest conservation requirements it applies to the forest owners so as to maximize domestic welfare. Letting $(1 - F^i)$ denote the proportion of non-forest owners over the entire population, the government's problem can be stated as

$$\begin{aligned} \max_{\{\bar{h}^i\}} \quad W^i(\bar{h}^i, \bar{h}^j) &= \Pi^i(k^i, k^j) + (1 - F^i)v^s(\bar{h}^i), \\ s.t. \quad \bar{h}^j &= \bar{h}^i_f \end{aligned} \tag{5.1}$$

where $(1 - F^i)v^s(\bar{h}^i)$ describes the social benefit of forest conservation reflecting the utility of non-forest owners in terms non-timber output, such as biodiversity and amenities, of forests. The function $v^s(\bar{h}^i)$ has the same properties as forest owners' function $v(\bar{h}^i)$.[27]

Let us then illustrate the first-best solution to (5.1) which will be used as a bench-

[27] It is important to note that forest owners' payoff function does not enter the welfare function, because the contract leaves the forest owners at their reservation utility which is constant in $\bar{h}^i$.

mark case in each country. The first-best level can be defined as follows:

$$\bar{h}^i_f = \arg\max \; W^i(\bar{h}^i, \underline{h}^j_0)$$
$$s.t. \quad \theta'(\bar{h}^i) = 0 \quad and \quad \frac{dq^j}{d\bar{h}^i} = 0$$

where the constraints reflect the presumption that the government does not recognize the impact of its choice on the industry equilibrium. The following first-order condition gives an implicit solution to this policy schedule:

$$\frac{\partial W^i(\bar{h}^i, \underline{h}^j_0)}{\partial \bar{h}^i} = (1 - F^i) v^{s\prime}(\bar{h}^i_f) - q^i t'(\bar{h}^i_f) = 0, \tag{5.2}$$

where $q^i t'(\bar{h}^i)$ expresses a marginal increase in firm i's costs due to higher timber price. Policy $\bar{h}^i_f$ thus satisfies the usual first-best rule in environmental economics: Marginal social benefit of conservation equals the marginal economic cost in the form of an increase in domestic timber prices.[28]

The next step in the analysis involves the determination of strategically optimal conservation level, $\bar{h}^i_s$. The definition of $\bar{h}^i_s$ is

$$\bar{h}^i_s = \arg\max \; W^i(\bar{h}^i, \underline{h}^j_0)$$
$$s.t. \quad \theta'(\bar{h}^i) \geq 0 \quad and \quad \frac{dq^j}{d\bar{h}^i} \begin{cases} < 0 & for \quad \underline{h} > \bar{h}^i_s \\ > 0 & for \quad \underline{h} < \bar{h}^i_s \end{cases}$$

where the constraints describe the consequences of domestic policy on industry equilibrium derived in Result 2. Using the envelope theorem, we obtain a first-order condition which implicitly characterizes the solution to (5.1). Rearranging the first-order condition gives:

$$(1 - F^i) v^{s\prime}(\bar{h}^i_s) - q^i t'(\bar{h}^i_s) = -\Pi^i_{q^j}(k^i, k^j) \left(\frac{\partial q^j}{\partial \bar{h}^i} + \frac{\partial q^j}{\partial k^j} \frac{\partial k^j}{\partial \bar{h}^i} \right) - \theta'(\bar{h}^i_s)(a - q^i) q^i. \tag{5.3}$$

The right hand side of (5.3) illustrates the two effects which address the implications

[28] Observe that an optimal constraint is always binding. This is because a non-binding constraint $\bar{h}^i < \underline{h}^i_0$ implies $t'(\bar{h}^i) = 0$. Such constraint cannot constitute an optimal policy as the solution to government's problem implies $v^{s\prime}(\bar{h}^i) = 0$ for $\bar{h}^i < \underline{h}^i_0$ indicating no supply of timber in country i.

of forest conservation policy we are discussing and the sign of the sum of these effects determines the potential distortions in the forest conservation policy.

We refer the first effect as the *output effect*, because it describes the firm j's response to forest conservation policy in quantity-space. This effect essentially restates the Brander and Spencer's (1985) analysis of export subsidies: A higher conservation requirement will increase domestic timber prices making the domestic firm less competitive, and by Lemma 1 it is clear that when this increase in timber price is sufficiently high, the foreign firm j is induced to expand its output harming the domestic firm.

The second effect is the *price effect* reflecting the consumers' direct response to the change in the firms' positioning in quality space. A raise in conservation requirements the government applies to forest owners differentiates the domestic wood products from other products on the export market. As a result, the green-image effect increases the consumers' willingness to pay for wood products originating from country i, which segments the market and allows firm i to charge higher price for its output. This effect gives the government an incentive to impose higher conservation requirements so as to generate a market environment in which the domestic firm can capitalize on the price premium.

Using Result 2, we can determine the policy distortions resulting from government's strategic behavior. These results are summarized in the following proposition:

Proposition 1 *Strategically optimal forest conservation level is always higher than $\underline{h}$; hence, the output effect in (5.3) is positive. The optimal policy schedule exhibits the following properties:*

(i) *When $\bar{h}^i_f \leq \underline{h}$, the strategically optimal policy is higher than the first-best, i.e. $\bar{h}^i_s \geq \bar{h}^i_f$;*

(ii) *When $\bar{h}^i_f \geq \underline{h}$, an increase in $\bar{h}^i$ decreases the output of firm j. Hence, the strategically optimal conservation level is higher than the first-best, unless the output effect dominates the price effect.*

Proof. See the appendix. ■

The intuition for this result is simple. A marginal increase in the conservation requirement in country i induces the forest owners to raise the price of timber. This effect passes into the firm i's costs and, consequently, the output of firm i is displaced by that of firm j. However, when the first-best conservation requirement is sufficiently low, so that the impact of marginal increase in harvesting constraint on timber price is relatively small, the positive green-image demand effect on the demand side of the market is likely to dominate the cost-effect. It then follows that the optimal strategy for the government i entails increasing both domestic income and the non-forest owners utility by imposing higher conservation requirements.

The relationship between strategically optimal and the first-best conservation policy is, however, reversed when the demand effect is weak. Consumers on the export market appreciate the higher environmental quality offered by the firm i, but the higher price of domestic timber induces a contraction in the firm's output and profit nevertheless. Anticipating this, the government is induced to impose a lower harvesting constraint than the first-best. This implies that the government engages in ecological dumping in the sense that it chooses inefficiently low conservation requirements in order improve the competitiveness of the domestic firm through lower timber prices.[29]

5.2 Non-cooperative Policy Game

The results just derived show that the government of country i has an incentive to behave strategically and modify the forest conservation policy in order to increase the domestic firm's profit in the export market. It is therefore plausible to think that the government of country j would also behave strategically. To illustrate the welfare implications of such non-cooperative policy process, we consider a game in which both governments simultaneously choose the conservation levels taking as given the other government's conservation level.[30]

Since the maximization problem and the information set of both governments is identical to (5.1), the optimal strategies in the policy game coincide with the one described in Proposition 1. Hence, we have the following proposition:

Proposition 2 *The equilibrium of the bilateral policy game exhibits the following features.*

[29] For more detailed discussion on 'ecological dumping' see Rauscher (1994).
[30] Our approach is similar to that in Barrett (1994).

(i) *The equilibrium policies coincide with the optimal conservation requirements derived in Proposition 1, i.e.* $\bar{h}_s^i = \bar{h}_s^j$.

(ii) *When* $\underline{h} \leq \bar{h}_f^i$ *and the output effect (price effect) dominates the price effect (output effect), each firm produces more (less) than in the case of first-best policy, implying a lower (higher) welfare in both countries.*

(iii) *When* $\underline{\underline{h}} \leq \bar{h}_f^i < \underline{h}$ *the equilibrium policies induce the firms to produce less than in the case of first-best conservation policy. As a result, the firms have higher revenue-levels, implying an increase in welfare in both countries.*

Proof. See the Appendix. ■

The second result in Proposition 2 can be linked to the usual Prisoners' Dilemma outcome in the policy game between the governments. Absent green-image effects both governments try to increase the domestic firm's rents by relaxing the environmental regulation. As a result, adverse policy equilibrium emerges as it involves higher aggregate output and lower industry profits. In addition to lower domestic income, the low conservation requirements exacerbate the environmental damages in the form of inefficiently high levels of logging in the forests of the producing countries.[31] In the present model this outcome emerges as equilibrium when the governments perceive the green-image demand effect insufficient to increase domestic profits on the export market and impose lower conservation requirements to domestic forest owners so as to prevent the increase in timber prices.[32]

When the governments perceive that the green-image demand is strong enough, the policy equilibrium entails higher conservation requirements than the first-best. This equilibrium does not exhibit similar Prisoners' Dilemma outcome as the one discussed above. The reason is that the policy decision is affected by the conjecture that raising conservation requirements will implement equilibrium in which the domestic wood products are differentiated from other products on the market. Since both governments have the same conjecture, the unintended consequence is that the product differentiation effect does not show up in demand implying lower output levels and thereby

[31] Here inefficiently low refers to the comparison between first-best and strategically optimal conservation levels.

[32] This is indeed a strategically stable equilibrium, because neither government has an incentive to shift back to the first-best policy schedule.

higher revenues for both firms. This outcome also exhibits a Pareto improvement as non-forest owners and industries in producing countries are better off due to higher industry revenues and tighter environmental regulation.

We should also note that Proposition 2 can be used as an argument for promoting certification programs designed and managed by the importing countries. More specifically, consider a straightforward extension of the present model in which the importing country imposes a set of standards including the harvesting constraints that the exporters have to meet in order to receive an environmental certification. Provided that the certification could be credibly monitored and it would induce the same green-image demand effect, the importing country could implement an outcome with the same equilibrium characteristics as the non-cooperative policy game under strong green image demand effects. The reason is that since the equilibrium of the non-cooperative policy game is strategically stable, a unilateral conservation requirement imposed by the importing country would induce both exporting countries to comply with the standards, and thus, the industry equilibrium would coincide with the one established in Proposition 2.

6 Conclusion

This paper has examined the design of optimal forest conservation requirements. The results establish that tighter conservation requirement tend to increase timber price on domestic market and thereby mitigate the domestic firm's incentives to invest in cost reducing technology, leading to contraction in domestic exports. The negative income effect thus provides an incentive for the governments to relax the conservation levels for trade policy purposes. The analysis of equilibrium of a non-cooperative policy game restates the usual Prisoners' Dilemma aspect in traditional strategic trade models as low conservation requirements reduce environmental quality and industry revenues.

The case for lowering the conservation requirements is less clear when conservation policy influences products' positioning in quality-space. If the price premium generated by the final product's green-image is high enough, a higher conservation level induces an output expansion and increases investments. This increases domestic profits, and therefore, the government has an incentive to impose tighter conservation requirement than the first-best level. Green-image demand also mitigates the adverse welfare outcome in the policy game. When both countries impose conservation requirements, the policies do not have the anticipated product-differentiation effect. As a result, the equilibrium policies, initially aimed to improve the wood products green image, implement equilibrium with lower aggregate output, higher industry revenues and higher amenity and biodiversity benefits generated by reduced logging in producing countries.

The results indicate that precise information about the conditions surrounding the oligopoly competition is needed. An interesting extension would allow for incomplete information about the parameters of the model and incentive-compatible conservation policies. The policies could be modeled as menus of contracts, which induce the firms to reveal information about demand and cost effects of the conservation policy.[33] Also, we considered incentives for non-cooperative, unilateral, government behavior, which is naturally welfare inferior to the joint-maximizing optimum. It is plausible to think that the policy makers would be willing to cooperate, when governments choose their forest conservation schedules.

Appendix

Proof of Result 1. (**i**) Argues that optimal offer involves $x^i = X - \bar{h}^i$. Actual contract is linear in price and harvest, optimal offer is thus decreasing in x, for an increase in forest owner's timber revenue allows for reduction in price offer. Formally, differentiating the contract price $t^i(h^i)$ with respect to x gives $dt^i(h^i)/dx^i = [v'(h) - t^i(h)]/x < 0$. Given $\bar{h}^i$, it is easy to see that optimal offer by the firm i is $t^i(\bar{h}^i)$.

(**ii**) Follows directly from (**i**)

(**iii**) Totally differentiate (3.6) at $t^i(\bar{h}^i)$ to obtain

$$xdt - [t - v'(\bar{h})]d\bar{h} = 0.$$

[33] For more information on strategic-trade policy under incomplete information, see for example Maggi (1999). Nannerup (1998) examines the strategic issues in the design of environmental policies under incomplete information.

This gives

$$\frac{dt^i(\bar{h}^i)}{d\bar{h}^i} = \frac{t^i(\bar{h}^i) - v'(\bar{h}^i)}{X - \bar{h}^i}$$

Given (**i**) we know that harvesting constraint is binding, thus, the numerator can be determined through the first-order conditions to the solution of the following forest owner's constrained harvesting problem:

$$\max L(x, \lambda) = t^i(\bar{h}^i)x + v(\bar{h}^i) + \lambda(X - \bar{h}^i - x),$$

where λ is the Lagrange-multiplier which reflects the shadow price of harvesting. The first-order conditions are

$$\begin{aligned} \frac{\partial L(x,\lambda)}{\partial x} &= t^i(\bar{h}^i) - v'(\bar{h}^i) - \lambda = 0 \\ \frac{\partial L(x,\lambda)}{\partial \lambda} &= X - \bar{h}^i - x = 0, \end{aligned}$$

This implies $t^i(\bar{h}^i) - v'(\bar{h}^i) = \lambda > 0$, hence $dt^i(\bar{h}^i)/d\bar{h}^i > 0$. ■

Proof of Lemma 1 . (**i**) The first-order condition (3.1) indicates that $(\overline{\alpha} - 2q^i) > 0$. Functions $\theta(\bar{h}^i)$ and $t^i(\bar{h}^i)$ are continuous on the domain $\bar{h}^i \in (0, X)$. Hence, $\bar{h}^i \to 0$ implies $t^{i\prime}(\bar{h}^i) = 0$ and $\theta'(\bar{h}^i) > 0$. Furthermore, $\bar{h}^i \to X$ implies $t^{i\prime}(\bar{h}^i) > 0$ and $\theta'(\bar{h}^i) = 0$. It follows that there is a single point of intersection between $\theta'(\bar{h}^i)(\overline{\alpha} - 2q^i)$ and $t'(\bar{h}^i)$, say $\underline{h}$. At this point $\theta'(\bar{h}^i)(\overline{\alpha} - 2q^j) - t'(\underline{h}^i) = 0$ holds, and

$$\begin{aligned} \theta'(\bar{h}^i)(\overline{\alpha} - 2q^i) - t'(\bar{h}^i) < 0 \qquad & for \quad \underline{h} < \bar{h}^i \\ \theta'(\bar{h}^i)(\overline{\alpha} - 2q^i) - t'(\bar{h}^i) > 0 \qquad & for \quad \underline{h} > \bar{h}^i. \end{aligned}$$

(**ii**) The proof follows immediately from the proof of (**i**) and from the first-order conditions (3.1) and (3.2). ■

Proof of Result 2. The proof of the first part of (**i**) is straightforward and therefore omitted.

The second part argues that $\frac{dq^i}{d\bar{h}^i} > 0$; $\frac{dq^j}{d\bar{h}^i} < 0$; $\frac{dk^i}{d\bar{h}^i} > 0$ and $\frac{dk^j}{d\bar{h}^i} < 0$ iff $\bar{h}^i < \underline{h}$. The impact on output follows immediately from Lemma 1, (3.3) and (3.4). To derive the effect on investments we totally differentiate the first-order conditions for both firms. This gives

$$\begin{bmatrix} \Pi^i_{k^ik^i} & \Pi^i_{k^ik^j} \\ \Pi^j_{k^jk^i} & \Pi^j_{k^jk^j} \end{bmatrix} \begin{bmatrix} dk^i \\ dk^j \end{bmatrix} = - \begin{bmatrix} \Pi^i_{k^i\bar{h}^i} d\bar{h}^i \\ \Pi^j_{k^j\bar{h}^i} d\bar{h}^i \end{bmatrix}$$

where $\Pi^i_{k^ik^i}(k^i,k^j) < 0$, $\Pi^j_{k^jk^j}(k^i,k^j) < 0$, $\Pi^i_{k^ik^j}(k^i,k^j) < 0$, $\Pi^j_{k^jk^i}(k^i,k^j) < 0$ and

$$\begin{aligned} \Pi^i_{k^i\bar{h}}(k^i,k^j) &= -\gamma q^j_{k^i}(k^i,k^j) q^i_{\bar{h}}(k^i,k^j) - C^i_{k^iq^i}(k^i,t^i,q^j) q^i_{\bar{h}}(k^i,k^j) = r\frac{q^i_h(k^i,k^j)}{q^i(k^i,k^j)} \\ \Pi^j_{k^j\bar{h}}(k^i,k^j) &= -\gamma q^i_{k^j}(k^i,k^j) q^j_{\bar{h}}(k^i,k^j) - C^j_{k^jq^j}(k^j,t^j,q^j) q^j_{\bar{h}}(k^i,k^j) = r\frac{q^j_h(k^i,k^j)}{q^j(k^i,k^j)} \end{aligned}$$

where, $q^i_h(k^i,k^j) > (<)0$ if $\bar{h}^i < (>)\underline{h}$. Hence, $\Pi^i_{k^i\bar{h}}(k^i,k^j) > (<)0$ and $\Pi^j_{k^j\bar{h}}(k^i,k^j) < (>)0$ if $\bar{h}^i < (>)\underline{h}$. Using Cramer's rule, the comparative static exercise gives us the following results

$$\begin{aligned} \frac{dk^i}{d\bar{h}^i} &= \frac{-\Pi^i_{k^i\bar{h}^i}\Pi^j_{k^jk^j} + \Pi^j_{k^j\bar{h}^i}\Pi^i_{k^ik^j}}{A} \begin{cases} > 0 & for \quad \bar{h}^i < \underline{h} \\ < 0 & for \quad \bar{h}^i > \underline{h} \end{cases} \\ \frac{dk^j}{d\bar{h}^i} &= \frac{-\Pi^i_{k^ik^i}\Pi^j_{k^j\bar{h}^i} + \Pi^i_{k^i\bar{h}^i}\Pi^j_{k^jk^i}}{A} \begin{cases} > 0 & for \quad \bar{h}^i > \underline{h} \\ < 0 & for \quad \bar{h}^i < \underline{h} \end{cases} \end{aligned}$$

Applying similar methods to the case of bilateral increase in $\bar{h}$ readily shows that the second part of Result 2 also holds. ■

Proof of Proposition 1. The proofs of the general result $\bar{h}^i_s > \underline{h}$ and (**i**) are by contradiction. The first-order condition characterizing the strategically optimal conservation level is

$$\Pi^i_{q^j}(k^i,k^j)\left(\frac{\partial q^j}{\partial \bar{h}^i} + \frac{\partial q^j}{\partial k^j}\frac{\partial k^j}{\partial \bar{h}^i}\right) + \theta'(\bar{h}^i_s)(a-q^i)q^i - q^i t'(\bar{h}^i_s) + (1-F^i)v^{s\prime}(\bar{h}^i_s) = 0, \quad \text{(A1)}$$

where

$$\begin{aligned} &\Pi^i_{q^j}(k^i,k^j)\left(\frac{\partial q^j}{\partial \bar{h}^i} + \frac{\partial q^j}{\partial k^j}\frac{\partial k^j}{\partial \bar{h}^i}\right) > 0; \quad and \\ &\theta'(\bar{h}^i_s)[a - q^i - t'(\bar{h}^i_s)] > 0 \quad for \quad \bar{h}^i_s < \underline{h} \end{aligned}$$

hence, $\bar{h}_s^i < \underline{h}$ is a contradicts (A1). Similarly, when $\bar{h}_f^i < \underline{h}$, the optimal level satisfies $\bar{h}_s^i > \bar{h}_f^i$.

The proof of result (**ii**) follows from the observation that

$$\exists \widetilde{h} > \underline{h} \quad s.t. \quad \underbrace{\Pi_{q^j}^i(k^i, k^j)}_{-} \underbrace{\left(\frac{\partial q^j}{\partial \bar{h}^i} + \frac{\partial q^j}{\partial k^j} \frac{\partial k^j}{\partial \bar{h}^i} \right)}_{+} + \theta'(\bar{h}_s^i) \underbrace{(a - q^i) q^i}_{+} = 0.$$

Hence, for $\bar{h}_f^i < \widetilde{h}$ $(\bar{h}_f^i > \widetilde{h})$ the optimal conservation level is $\bar{h}_s^i > \bar{h}_f^i . (\bar{h}_s^i < \bar{h}_f^i)$ ■

Proof of Proposition 2. Proof of (**i**) follows immediately from Proposition 1. To prove (**ii**), totally differentiate the welfare function of country i with respect to $\bar{h}^i$ and $\bar{h}^j$ to obtain

$$dW^i(\bar{h}_f^i, \bar{h}_f^j) = \frac{\partial \Pi^i(k^i, k^j)}{\partial \bar{h}^i} d\bar{h}^i + \frac{\partial \Pi^i(k^i, k^j)}{\partial \bar{h}^j} d\bar{h}^j + (1 - F^i) v^{s\prime}(\bar{h}^i) d\bar{h}^i$$

where

$$\begin{aligned} \frac{d\Pi^i(k^i, k^j)}{d\bar{h}^i} &= \frac{d\Pi^i(k^i, k^j)}{dq^j} \left(\frac{\partial q^j}{\partial \bar{h}^i} + \frac{\partial q^j}{\partial k^j} \frac{\partial k^j}{\partial \bar{h}^i} \right) + \theta'(\bar{h}_f^i)(a - q^i) q^i - q^i t'(\bar{h}_s^i), \\ \frac{d\Pi^i(k^i, k^j)}{d\bar{h}^j} &= \frac{d\Pi^i(k^i, k^j)}{dq^j} \left(\frac{\partial q^j}{\partial \bar{h}^j} + \frac{\partial q^j}{\partial k^j} \frac{\partial k^j}{\partial \bar{h}^j} \right) - \theta'(\bar{h}_f^j) q^j \end{aligned}$$

Imposing symmetry, $d\bar{h}^i = d\bar{h}^j$, the properties of the Cournot-Nash equilibrium indicate that

$$\begin{aligned} sign \left(\frac{\partial q^j}{\partial \bar{h}^i} + \frac{\partial q^j}{\partial k^j} \frac{\partial k^j}{\partial \bar{h}^i} \right) &= sign \left(\frac{\partial q^j}{\partial \bar{h}^j} + \frac{\partial q^j}{\partial k^j} \frac{\partial k^j}{\partial \bar{h}^j} \right), \\ \theta'(\bar{h}_f^i)(a - q^i) q^i - \theta'(\bar{h}_f^j) q^j &= \theta'(\bar{h}_f^i)(a - q^i - q^j) q^i > 0 \end{aligned}$$

Next, observe that $\underline{h} > \underline{\underline{h}}$, i.e. a bilateral, symmetric increase in $\overline{h}^i$ and $\overline{h}^j$ reduces the output of each firm insofar as $\overline{h}_f^i \geq \underline{h}$. Proposition 1 indicates: $d\overline{h}^i < 0$ for $\overline{h}_f^i > \widetilde{h}$ and $d\overline{h}^i > 0$ for $\overline{h}_f^i < \widetilde{h}$. Hence, by Result 2 and Proposition 1 we infer that

$$dW^i(\bar{h}_f^i, \bar{h}_f^j) \begin{cases} < 0 & for \quad \overline{h}_f^i > \widetilde{h} \\ > 0 & for \quad \overline{h}_f^i < \underline{h} \end{cases}$$

Result (**iii**) follows immediately from the proof of (**ii**) and the fact that $d\overline{h}^i > 0$ for $\overline{h}^i_f < \underline{h}$. ■

References

Arora, S. and Gangopadhyay, S.: 1995, Toward a theoretical model of voluntary over-compliance, *Journal of Economic Behavior and Organization* **28**.

Barrett, S.: 1994, Strategic environmental policy and international trade, *Journal of Public Economics* **54**.

Bergman, M. and Brannlund, R.: 1995, Measuring oligopsony power, *Review of Industrial Organization* **10**, 307–321.

Brander, J. and Spencer, B.: 1985, Export subsidies and international market share rivalry, *Journal of International Economics* **18**.

Bulow, J.; Geanakoplos, J. and Klemperer, P.: 1985, Multimarket oligopoly: Strategic substitutes and complements, *Journal of political Economy* **93**, 488–511.

Cason, T. N. and Gangadharan, L.: 2002, Environmental labeling and incomplete consumer information in laboratory markets, *Journal of Environmental Economics and Management* **43**(1), 113–134.

Greenpeace and The Finnish Nature League: 2001, Anything goes? Available at: http://www.pefcwatch.org/anything.html.

Hartman, R.: 1976, The harvesting decision when a standing forest has value, *Economic Inquiry* **14**, 52–58.

Jansen, M. and Lincé de Faria, A.: 2002, Product labeling, quality and international trade, *CEPR Discussion Paper* (3552).

Koskela, E. and Ollikainen, M.: 2001, Optimal forest conservation: Competitiveness versus green image effects, *Forest Science* **47**, 178–187.

Linden, M. and Uusivuori, J.: 2002, Econometric analysis of forest conservation: The finnish experience, *Environment and Development Economics* **7**(2), 281–297.

Maggi, G.: 1999, Strategic trade policies under incomplete information, *International Economic Review* **40**, 571–594.

Moeltner, K. and Van Kooten, G. C.: 2003, Voluntary environmental action and export destinations: The case of fores certification, *Journal of Agricultural and Resource Economics* **28**(2), 302–315.

Motta, M.: 1993, Endogenous quality choice: Price vs. quantity competition, *Journal of Industrial Economics* **41**(2), 113–131.

Murray, B. C.: 1995, Measuring oligopsony power with shadow prices: U.s. markets for pulpwood and sawlogs, *Review of Economics and Statistics* **77**(33), 486–498.

Murray, B. C. and Abt, R. C.: 2001, Estimating price compensation requirements for eco-certified forestry, *Ecological Economics* **36**(1), 149–163.

Nannerup, N.: 1998, Strategic environmental policy under incomplete information, *Environmental and Resource Economics* **11**, 61–78.

Ozanne, L. K. . and Smith, P. M.: 1998, Segmenting the market for environmentally certified wood products, *Forest Science* **44**(3), 379–389.

Ozanne, L. K. and Vlosky, R. P.: 1997, Willingness to pay for environmentally certified wood products: The consumer perspective, *Forest Products Journal* **47**(6), 1–8.

Porter, M.: 1991, America's green strategy, *Scientific American* **264**(4), 96.

Rauscher, M.: 1994, On ecological dumping, *Oxford Economic Papers* **46**, 822–840.

Sedjo, R.: 1997, The forest sector: Important innovations, *Resources for the Future, Discussion Paper* **97-42**.

Simpson, R. D. and Bradford, Robert L., I.: 1996, Taxing variable cost: Environmental regulation as industrial policy, *Journal of Environmental Economics and Management* **30**, 282–300.

Spencer, B. and Brander, J.: 1983, International r&d rivalry and industrial strategy, *Review of Economic Studies* **50**, 707–722.

Stier, J. C. and Bengston, D. N.: 1991, Technical change in the north american forestry sector: A review, *Forest Science* **38**(1).

Ulph, A.: 1996a, Environmental policy and international trade when governments and producers act strategically, *Journal of Environmental Economics and Management* **30**, 265–281.

Ulph, A.: 1996b, Strategic environmental policy and international trade - the role of market conduct, *in* Y. K. C. Carraro and A. Xepapadeas (eds), *Environmental Policy and Market Structure*, Kluwer Academic Publishers.

Essay II: Optimal Forest Conservation Under Endogenous Mode of Competition: The Role of Timber Imports

Abstract

This paper develops a model, in which forest owners bargain over timber prices with a firm that produces wood products for the export-market. The oligopoly-competition in the export-market is endogenous and the outcome of the game ranges between Cournot and Bertrand, depending on the extent to which timber importation diminishes the commitment-value of domestic timber inputs. This model is employed to examine the role of timber importation in the design for forest conservation policies. The results show that low cost of importation allows for the design for a first-best conservation policy, as the use domestic timber inputs becomes a less important determinant of the firms' competitiveness. In addition, a lower cost of importation decreases timber and final-good prices, and hence, diminishes the forest owners' harvest revenue.

Keywords: Strategic trade, environmental policy, timber imports, timber price bargaining

JEL Classification: F12, F18, Q28

1 Introduction

An interesting trend has been detected in the international forest industry. Many firms are importing timber inputs which formerly would have been acquired from local forests. This has directed attention in discussion of forest conservation onto two overlapping issues. Increase in the international demand for industrial wood has raised concerns for deforestation in tropical rain forests, as well as in forests of Asian Siberia and Western Russia.[1] At the same time, some argue that while globalization imposes economic pressure on these valuable ecosystems, it also provides opportunities for forest conservation in the major industrialized countries exporting wood products as the supply of wood inputs will be increasingly confined to areas with high productivity and intensive management.[2]

In major wood-producing countries, processed wood-products account for a large share of total exports. Forest conservation increases the cost of forest management or decreases forest owners' timber revenue. These effects tend to increase timber price, and give a raise to a trade-off between ecological benefits and economic costs in terms industries' competitiveness. The basic conservation problem in the case of industrialized countries that produce processed wood-products thus resembles the problem of the optimal design of environmental policies in the presence of international trade and local environmental externalities. In particular, since most large exporters

Several authors have examined the distortions in national environmental policies generated by international trade. Barrett (1994) uses a similar set-up as Brander and Spencer (1985) and establishes that regulators have an incentive to use environmental policy as an indirect output subsidy to shift rents toward domestic firms. The key idea underlying the results is that export subsidies, or indirect subsidies in the form of inefficiently low environmental requirements, constitute a credible pre-commitment for the domestic firm to increase output or prices on the export-market. The policies can thus be used to increase the profit of the domestic firm. A particular theoretical weakness of the strategic trade theory, however, emerges in several studies. Eaton and Grossman (1986) establish that the sign of optimal policy in Brander and Spencer (1985) is reversed, if one presumes Bertrand conjectures instead of Cournot. More specifically, under price competition the optimal policy calls for export tax rather than subsidy. Similarly, a strategically optimal environmental policy entails an inefficiently high environmental requirements, when the firms compete on the basis of Bertrand

[1] Forests of former Soviet Union, especially, in western Russia and Asian Siberia accounts for more than 20% of world's forests. Improvements in the transportation system in these regions, implies that gaining access to these forests will potentially have an important impact on trade flows of industrial wood inputs.

[2] See e.g. Sedjo (2001).

competition.[3]

Maggi (1996) examines the sensitivity of these results to assumptions about the mode of competition, and considers a strategic trade-policy model, in which the mode of competition is endogenous. The model develops a two-stage game, where the firms first choose output capacities and then compete on the basis of capacity-constrained price competition. The mode of competition is endogenous, because the firms have an option to produce in excess to a predetermined capacity-level, and the cost of producing beyond chosen capacity determines the extent to which the firms can use capacities to relax the price competition at the production-stage. Reflecting the feature that the model is, essentially, a reduced form version of a seminal paper by Kreps and Scheinkman (1983), Maggi (1996) shows that the mode of competition approaches to Cournot benchmark, when the cost of producing in excess of capacity is high enough. However, when the capacity constraint becomes flexible, the market equilibrium coincides with that of pure Bertrand competition. In what comes to optimal trade and industrial policies, the conclusion is that a capacity subsidy is weakly welfare-improving, regardless of the particularities of the market studied.

The concept of capacity pre-commitment is arguably an important feature in imperfectly competitive markets. Especially, in the case of vertical markets, where upstream producers sell inputs to manufacturers of the final goods, the role of inputs as capacity constraints cannot be ignored. However, the previous research on strategic trade and environmental policy in the presence of vertical markets has not been conclusive.[4] The present study extends the literature on strategic environmental policy and forest conservation in this respect. First, it develops a model of a forest industry in the presence of timber trade, when domestic firm produces processed wood products for an export-market and domestic timber price is determined endogenously. Second, the

[3] Barrett (1994) focuses on the role of market conduct in environmental policy decisions, and effectiveness of such policies as a trade policy instruments. Ulph (1996) extends this framework and allows for multi-stage competition. Rauscher (1994) examines policy decisions in general equilibrium framework. For a survey see Ulph (1997).

[4] To the author's knowledge, the only paper that examines strategic environmental policy and input markets is Hamilton and Requate (2004). Hamilton and Requate show that when firms buy polluting inputs from upstream producers, they can use contractual arrangements to implement an optimal cost structure so that environmental policy has no effect on their competitiveness. However, despite the feature that the contract implicitly specifies firms' output capacities, the model does not consider the role of inputs as a capacity constraint.

model illustrates how capacity constraints generated by the input market influence the design of optimal environmental policy.[5] Finally, unlike Maggi (1996), we consider a model in which the cost of capacity is determined endogenously in national timber market, which is also affected by the policy decisions.

The main contributions of the paper are as follows. Although the firms producing exported wood-products do not engage in timber importation, a lower cost of importing timber induces more competitive pricing on the export-market for the final goods and depresses the prices in the domestic timber market. This result has two welfare implications. First, the downward pressure on the domestic timber prices diminishes the forest owners' harvest revenue. Second, a low cost of timber importation allows for the design for first-best conservation requirements as the price of domestic timber inputs becomes a less important determinant of the firms' competitiveness. However, optimal policy calls for a lower conservation requirement than the first-best, when the use of domestic timber inputs has its full value as a commitment-device.

The last result entails a qualification to the usual findings on strategic environmental-policy in the sense that the optimal policy is less sensitive to assumptions about the mode of competition. The intuition is that the option to engage in timber importation makes the export market less sensitive to asymmetric changes in domestic timber prices. As a result, the economic cost of higher conservation requirements in the form of reduction in domestic firm's share of the export market diminishes. Contrary to the usual findings in the literature on strategic environmental policy, this means that the optimal policy coincides with the one that would obtain under perfectly competitive international markets for the final goods.

The remainder of this paper is organized as follows. The following section introduces the structure of the model, and, describes forest owners' utility and the firms' cost structures. Section 3 examines the price competition on the export-market. Section 4 derives the equilibrium outcomes of the game between the firms and describes the bargaining process, whose outcome determines the price and the quantity of domestic timber traded at domestic market. Section 5 analyses optimal forest conservation

[5] Section two provides more detailed discussion on the extent to which timber inputs can be considered as a commitment device.

policies, and section 6 concludes. The Appendices consist of most of the proofs and some derivations of the main results.

2 The Model: Timber Supply and Costs

The model entails two countries, so that country-specific variables and functions are denoted with superscripts i and j. We assume that in each country there is a forest industry consisting of a firm that produces processed wood products for the export-market and a competitive fringe of firms producing a non-tradable good for the domestic market.[6] The firms have the option to buy timber inputs from domestic forest owners or import the inputs from the international market.

The timing of the model is as follows. At the first stage, regulator of country i chooses a forest conservation requirement that it applies to domestic forest owners. At the second stage, forest owners and the firm bargain over timber prices.[7] This process determines the timber prices and the firms then unilaterally decide upon the quantity of timber inputs they acquire from the forest owners. Finally, after the national timber markets have cleared, each firm observes the capacity constraints determined by the quantity of domestic timber acquired in the domestic market and choose prices of the final goods. At this stage the firms have the option to expand production beyond the chosen input capacity, but this requires timber importation.[8]

[6] Although the assumptions about the structure of the domestic and export market are introduced in order to highlight the strategic trade argument in forest conservation policy, the qualitative results do not depend on the number of firms or which particular firm produces for export markets in each country. One interpretation of the approach is that the exporting firm is in fact a representative of few identical replications. Since the international market for refined wood products, such as fine paper and wood fiber, is dominated by relatively few wood producing countries, the assumption of imperfectly competitive export-market is plausible. The assumption about perfectly competitive domestic market, in turn, reflects the observation that the market for less processed products, say sawtimber, is often local and consists of many small retailers.

[7] Observations in some wood producing countries lend little support to assumption on perfectly competitive timber markets. Due to high trade costs of timber inputs, forest owners can employ market power that is associated with spatial monopsony in each wood producing country (see Johansson and Löfgren (1985) chapter 8). Recent economic literature also provides empirical evidence on timber market imperfections. See, for example, Koskela and Ollikainen (1998); and Bergman and Brännlund (1995).

[8] It is worth noting that the effect timber trade on international forest industry is becoming more pronounced. Recent empirical studies show that global export-volumes of industrial roundwood have increased by 22 percent since 1970 to 1997, see, e.g. Bourke and Leitch (2000).

The analysis of the last two stages of the game follows closely the model of oligopoly competition presented in Maggi (1996). The output capacity determines the conditions for the price competition at the following stage where the firms engage in capacity constrained price competition. The capacity level is explicitly modeled as the volume of timber inputs traded at the domestic market. Hence, the analysis departs from Maggi (1996) in that the cost of capacity is endogenously determined.

The assumption that domestic timber inputs can be used to establish a capacity precommitment, is open to the criticism that firms cannot recognize their market power as sellers of the final goods, and thereby act non-strategically in timber markets. The justification for our approach is that, in practice, the firms can change their price more quickly than the amount of timber they have acquired. Hence, after lowering prices the firms' ability to meet all the forthcoming demand, depends on whether the firms' can procure additional timber inputs without frictions in the domestic timber markets. Provided that there are such frictions and the cost of timber importation is high, it is not implausible to think that domestic supply of timber is a capacity constraint, and the extent to which this constraint is binding depends on the cost of acquiring timber from alternative locations.

Harvesting Decision of a Representative Forest Owner: Forest owners' utility consists of harvest revenue and amenity benefits generated by the forest stock left standing.[9] Timber price t^i is determined by negotiations between the forest owners and the buyer. The negotiations specify a linear price the firm pays to forest owners in exchange for industrial roundwood.

Representative forest owner's utility can be written as a function of timber harvest, i.e.

$$\begin{aligned} U(x) &= t^i x + v(m) - G(x), \qquad (2.1) \\ s.t. \quad m &= M - x \end{aligned}$$

where x denotes harvesting and function $v(m)$ denotes forest owner's amenity valuation

[9] Several studies in forest economics argue that forest owners in addition to harvest revenues also value amenity benefits of forests. See, e.g. Hartman (1976).

of forest stock that is left standing.[10] This can be expressed as $m = M - x$, where M denotes the initial forest stock. We assume that $v(m)$ satisfies $\partial v(m)/\partial m > 0$; $\partial^2 v(m)/\partial m^2 < 0$. Parameter $G(x)$ is a dummy-variable that takes values $G(0) = 0$, and $G(x) = G > 0$ for $x > 0$. Variable $G(x)$ denotes a fixed cost of harvesting and captures the feature that timber sales entail costs which are independent of harvest quantity.

To illustrate the forest owners harvesting decision, let x^* denote laissez-faire level of timber harvest. Keeping in mind that $U(0) = v(M)$ and setting $U(x^*)|_{t^i=\widehat{t^i}} = U(0)$, we obtain the reservation price, $\widehat{t^i}(m)$, representing the lowest acceptable price for which the sells a quantity $x^* = M - m^*$:

$$t^i \geq \widehat{t^i}(m^*) = \frac{v(M) - v(m^*) + G}{M - m^*}. \tag{2.2}$$

In what comes to forest conservation policy and forest owners' harvesting decisions, we assume that the regulator can apply mandatory harvesting constraints to forest owners. Formally, a binding harvesting constraint, $\bar{m} > m^*$, is such that $x^* > M - \bar{m}$. In the Appendix A, we show that the reservation price is increasing in $\bar{m}$:

$$\frac{d\widehat{t}}{d\overline{m}} = \frac{\lambda}{M - \overline{m}} > 0, \tag{2.3}$$

where λ is the Lagrange-multiplier of forest owners' constrained utility maximization problem.[11] This effect can be understood intuitively in the following way. Binding conservation requirement decreases representative forest owner's timber revenue. Since the forest owner's timber revenue is linear in x, but the outside option is fixed, a feasible contract requires the buyer to compensate the welfare loss through a higher unit price.

Production Costs: An exporting firm i produces output Q^i with timber x^i. By choice of units, we assume a linear production technology which satisfies $dQ^i/dx^i = 1$ for all Q^i. The firm i's cost function consists of two components. The firm pays a linear

[10] While harvesting decision is fundamentally a dynamic problem, this approach can be justified by a notion that harvesting decisions are made around a stable steady state. For a similar treatment of the forest owners' utility, see Koskela and Ollikainen (2000).

[11] The reason why the forest owners always harvest up to constrained level is that variable $G(x)$ introduces a nonconvex component to forest owners' harvesting problem. This ensures that $t^i \to 0$ is not a feasible price.

price, t^i, for each unit of timber they buy from the forest owners before the production takes place. Furthermore, at the production stage the firm incurs a cost c of producing one additional unit of Q^i.[12] Given timber price t^i, firm i may thus produce up to level $Q^i = x^i$ with fixed total cost $(t^i + c)Q^i$. Firms may also import timber inputs to produce in excess of x^i, but this requires a cost $\bar{t} = \tau + s$, where τ is the world market timber price and s is transportation cost.[13] Hence, firm i's cost function can be written as

$$\begin{aligned} C^i &= (c + t^i)\, Q^i & for \quad Q^i \leq x^i, \\ \overline{C}^i &= (c + t^i)\, x^i + \left(c + \bar{t}\right)(Q^i - x^i) & for \quad Q^i > x^i, \end{aligned}$$

where C^i expresses the production costs when firm i uses domestic timber only, and $\overline{C}^i$ denotes the production costs when firm i imports a proportion $(Q^i - x^i)/Q^i$ of timber inputs.

The key feature in the model is that the domestic timber price t^i is sunk at the output stage, but for each unit of output in excess of x^i the firm has to pay an additional cost equal to $\bar{t} + c$. The cost-function is therefore piecewise linear, but globally convex, and the cost parameter $\bar{t} > t^i$ determines this convexity, for higher parameter-value $\bar{t}$ increases the vertical segment of the marginal cost function.

Production Costs and Consumers in Domestic Market: The domestic firms which produce non-tradable good q^d have a similar cost functions as the exporting firms. They incur a constant marginal cost t^i for each unit of output produced with domestic inputs. However, for timber importation they have to pay the price $\bar{t}$ of imported timber. Since the market for non-tradable good is perfectly competitive, it follows immediately that the price, r, for the final good equals the timber price t^i or $\bar{t}$, depending on the source of the input. Hence, the profit of these firms can be written as

$$\pi^d = (r^d - t^i)q^d$$

The consumers' utility in domestic country depends on environmental quality of

[12] Cost parameter c reflects the costs that are unrelated to the use of timber inputs, such as wages and cost of capital.

[13] The existence of price agreement between firms and forest owners requires positive gains of trade. This is ensured if the parameters satisfy $s > \widehat{t^i} - \tau > 0$.

the domestic forests and consumption of good q^d. For the sake of simplicity we assume that this utility function is additively separable in its arguments, so that the expression for the indirect utility function is

$$S(t^i, \overline{m}) = u[d(r^d)] - rd(r^d) + v(\overline{m}),$$

where $u[d(r^d)]$ is he utility associated with consumption of q^d; $d(r^d)$ denotes the demand for the non-tradable good and $v(\overline{m})$ is the *social* amenity valuation of forests left standing by the forest owners. Without a loss of generality, we assume that social amenity valuation is identical to that of the forest owners'. The expressions satisfy the following properties: $u'[d(r^d)] > 0$ and $u''[d(r^d)] \leq 0$; and; $d'(r^d) < 0$.[14]

The solution method of the model is that of backward induction: As a first step, we solve for the subgame perfect equilibrium in prices for given x^i and x^j. Second, we analyze firms' choice of timber inputs for given timber prices. The analysis of these last two stages of the game is a direct application of the duopoly model presented in Maggi (1996). The third step in the analysis examines the national timber markets and solves for the equilibrium timber prices as determined in a bargaining process between forest owners and the firms. Finally, we analyze the optimal forest conservation requirement.

3 Output Stage: Price Competition in the export-market

At the final stage of the game, each firm observes the outcome on the timber markets in both producing countries. This involves the quantity of timber inputs, x^i and x^j, acquired from the local forest owners. The quantity of timber inputs is thus a choice of scale which determines the firms' cost structures, and essentially, the conditions for the price competition.

Given the firms cost-structure firm i chooses its price level, assuming that firm j

[14] Since the transactions between the firms and the forest owners incur within the economy and the welfare effects of forest conservation in the case of non-exporting firms are realized through perfectly competitive markets, the focus of the analysis is predominantly on the firms in the export market.

keeps its price fixed. This program can be stated as

$$\max_{p^i} \pi^i(p^i, p^j) = \begin{cases} (p^i - c)Q^i(p^i, p^j) & for \quad Q^i(p^i, p^j) \leq x^i \\ (p^i - c - \bar{t})Q^i(p^i, p^j) - (t^i - \bar{t})x^i & for \quad Q^i(p^i, p^j) \geq x^i, \end{cases} \tag{3.1}$$

where $Q^i(p^i, p^j) = a - bp^i + gp^j$ $(b > g > 0)$ denotes firm i's linear demand.[15]

The following first-order condition characterizes the solution to (3.1)

$$\frac{\partial \pi^i(p^i, p^j)}{\partial p^i} = \begin{cases} -(p^i - c)g + Q^i(p^i, p^j) = 0 & for \quad Q^i(p^i, p^j) \leq x^i \\ -(p^i - c - \bar{t})g + Q^i(p^i, p^j) = 0 & for \quad Q^i(p^i, p^j) > x^i. \end{cases} \tag{3.2}$$

Solving (3.2) for p^i we obtain two functions demonstrating firm i's price-responses under two explicit cost structures:

$$r(p^j, \cdot) = \begin{cases} r^i\left(p^j, c\right) = \dfrac{a + gp^j}{2b} + \dfrac{c}{2} & for \quad Q^i(p^i, p^j) \leq x^i \\ and & \\ r^i\left(p^j, c + \bar{t}\right) = \dfrac{a + gp^j}{2b} + \dfrac{c + \bar{t}}{2} & for \quad Q^i(p^i, p^j) > x^i. \end{cases} \tag{3.3}$$

Function $r^i\left(p^j, c\right)$ expresses a price-response function, when the firm i chooses to use domestic timber only. If the firm i chooses to produce in excess of the predetermined output capacity, the price-response is based on function $r^i(p^j, c + \bar{t})$.

To gain understanding on the timber acquisitions' role as a capacity constraint in price competition, we need to define a third price-response function. This isoquantity function determines the optimal price-combinations that satisfy $x^i = Q^i(p^i, p^j)$. The isoquantity function can be derived by substituting x^i into (3.2) and solving for p^i to obtain:

$$\rho^i(p^j, x^i) = \frac{a + gp^j - x^i}{b} \quad for \quad Q^i(p^i, p^j) = x^i. \tag{3.4}$$

The following Result reproduces Lemma 1 in Maggi (1996) which characterizes firm i's

[15] The linearity of demand and costs is not essential for the results, but simplifies their presentation. We consider the case of differentiated products for two reasons. The first reason is technical. If the goods were considered homogeneous, the competition in the export market would resemble Kreps and Scheinkman (1983). Development of such model in the presence of input markets would be difficult and complicate the exposition. Second, processed wood products, for instance fine paper, have several different quality dimensions, hence, it is plausible to assume that the final goods are differentiated.

subgame best-response function in price-space.

Result 1 *For any arbitrary level* $\overline{x}^i$*, there exists a unique price-pair* $\mathbf{A} = [p_A^i, p_A^j]$ *and* $\mathbf{B} = [p_B^i, p_B^j]$*, where* $p_A^j < p_B^j$*, such that*

$$r^i(p_A^j, c) = \rho^i(p_A^j, \overline{x}^i)$$
$$r^i(p_B^j, \overline{t}) = \rho^i(p_B^j, \overline{x}^i).$$

Hence, the relevant branches of $r^i\left(p^j, c\right)$*,* $\rho^i(p^j, x^i)$ *and* $r^i(p^j, c+\overline{t})$ *constitute the following subgame best-response function in price-space*

$$R^i(p^j, \overline{x}^i) \begin{cases} = r^i\left(p^j, c\right) & for \quad p^j < p_A^j \\ = \rho^i(p^j, \overline{x}) & for \quad p_A^j \leq p^j \leq p_B^j \\ = r^i(p^j, c+\overline{t}) & for \quad p^j > p_B^j. \end{cases}$$

Proof. See Appendix B. ■

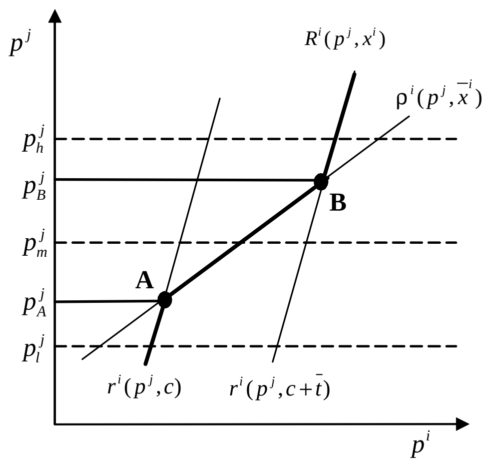

Figure 1: Function $R^i(p^j, x^i)$

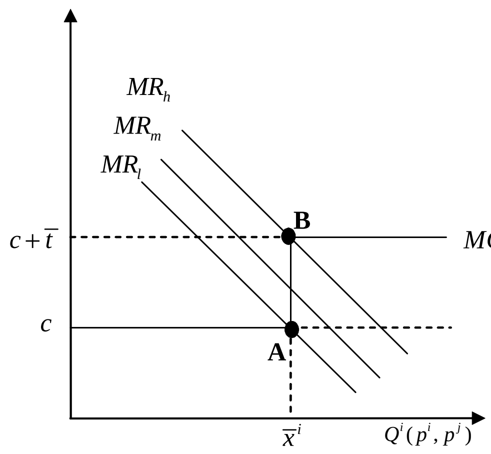

Figure 2: Decision in output space

In Figure 1, the bold line illustrates the best-response function for firm i. Given $x^i = \overline{x}^i$ equilibrium of the game can be found at the point of intersection between $R^i(p^j, x^i)$ and $R^j(p^i, x^j)$. The result is driven by the convexity of the marginal cost function illustrated in Figure 2. For low levels of $p^j < p_A^j$ the optimal response coincides with the function $r^i(p^j, c)$. The reason is that along this line firm i has enough timber inputs to satisfy any demand level between the lines $r^i(p^j, c)$ and $\rho(p^j, \overline{x}^i)$. Hence, the level of timber inputs is not binding constraint for firm i, and thus, the best response is identical to the standard Bertrand response with marginal cost c.

For higher p^j, the prices along the segment $r^i(p^j, c)$ no longer constitute a feasible strategies for firm i, because they imply $Q^i(p^i, p^j) > \bar{x}^i$ and a marginal cost $c + \bar{t}$. For this region the best response thus must coincide with $\rho^i(p^j, \overline{x}^i)$. In Figure 2 this branch is illustrated by the vertical segment of the marginal cost function MC. As the vertical segment increases, the marginal-cost of price-cutting (increasing production) increases when producing at $Q^i(p^i, p^j) = \bar{x}^i$. A higher $\bar{t}$ thus generates a disincentive to increase output in excess of $\overline{x}^i$, and firm i's price response coincides with $\rho(p^j, \overline{x}^i)$. This effect is, however, offset for high enough p^j. When $p^j > p^j_B$, the marginal revenue of increasing production, MR, is higher than marginal cost of increasing production beyond $\bar{x}^i$. It then follows that the best response-function $R^i(p^j, x^i)$ coincides with $r^i(p^j, c + \bar{t})$ at point $[r^i(p^j_B, c + \bar{t}), p^j_B]$.

These considerations indicate that an equilibrium which can be implemented through firms' pre-commitment to use domestic timber-inputs, lies between points **A** and **B**, in the region between Bertrand reaction functions $r^i(p^j, c)$ and $r^i(p^j_B, c + \bar{t})$. This region entails the relevant points which constitute a strategically stable equilibrium of the full game which will be analyzed below.

4 Timber Market: Capacity Decision and Timber Price Bargaining

This section characterizes the equilibria of the full game between the firms. First, assuming symmetric timber prices in each country, we solve for the equilibrium quantity of domestic timber inputs used by the exporting firms. Second, after solving for the optimal capacity levels in terms of timber inputs, we characterize the bargaining problem in domestic timber markets, the solution of this problem then determines the effective timber prices.

4.1 Demand for Domestic Timber

Following Maggi (1996), we solve for the symmetric equilibrium in timber-capacities x^i and x^j in three steps. First, based on the best-response function described in Result 1, we determine the price-pairs which can be implemented through firms' capacity decisions under different values of $\bar{t}$. Second, given the set of equilibrium candidates, we choose a strategically stable price equilibrium which implicitly determines the equilibrium levels of x^i and x^j. Finally, we analyze the equilibrium properties.

After timber price bargaining, firm i unilaterally chooses the amount of domestic timber it will use in production at the following stage. This problem can be formalized as follows

$$\max_{x^i} \pi^i = (p^i - c)Q^i(p^i, p^j) - t^i x^i \tag{4.1}$$

$$s.t. \quad p^j = R^j(p^i, x^j)$$

$$Q^f(p^i, p^j) = x^f, \quad f = i, j \tag{C1}$$

$$r^i\left(p^j, c\right) \leq p^i \leq r^i(p^j, c + \bar{t}) \quad s.t. \quad \bar{t} \leq \bar{t}^c \tag{C2}$$

The key in understanding the problem is in the constraints illustrating the price-pairs the firm i can implement through an appropriate level of x^i.

The first constraint in (4.1), $p^j = R^j(p^i, x^j)$, determines the price-pairs which can be implemented in the proceeding price-subgame for given x^j. This set is refined by the second constraint (C1), implying that both firms always produce at capacity; hence, the relevant price-pairs can be found on the isoquantity line $\rho^j(p^i, x^j)$.[16] Finally, the constraint (C2) establishes a lower and an upper bound for these prices. These bounds are determined by branches $r^i\left(p^j, c\right)$ and $r^i(p^j, c + \bar{t})$ of $R^i(p^j, x^i)$. The lower bound is readily fixed by the cost parameter c, but the region increases with higher levels of $\bar{t}$. However, there is an upper limit for prices which can be supported as an equilibrium. That is, there is a unique parameter value $\bar{t} = \bar{t}^c$ and a corresponding symmetric price $p^i_c = r^i(p^j_c, c + \bar{t}^c)$, above which an increase in prices leads to reduction in profits.[17]

[16] For the proof of (C1), see the Appendix B.

[17] Note that $r^i(p^j_c, c + \bar{t}^c)$ is linear and increasing in $\bar{t}$. Furthermore, symmetric price $p^i = a/(b - g)$ implies zero demand. Hence, there is $\bar{t}^0$ that satisfies $r^i(p^j, c + \bar{t}^0) = a/(b - g)$. By observation

A combination of these constraints determines a condition which the equilibrium price-pair must satisfy. Define $\mathbf{\Pi}^{\bar{t}}$ as a region consisting of price-pairs that satisfy (C2) for both firms. Furthermore, define $\mathbf{\Phi}^{x^j}$ as the set of price-pairs which satisfy (C1) for given x^j, and note that these prices lie on the isoquantity function $\rho^j(p^i, x^j)$. Using $\mathbf{\Pi}^{\bar{t}}$ and $\mathbf{\Phi}^{x^j}$ we obtain a set of price-pairs which can be implemented by an appropriate level of x^i

$$\mathbf{\Pi}^{\bar{t}} \cap \mathbf{\Phi}^{x^j}. \tag{C3}$$

In Figure 3, the bold lines illustrate the region $\mathbf{\Pi}^{\bar{t}}$ and the bold section of the isoquantity line $\rho^j(p^i, x^j)$ illustrates the condition (C3).

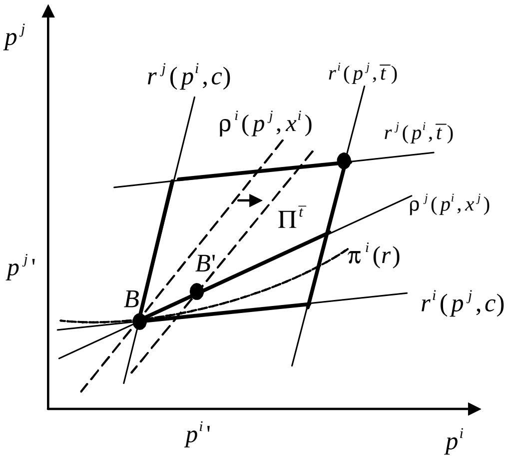

Figure 3

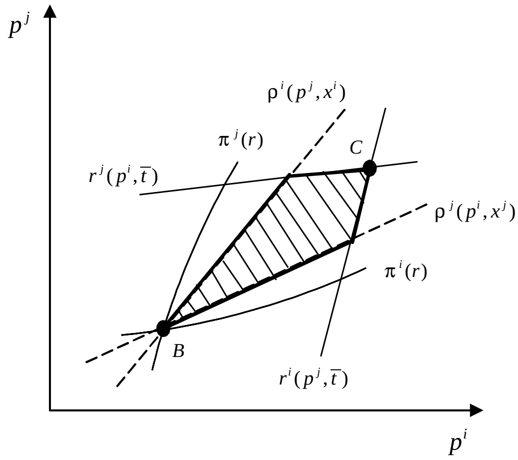

Figure 4

Having defined the condition the equilibrium price-pair must satisfy, we can determine the symmetric and strategically stable equilibria under different parameter values $\bar{t}$.[18] We begin the equilibrium analysis by examining the Cournot benchmark in price-space under symmetric timber prices, i.e. $t^i = t^j$. Let $\tilde{\pi}^i(r)$ denote the firm i's isoprofit curve yielding profit equal to r, i.e. $\tilde{\pi}^i(r) = \{p^i, p^j \geq 0; \pi^i(p^i, p^j) = r\}$. Since $\pi^i(p^i, p^j)$ is continuously differentiable for $Q^i(p^i, p^j) \leq x^i$, the isoprofit curve is smooth and differentiable. Because $\partial \pi^i / \partial p^j > 0$, when neither firm prices itself out of the market, an increase in p^j shifts $\pi^i(r)$ further away from the p^i axis, yielding higher

$\partial r^i(p^j, c + \bar{t}^0)/\partial \bar{t} < 1$ we infer that there is $\bar{t}^c < \bar{t}^0$ and $p^i_c = r^i(p^j_c, c + \bar{t}^c)$ under which a further increase in prices leads to reduction in profit as the rival can price the firm out of the market.

[18] Although the game allows for asymmetric outcomes, we focus on symmetric equilibria. Maggi (1996) examines asymmetric equilibria in more detail. It should, however, be noted that the main results remain unchanged in the case of asymmetric outcomes.

profits for firm i. It then follows immediately, that when $\partial p^j \partial x^i < 0$ a reduction in x^i is a dominating strategy for firm i.

Consider then figure 3 and the Bertrand equilibrium at point $\mathbf{B} = (\underline{p}^i, \underline{p}^j)$. At this point, the slope of $\pi^i(r)$ equals $r^j(p^i, c)$, and when $Q^f(\underline{p}^i, \underline{p}^j) = \underline{x}^f$ $(f = i, j)$, the isoquantity lines $\rho^i(p^j, \underline{x}^i)$ and $\rho^j(p^i, \underline{x}^j)$ trace through this point. By condition (C3) firm i can thus implement any price-pair on the isoquantity line $\rho^j(p^i, \underline{x}^j)$ within the region $\mathbf{\Pi}^{\bar{t}}$. Since at point $\mathbf{B}$ the isoquantity line $\rho^j(p^i, \underline{x}^j)$ is steeper than $r^j(p^i, c)$, a *reduction* in $\underline{x}^i$ shifts $\rho^i(p^j, \underline{x}^i)$ to left and implements a price-pair $\mathbf{B}' = (\underline{p}^{i\prime}, \underline{p}^{j\prime})$ on a higher isoprofit curve. This reflects the fact that when a firm sets its quantity, the price it can get for its products is increasing in rival's price. The shaded area in Figure 4 illustrates the set of feasible price-pairs which dominate the Bertrand equilibrium **B**.[19] Given the value of x^j, an optimal x^i is the one that implements a price pair which is as far away from the p^i-axis as possible and still has at least one point in common with the best response function $R^j(p^i, x^j)$.

Consider then the point $\mathbf{C} = (p^i_c, p^j_c)$ at the intersection between the lines $r^i(p^j, c+\bar{t}^c)$ and $r^j(p^i, c + \bar{t}^c)$ in Figure 4. This point represents a symmetric Cournot equilibrium. The reason is that at any other point within the shaded area between points **B** and **C** the firms have an incentive to reduce x^f. The only price pair within this region, in which neither firm can profit from a output reduction is point **C**, where the input level $x^j_c = Q^j(p^i_c, p^j_c)$ is firm j's best response to $x^i_c = Q^i(p^i_c, p^j_c)$.[20] Figure 5 shows that at point **C**, the slope of firm i's isoprofit function coincides with $\rho^j(p^i, x^j_c)$ and neither

[19] That is, these points lie on a higher or on the same isoprofit lines than point **B**.

[20] This is because within this region the slope of the firms' isoprofit function is lower than that of the rival's isoquantity function. Hence, the firms have an incentive to reduce x so as to implement a price pair on a higher isoprofit function.

firm has an incentive to increase or reduce x.

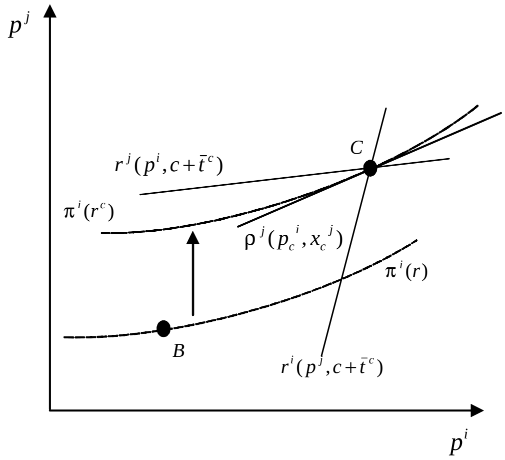

Figure 5

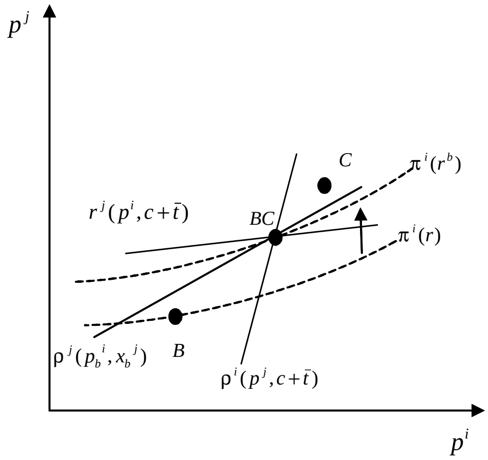

Figure 6

Figure 6 describes the equilibrium outcome under intermediate level of $\bar{t}$. For parameter values $\bar{t} < \bar{t}^c$, the Cournot outcome cannot be sustained as an equilibrium, because a lower cost of timber importation induces the firms to cut prices and increase production. To illustrate this, suppose that $\bar{t} < \bar{t}^c$ and both firms set their quantity of domestic timber inputs equal to x_c^i. The point **C**, however, does not survive the elimination of dominated strategies, because for given price p_c^i and isoquantity line $\rho^i(p^j, x_c^i)$ the optimal response for firm j is $p^j = r^j(p_c^i, c+\bar{t}) < p_c^j$. The reason is that the marginal revenue from expanding the production outweighs firm j's cost of timber importation. Repeating this exercise for any other point between the points **BC** and **C** readily implies that the only symmetric equilibrium surviving the elimination of dominated strategies is at point **BC**, where firm i produces a quantity $x_b^i = Q^i(p_b^i, p_b^j) > Q^i(p_c^i, p_c^j)$. In a similar manner as in the case of the Cournot equilibrium we can see that at any point below **BC** on the diagonal, a dominating strategy involves an output reduction. Hence, the symmetric equilibria under parameter values $\bar{t} < \bar{t}^c$ are located at the intersection between lines $r^i(p^j, c+\bar{t})$ and $r^j(p^i, c+\bar{t})$.

The following result summarizes these findings

Result 2 *Suppose that timber prices are symmetric in producing countries. In equi-*

librium each exporting firm produces with domestic timber, i.e.

$$x^f = Q^f(p^i, p^j) \qquad f = i, j$$

and the symmetric price-equilibrium is determined by the cost of timber importation. In particular, when timber importation is costly, i.e. $\bar{t} > \bar{t}^c > t^i$*, the equilibrium prices coincide with Cournot prices. For parameter values* $\bar{t}^c > \bar{t} > t^i$*, the equilibrium prices coincide with Bertrand-prices with marginal cost* $c + \bar{t}$*. Formally:*

$$\begin{aligned} \mathbf{P}^b &= \left\{(p_b^i, p_b^j) : p_b^i = r^i \left[r^j(p_b^i, c+\bar{t}), c+\bar{t}\right]\right\} \qquad &for \quad t^i < \bar{t} \leq \bar{t}^c, \quad and \\ \mathbf{P}^c &= \left\{(p_c^i, p_c^j) : p_c^i = r^i \left[r^j(p_c^i, c+\bar{t}^c), c+\bar{t}^c\right]\right\} \qquad &for \quad \bar{t} \geq \bar{t}^c. \end{aligned}$$

The demand for domestic timber demand is (weakly) decreasing in $\bar{t}$*, but independent of symmetric changes in* t^i *and* t^j*.*

Proof. See Appendix B. ■

Result 2 establishes two equilibrium properties which are relevant to the analyses of the timber market and the optimal forest conservation policy. First, the cost of importing timber determines the price of the final good in the export market. High unit cost of timber importation increases the prices of the final-goods, for it allows the firms to credibly contract their output through the established a pre-commitment to lower output capacity. A lower cost of timber importation, in turn, is conducive to tougher price competition and higher output levels in the export-market, and consequently, increases the demand for domestic timber.

Second, although domestic timber prices influence the firms' cost structures and profits, their role in the export-market is relatively small. When $\bar{t} \leq \bar{t}^c$ domestic timber prices do not influence the equilibrium outcome of the game in price-space. This result is robust to symmetric and asymmetric changes in t^i and t^j, but for parameter values $\bar{t} > \bar{t}^c$ the impact of an *asymmetric* change in t^i requires more detailed comparative statics. This issue will be examined in the following subsection.

4.2 Timber Price Bargaining

In most large wood producing countries, buyers can employ monopsony power in the timber price negotiations with the forest owners.[21] Hence, the degree of competition on timber market depends on the forest owners' bargaining power on the other side of the market.[22] A convenient way to capture the potential imperfections in timber market is to assume that the price is determined through a Nash-bargaining process between the firm and forest owners, subject to the constraint that domestic firm unilaterally decides upon the use of timber. In modeling the bargaining process, we assume that the firms producing the non-tradable good are price takers and the market price is determined by the negotiations between the exporting firm and the forest owners.[23]

In each country the firm and the forest owners first observe the available harvest of a representative forest owner $x \leq M - \overline{m}$. The bargainers then agree on timber prices and the market clears so that each forest owner in the market sells her harvest to firm i or to other companies in the forest sector. We restrict the bargainers to condition the prices on the actual harvest and output decisions of firm i.[24] Firm i cannot condition timber prices on the elasticity-factor describing the extent to which timber price influences the outcome of the game in the export-market.[25]

In the case of disagreement, forest owners' utility coincides with the reservation utility $U^0(0) = v(M)$. The target function of a representative forest owner thus becomes $\widetilde{U}(t^i) = U(t^i, x^*) - U^0(0) = \left[t^i - \widehat{t^i}(\overline{m})\right] x^*$, where $x^* = M - \overline{m}$. Since the output of firm i is determined by $\bar{t}$ and the quantity of timber traded in the domestic market is unilaterally decided by firm i, the target functions of the forest owners can

[21] For empirical evidence on oligopsony power on timber market see, e.g. Bergman and Brännlund (1995).

[22] In Finland the practice of price agreements, for timber sales was common in the 1990s. The agreements were an outcome of a collective bargaining process that determined annual price recommendations for forest owners.

[23] This can be justified by the notion that since the profit tend to zero in domestic market under perfect competition, these firms have reduced incentives to engage in timber price negotiations.

[24] See, e.g. Kuhn (1997).

[25] The reason for this assumption is intuitive. Although lower timber prices might induce an expansion in the total demand of domestic timber, this output effect does not carry over to individual forest owner's welfare, as her timber supply is limited to x^*.

be combined to obtain the following collective target function

$$\widetilde{U}(t^i) = \begin{cases} \left[t^i - \widehat{t^i}(\overline{m})\right] x^i_b(\overline{t}) & for \quad \overline{t} \leq \overline{t}^c \\ \left[t^i - \widehat{t^i}(\overline{m})\right] x^i_c(\overline{t}^c) & for \quad \overline{t} \geq \overline{t}^c, \end{cases}$$

where $x^i_b(\overline{t}) = Q^i(p^i_b, p^j_b)$ and $x^i_c(\overline{t}^c) = Q^i(p^i_c, p^j_c)$ denotes the fixed demand of timber inputs determined by the cost parameter $\overline{t}$.

Firm i's target function is $\widetilde{\pi}^i = \pi^i - \overline{\pi}^i$, where $\overline{\pi}^i$ represents a disagreement point at which the firm withdraws from negotiations and shifts to importation. For parameter range $\overline{t} > \overline{t}^c$ the threat point is at $\overline{t}^c$, because for $\overline{t}^c < t^i$ the costs become too high and the firm will price itself out of the market. Hence, by (3.1) the firm i's target function becomes

$$\widetilde{\pi}^i(t^i) = \begin{cases} (\overline{t} - t^i) x^i_b(\overline{t}) & for \quad \overline{t} \leq \overline{t}^c \\ (\overline{t}^c - t^i) x^i_c(\overline{t}^c) & for \quad \overline{t} \geq \overline{t}^c, \end{cases}$$

where $0 \leq \gamma \leq 1$ reflects the bargaining power of the forest owners.

In accord with Nash (1950), the bargaining problem can be stated as

$$\begin{aligned} \max_{t^i \in [\widehat{t^i}, \overline{t}]} \Omega(t^i) &= \widetilde{U}(t^i)^{\gamma} \widetilde{\pi}^i(t^i)^{1-\gamma} \\ s.t. \quad x^i &= x^i(\overline{t}) \end{aligned}$$

Solving the first-order condition for t^i yields

$$t^i_s = \begin{cases} \gamma\overline{t} + (1-\gamma)\,\widehat{t^i}(\overline{m}) & for \quad \overline{t} \leq \overline{t}^c, \\ \gamma\overline{t}^c + (1-\gamma)\,\widehat{t^i}(\overline{m}) & for \quad \overline{t} > \overline{t}^c, \end{cases} \tag{4.2}$$

Proposition 1 characterizes this solution.

Proposition 1 *When forest owners' reservation price is lower than the cost timber importation, i.e.* $\widehat{t^i} < \overline{t}$, *the firm and forest owners reach an agreement on timber price. The agreement has the following properties:*

(i) *Lower parameter value* $\overline{t}$ *depresses domestic timber prices and reduces the individual forest owner's harvest revenue.*

(ii) *Tighter conservation requirement reduces the forest owner's harvest revenue and* *increases the domestic timber price.*

Proof. The proof follows directly from the observation that $\partial t_s^i / \partial \overline{m} = (1 - \gamma) \left[\partial \widehat{t^i}(\overline{m}) / \partial \overline{m} \right] \geq 0$ and $\partial t_s^i / \partial \overline{t} = \gamma \geq 0$. ■

The solution to the bargaining problem determines the division of rent generated by the difference between the admissible timber prices and cost of timber importation. The intuition is as follows. Result 2 readily shows that for $t_s^i \leq \overline{t}$ timber demand is fixed and determined by $\overline{t}$. Furthermore, the bargainers cannot condition timber prices on the output decision of the outside firm, indicating that a lower value of $\overline{t}$ decreases the rent and imposes downward pressure on timber prices. Raising conservation requirement, in turn, increases the forest owners' reservation price and timber prices. Both of these effects tend to reduce forest owners' harvest revenue by decreasing the difference between the highest and the lowest admissible timber price, respectively.

As is usual in bargaining situations, the extent to which the outside options of the bargainers affect the outcome depends on their bargaining power. If the forest owners' bargaining power is high (i.e. $\gamma \to 1$), they capture the entire rent generated by the lower price of domestic inputs, i.e. $t_s^i = \overline{t} > \widehat{t^i}$. In this case raising conservation requirement has no effect on timber prices, because a further increase in timber price would induce firm i to shift to importation and the deal becomes unfeasible. By similar lines of reasoning it is easy to see that a reduction in $\overline{t}$ passes through to timber price in full.

When the firm has all the bargaining power, the timber price coincides with the reservation price. Hence, a lower importation costs does not influence the timber price as the deal becomes unfeasible from the forest owners' viewpoint. Furthermore, the effect of raising conservation requirement pass to timber price level in full as the change in timber price equals the loss in forest owners' timber revenue.

Before turning to conservation issues it useful to discuss the implications of conservation on firms' use of domestic timber. To this end, consider an increase in forest conservation level $\overline{m}$. This increases timber prices by $\partial t_s^i / \partial \bar{m}$ and the effects on industry equilibrium are as follows:

Result 3 *When the cost of importation is low, a raise in the conservation requirement* *has no effect on firms' timber demand. Under high $\bar{t}$, tighter conservation requirement in country i increases firm j's use of timber inputs and output. This effect reduces firm i's profit, timber demand and hence, its market share:*

$$\frac{d\pi^i}{dt^i} = -x_b^i \frac{dt_s^i}{d\overline{m}} \qquad for \quad t_s^i < \bar{t} \leq \bar{t}^c$$

$$\frac{d\pi^i}{dt_s^i} = \frac{d\pi^i}{dx_b^j}\frac{dx_b^j}{dt_s^i} - x_b^i \frac{dt_s^i}{d\overline{m}} < 0 \qquad for \quad \bar{t} \geq \bar{t}^c > t_s^i,$$

where $\frac{d\pi^i}{dx_b^j}\frac{dx_b^j}{dt_s^i} < 0.$

Proof. See Appendix B. ■

The first part of Result 3 follows immediately from Result 2, which established that asymmetric changes in timber prices do affect the export market equilibrium, when $t_s^i < \bar{t} < \bar{t}^c$. However, an increase in timber price induces an asymmetric change in the competition environment and affects the equilibrium, when the capacity constraint is rigid. The intuition is the following. Higher timber price increases firm i's marginal cost of production. As in standard Cournot-game, a higher marginal cost of production, $c + t_s^i$ induces firm j to increase its capacity. Firm i anticipates this and is induced to reduce its capacity to counter the downward pressure on prices and profit. Therefore, raising conservation requirement applied to domestic forest means that the firm i's output is in the export market becomes replaced by that of the firm j.

5 Optimal Forest Conservation Policy

Proposition 1 and Result 3 characterize the behavioral constraints the regulator faces in the design for optimal conservation policy. The constraints illustrate how an asymmetric changes in the conservation requirements influence the market outcomes in both domestic timber markets and the export market for final goods. These results constitute the behavioral constraints in the design for optimal conservation policy in the exporting countries.

Regulator of country i chooses $\overline{m}$ to maximize welfare. By choice of units, we set the total population of country i equal to one and let $\overline{n}^i < 1$ denote the proportion of forest owners. Hence, the regulator's program can be written as

$$\max_{\overline{m}} G^i = \overline{n}^i U[x(t^i)] + \pi^i(p^i, p^j; t^i) + \pi^d(r^d, t^i) + (1 - \overline{n}^i) S(t^i, \overline{m}) \quad s.t. \tag{5.1}$$

$$t^i = t^i_s; \tag{BC1}$$

$$\frac{dx^j}{dt^i_s}\frac{dt^i_s}{d\overline{m}} = 0 \quad for \quad \bar{t} < \bar{t}^c; \qquad \frac{dx^j}{dt^i_s}\frac{dt^i_s}{d\overline{m}} > 0 \quad for \quad \bar{t} \geq \bar{t}^c \tag{BC2}$$

where expressions (BC1) and (BC2) restate the behavioral constraints of Proposition 1 and Result 3. Constraint (BC1) expresses the effect of policy decision on timber prices. Constraint (BC2) describes the effects of conservation policy on the equilibrium in the export-market.

The welfare-analysis is in three steps. First, we provide a general first-order condition characterizing the solution to (5.1). Using this condition, we determine the first-best policy. Finally, we examine the implications of the behavioral constraints on the optimal policy decision and examine circumstances which give a raise to policy distortions from the first-best.

The first-order condition for a solution to problem (5.1) is

$$\frac{\partial G^i(\overline{m}^*)}{\partial \overline{m}} = \overline{n}^i \left[-t^i_s + \frac{\partial v(\overline{m}^*)}{\partial \overline{m}} + \frac{\partial t^i}{\partial \overline{m}} x^* \right] + \frac{\partial \pi^i}{\partial \overline{m}} + (1 - \overline{n}^i) \frac{\partial S(t^i, \overline{m})}{\partial \overline{m}} = 0. \tag{5.2}$$

Observe that the effect of higher timber prices on domestic timber market and on the domestic market for non-tradable goods are transactions within the economy.[26] Therefore, we can rearrange the above expression to obtain

$$\frac{\partial G^i(\overline{m}^*)}{\partial \overline{m}} = -\overline{n}^i t^i_s + \frac{\partial Q^i(p^i, p^j)}{\partial \overline{m}}(p^i - c) + (1 - \overline{n}^i) \frac{\partial S(t^i, \overline{m})}{\partial \overline{m}} = 0$$

Using (5.2) we obtain a term Δ^i which can be used to relate the optimal policies

[26] That is,

$$\frac{\partial(\overline{n}^i t^i x)}{\partial \overline{m}} = \frac{\partial[t^i Q^i(p^i, p^j) + t^i q^d]}{\partial \overline{m}} \quad \text{and} \quad \frac{\partial[d(r^d) r^d]}{\partial \overline{m}} = \frac{\partial(r^d q^d)}{\partial \overline{m}}.$$

to the first-best:

$$\Delta^i = \frac{\partial u[d(r^d)]}{\partial d(r^d)} \frac{\partial d(r^d)}{\partial r^d} \frac{\partial r^d}{\partial \overline{m}} + \frac{\partial v(\overline{m})}{\partial \overline{m}} - \overline{n}^i t_s^i \tag{5.3}$$

In the present model the definition of the usual first-best rule in environmental economics is as follows: The marginal social benefit of forest conservation, $\partial v(\overline{m})/\partial \overline{m}$, equals the combined economic loss in terms of reduction in harvesting, $-\overline{n}^i t_s^i$ and the loss in consumer surplus in the market for non-tradable goods. Formally, the first-best policy implies $\Delta^i = 0$. Since $v(\overline{m})$ is strictly concave in $\overline{m}$, a policy scheme with $\Delta^i > 0$ indicates a policy distortion from the first-best as it entails lower conservation requirement than warranted by the marginal social benefit of forest conservation. A similar reasoning indicates that when $\Delta^i < 0$, the harvesting constraint is tighter than the first-best.

The conservation policy influences the distribution of rent within the forest sector, because it affects the division of surplus between the firms and forest owners in the form of higher timber prices.[27] This effect, however, occurs *within* the economy and should not exert distortions on the conservation policy. It then follows that a potential policy-distortion must be driven by the reasons related to the firms' competitiveness, which are treated in more detail in results 2 and 3. Proposition 2 examines the policy implications of these results:

Proposition 2 *Optimal policy applies first-best harvesting constraints to forest owners, unless the cost of importing timber inputs is high enough. Specifically,*

(**i**) *For low cost of timber importation, $t^i < \bar{t} < \bar{t}^c$, optimal policy coincides with the first-best.*

(**ii**) *For high cost level, $\bar{t} > \bar{t}^c$, optimal policy is lower than the first-best.*

Proof. A full description of optimal policies is in Appendix C. ■

Recall that Result 2 indicated that when the cost of timber importation is sufficiently low, the market equilibrium is determined by cost parameter $\bar{t}$ and asymmetric changes in domestic timber prices do not affect the equilibrium. Result 3, in turn, shows

[27] Observe that for $\gamma = 0$ term $U(x) = v(M)$, hence, conservation policy does not influence forest owners' welfare. A similar line of reasoning applies to case $\gamma = 1$. In such case $\partial \pi / \partial \overline{m} = 0$.

that in Cournot equilibrium a small asymmetric change in domestic timber price induces a reduction in domestic firms' market share, indicating that around symmetric equilibrium a small reduction in the first-best conservation requirement increases the income of domestic country.[28]

The implications on the optimal conservation policy can be understood intuitively as follows. Although the wood processing industry does not engage in timber importation, the mere opportunity for this influences the market outcome and may allow for the design for a first-best forest conservation policy. This is because when imported timber is more affordable, domestic forest resources becomes a less important factor in the competition for international market-shares. As domestic timber prices do not affect the international market for processed wood-products, the opportunity cost of forest conservation becomes lower. As a result, the regulator can increase the conservation requirements and implement a first-best conservation program.[29]

When the cost of timber importation is high enough so that importation is an unfeasible option for the firms, the price of domestic timber essentially determines the competitive environment in the export market. The opportunity cost of forest conservation becomes thus higher as it affects the domestic income not only through higher timber prices, but also by diminishing domestic profit in the export market. Anticipating this, a welfare maximizing regulator is induced to apply lower harvesting constraints to the forest owners so as to increase the domestic income.

6 Conclusion

This paper examined optimal forest conservation policy and international trade in forest products with an attention to country-specific timber markets and timber importation. The analysis demonstrates that when timber importation is costly, the firms can establish a credible pre-commitment to use less domestic timber inputs to sustain higher prices in the export-market. The commitment device is especially effective, when the

[28] A small change in timber price refers to a change that does not change the set of relevant equilibria. That is, the ex-post timber price satisfies $t^i < \bar{t}$.

[29] In particular, in the present model a first-best conservation requirement constitutes an optimal policy insofar as domestic forest owners survive on the market for industrial roundwood, i.e. $\hat{t}(\bar{m}) \leq \bar{t} < \bar{t}^c$.

unit cost of timber imports is high enough, so that the market-outcome coincides with that of Cournot competition. However, when the cost of timber imports becomes lower, the competition on the export market becomes tougher and the prices coincide with a Bertrand benchmark. Tougher competition in export-market also adds downward pressure on prices in local timber markets, because the outside option for the firms in the form of timber importation becomes more affordable.

The welfare analysis of forest conservation and the policy propositions therein introduce qualifications to the findings in the literature on environmental policy and international trade. Although the game allows for the Cournot and Bertrand outcomes, the optimal policy exhibits distortions in a rather limited circumstances. Namely, it is optimal to apply inefficiently low harvesting constraint to forest owners, when the price imported timber is high. However, when timber importation becomes less costly, the optimal policy coincides with the first-best. This result undermines the usual finding that under oligopoly-competition the optimal policy decision is sensitive to assumptions about the mode of competition.

The result can be understood intuitively as follows. When the cost of timber importation is high, the competitive environment of the exporting firms is determined by the cost of producing with domestic timber. Under these circumstances forest conservation and the resulting increase in timber prices involves a cost in the form of lower domestic income due to reduced market share in the export market. This effect is less pronounced when the price of imported timber is low. The reason is that the firms' behavior in the export market is guided by the cost of timber importation. As a result, conservation policy and its effect on timber prices does not play a role in the export market, allowing the government to raise the conservation requirements with lower opportunity cost.

Appendix A

Proof of (2.3). Reservation price $\hat{t}$ satisfies $U(x^*)|_{t^i=\hat{t}^i} = U(0)$. Where $x^* = \arg\max U(x)$. The first property of (2.3) implies that under binding harvesting constraint $x^* = M - \overline{m}$. It can be shown that for sufficiently high G any constraint satisfying $\overline{m} > 0$ is binding. Hence, differentiating $U(x^*)|_{t^i=\widehat{t^i}} = U(0)$ with respect to $\overline{m}$ we obtain $d\widehat{t}/d\overline{m} = [t^i - v'(\overline{m})]/(M - \overline{m}) \geq 0$. Under binding constraint, forest owners' harvesting decision can be formalized into following Lagrangian:

$$L(x, \lambda) = \widehat{t}x + v(\overline{m}) + \lambda(M - \overline{m} - x).$$

The first-order conditions are

$$\begin{aligned} \frac{\partial L(x,\lambda)}{\partial x} &= \widehat{t} - v'(\overline{m}) - \lambda = 0 \\ \frac{\partial L(x,\lambda)}{\partial \lambda} &= M - \overline{m} - x = 0. \end{aligned}$$

This implies that $[t^i - v'(\overline{m})] = \lambda > 0$, hence $d\widehat{t}/d\overline{m} > 0$. ■

Appendix B

Proof of Result 1. Consider firm i's optimal response in price and output space as depicted in Figures 1 and Figure 2, respectively. Keeping x^i fixed at, say $\overline{x}^i$, firm i chooses price level to maximize profits. Given p^j and cost parameters t^i and $\bar{t}$, profit maximization amounts to picking a price level p^i such that marginal cost of price-cutting, MC, equals firm i's marginal revenue of increasing production, MR.

Suppose, first that $p^j = p^j_l < p^j_A$, hence $r^i(p^j_l, c) > \rho^i(p^j_l, \overline{x}^i)$. This implies that MR crosses MC before $\overline{x}^i$ and therefore $r^i(p^j_l, c)$ is the optimal reply, for $r^i(p^j_l, c)$ implies $Q^i[r^i(p^j_l, c), p^j_l] < \overline{x}^i$. Then let $p^j = p^j_m \in [p^j_A, p^j_B]$. This implies that MR crosses MC at its vertical segment and $\overline{x}^i$ is the optimal output. Hence, optimal reply is $\rho^i(p^j_m, \overline{x}^i)$ that satisfies $r^i(p^j_m, c) < \rho^i(p^j_m, \overline{x}^i) < \rho^i(p^j_m, c + \bar{t})$. Finally, suppose that $p^j = p^j_h \geq p^j_B$. This implies that $\rho^i(p^j_h, \overline{x}^i) > r^i(p^j_h, c + \bar{t})$ and MR crosses MC at $c + \bar{t}$, thus optimal reply coincides with $r^i(p^j_h, c + \bar{t})$. ■

Proof of Constraints (C1) and (C2). Constraint (C1) ensures that firm i always produces at capacity, $x^i = Q(p^i, p^j)$. By contradiction, consider an equilibrium price-pair $\mathbf{P}^o = (p^i_o, p^j_o)$ and capacity level $\overline{x}^i$ that satisfies $\overline{x}^i > Q^i(p^i_o, p^j_o)$. Thus, firm i can reduce its costs by using less timber inputs. This implies that optimal capacity

x_o^i satisfies $\rho^i(p_o^j, \overline{x}_o^i) = r^i(p_o^j, c)$, and $x_o^i = Q^i(p_o^i, p_o^j)$.

Similar logic applies if $\overline{x}^i < Q^i(p_u^i, p_u^j)$. By Result 1, price-pair $\mathbf{P}^u = (p_u^i, p_u^j)$ lies on the segment $r^i(p^j, c+\overline{t})$ on $R^i(p^j, \overline{x}^i)$. Hence, firm i can reduce its costs by substituting timber imports by domestic inputs. This increases profit without affecting the equilibrium prices. It follows that $N^i x^* \geq Q^i(p^i, p^j) : p^i, p^j \in \Pi^{\overline{t}}$ optimal x^i satisfies $x^i = Q(p^i, p^j)$.

Constraint (C2) implies that the set of feasible prices for firm i is determined by $\overline{t}$, and the upper bound for these prices is:

$$\begin{array}{lll} \overline{p}^i, \overline{p}^j : r^i(\overline{p}^j, c+\overline{t}) = r^j(\overline{p}^i, c+\overline{t}) & for & \overline{t} < \overline{t}^c \\ p_c^i, p_c^j : r^i(p_c^j, c+\overline{t}^c) = r^j(p_c^i, c+\overline{t}^c) & for & \overline{t} \geq \overline{t}^c. \end{array}$$

To show that prices $\overline{p}^i > p_c^i$ are not feasible we will establish that there exists a price-pair (p_c^i, p_c^j) that lies in the intersection between $r^i(p^j, c+\overline{t}^c)$ and $r^j(p^i, c+\overline{t}^c)$, so that a symmetric price increase generated by higher $\overline{t}$ induces a reduction in firms' profit. To see this note that for a symmetric price $p^0 = a/(b-g)$ it holds that $Q^i(p^0, p^0)$. Using function $r^i(p^j, c+\overline{t}^c)$ we can solve for a parameter value $\overline{t}^0$ generating this symmetric price, $\overline{t}^0 = a/(b-g) - c$. Next, observe that $\partial r^i(p^j, c+\overline{t})/\partial\overline{t} = \dfrac{1}{2}$. Hence, given that $\overline{p}^i - \overline{t} - c > 0$ for $\overline{t} < \overline{t}^0$, there must be a unique $\overline{t}^c$ st.

$$\begin{array}{lll} \dfrac{\partial Q^i[r^i(p^j, c+\overline{t}), r^j(p^i, c+\overline{t})]}{\partial \overline{t}} \geq 0 & for & \overline{t} \leq \overline{t}^c \\ \dfrac{\partial Q^i[r^i(p^j, c+\overline{t}), r^j(p^i, c+\overline{t})]}{\partial \overline{t}} \leq 0 & for & \overline{t} \geq \overline{t}^c. \end{array}$$

Price $\overline{p}_c^i = r^i(p_c^j, c+\overline{t}^c)$ is thus the highest feasible price under parameter values $\overline{t} \geq \overline{t}^c$.
■

Proof of Result 2. First, observe that $0 < \partial r^j(p^i, c+\overline{t})/\partial p^i < \partial \rho^j(p^i, x^j)/\partial p^i < 1$. Then, define a region $\mathbf{\Pi}^{\overline{t}^c}$ and a unique $x^j = x_c^j$, for which $r^i(p^i, c+\overline{t}^c)$ traces through a point, $\mathbf{P}^c = (p_c^i, p_c^j)$ (on the diagonal), at this point the slope of firm i's isoprofit function π^i equals $\rho^j(p^i, x_c^j)$. $\mathbf{P}^c$ is illustrated in Figure 5.

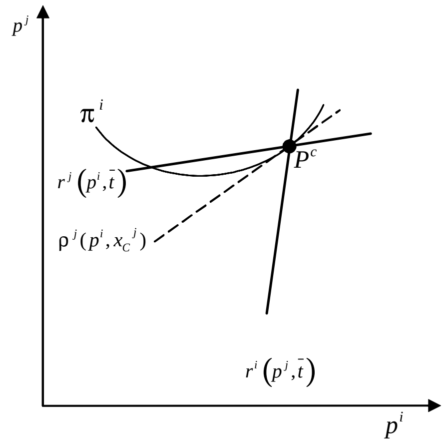

Figure 7: Parameter $\bar{t}^c$

First , consider the case $\bar{t} < \bar{t}^c$. To verify that $\mathbf{P}^b = (p_b^i, p_b^j)$ constitutes a stable equilibrium of the full game, we need show that when $x^j = Q^j(p_b^i, p_b^j)$, optimal x^i for firm i is $x_b^i = Q^i(p_b^i, p_b^j)$. Note that for given x_b^j, symmetric pair $\mathbf{P}^b$ is the highest point that satisfies (C2), and $\bar{t} < \bar{t}^c$ implies that point $\mathbf{P}^b$ lies lower on the diagonal than $\mathbf{P}^c$. Hence, the slope of $\rho^j(p^i, x_b^j)$ is higher than that of the highest isoprofit function, ensuring that $x_b^i = Q^i(p_b^i, p_b^j)$ is optimal capacity level for firm i. By symmetry, this is the unique symmetric equilibrium.

To show that $\mathbf{P}^c = (p_c^i, p_c^j)$, is the unique equilibrium when $\bar{t} \geq \bar{t}^c$, we need to check that for $x^j = Q^j(p_c^i, p_c^j)$ firm i's optimal choice is $x^i = Q^i(p_c^i, p_c^j)$. Firm i observes that for suitable x^i it may implement any price-pair that satisfy (C3). For $x^j = x_c^j$ and $\bar{t} \geq \bar{t}^c$, the highest admissible price-pair is $\mathbf{P}^c$. By definition of $\bar{t}^c$, price-pair $\mathbf{P}^c$ yields highest profit for i, hence, optimal x^i is such that $\rho^i(p^j, x_c^j)$ intersects $\rho^j(p^i, x_c^j)$ at point $\mathbf{P}^c$. Symmetry implies that (x_c^i, x_c^j) is unique equilibrium.

The proof of the result that timber demand is weakly decreasing $\bar{t}$ and independent of t^i follows immediately from constraint (C1). ■

Proof of Result 3. The proof amounts to checking whether an asymmetric change in t^i influences the equilibrium outcome of the game played by the firms in the export-market. Result 2 establishes that when $\bar{t} \leq \bar{t}^c$, regardless of parameter values

$t^i < \bar{t}$, a small change in t^i does not influence the outcome of the game, because the symmetric equilibrium is determined by the best-response functions $r^i(p^j, c+\bar{t})$ and $r^i(p^j, c+\bar{t})$. Hence, we focus on the case $\bar{t} \leq \bar{t}^c$.

For $\bar{t} > \bar{t}^c$ the equilibrium output is given by $Q^i(p_c^i, p_c^j)$, where (p_c^i, p_c^j) lies at the intersection between functions $\rho^i(p^j, x_c^i)$ and $\rho^j(p^i, x_c^j)$. To illustrate the Cournot conjectures in price-space consider firm i's optimal x^i for any given x^j. That is, firm i chooses its capacity such that $\rho^i(p^j, x^i)$ traces through the point of tangency between the highest isoprofit function and $\rho^j(p^i, x^j)$. These points constitute the following continuous line in price space

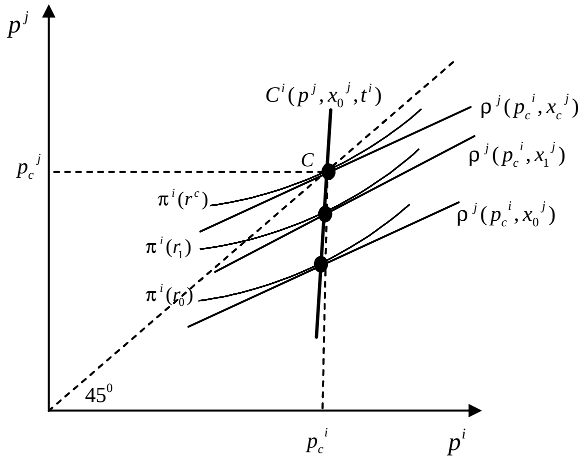

Figure 7: Cournot equilibria in price space

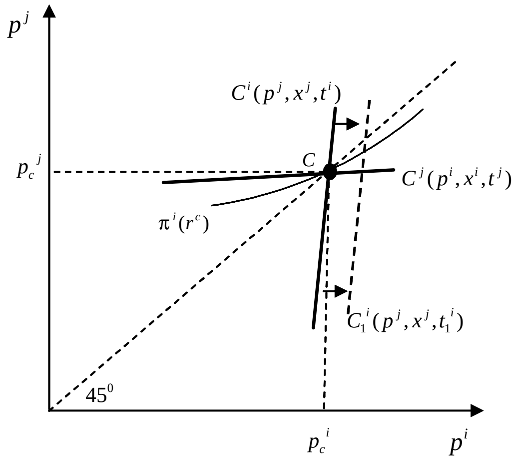

Figure 8: Asymmetric change in t^i

Figure 7 illustrates the line that depicts the potential Cournot equilibria under different x^j. A closed form expression for this line is

$$C^i(p^j, x^j, t^i) = \frac{1}{2b^2 - g^2}\left[bgp^j + ab + (c + t^i)(b^2 - g^2)\right], \tag{6.1}$$

The effect of an asymmetric increase in t^i is depicted in Figure 8 in which the higher t^i shifts $C^i(p^j, x^j, t^i)$ further away from p^j axis which reduces firm i's profit. Using (6.1) this be formalized as follows

$$\frac{dC^i(p^j, x^j, t^i)}{dt^i} = \frac{(b^2 - g^2)}{2b^2 - g^2} > 0,$$

and for firm j

$$\frac{dC^j(p^i, x^i, t^j)}{d\overline{m}} = \frac{bg}{2b^2 - g^2}\frac{dp^i}{dt^i} = \frac{bg}{2b^2 - g^2}\frac{(b^2 - g^2)}{2b^2 - g^2}\frac{\partial t^i}{\partial \overline{m}} > 0$$

where $gb/(2b^2 - g^2) < 1$. Hence, a raise in t^i increases the prices of each firm. Property $[dC^j(p^i, x^i, t^j)/dt^i] < [dC^i(p^j, x^j, t^i)/d\overline{m}]$ and equilibrium condition (C1) imply that $\partial Q^i(p_c^i, p_c^j)/\partial t^i \equiv (\partial x_c^i/\partial t^i) < 0$ and $\partial Q^j(p_c^i, p_c^j)/\partial t^i \equiv (\partial x_c^j/\partial t^i) > 0$. Thus, the output of the firm i (j) decreases (increases) as t^i increases. Proposition 1 and the observation that in Cournot equilibrium an increase in the firm j's output reduces firm i's profit thus indicate that higher conservation requirement reduces the output and profit for firm i. ■

Appendix C

Proof of Proposition 2. For expositional purposes we use the following notation: when $N^i x^* \geq Q(p_b^i, p_b^j) \geq N^j x^*$ the share of landowners in country i (j) is denoted by L (S).

The proof is in three parts. We show that: (**i**) when $\bar{t} < \bar{t}^\alpha < \bar{t}^c$ the regulator has no incentives to distort the policy from the first-best level; (**ii**) for $\bar{t}^\alpha < \bar{t} < \bar{t}^c$ optimal policy imposes $\Delta^i > 0$, if $Q^i(p_b^i, p_b^j) \geq N^i x^*$; and (**iii**) when $\bar{t} \geq \bar{t}^c$ optimal policy satisfies $\Delta^i > 0$.

(**i**) Result 2 and Lemma 1 imply that for $t^i < \bar{t} < \bar{t}^\alpha$ conservation requirement is not relevant to the equilibrium outcome of the game. The reason is that for these parameter-values $dx^i/d\overline{m} = 0$. The remainder of the proof thus focuses on the two relevant cases.

(**ii**) If $(N^i, N^j) = (S, S)$ a marginal change in $\overline{m}$ does not influence equilibrium price-pair, for both firms are importing timber, hence $\partial x^i/\partial x^j = 0$. When $(N^i, N^j) = (L, S)$, if $\bar{t} < \bar{t}^\alpha < \bar{t}^c$, equilibrium property $p^i \notin \Pi^{\bar{t}} \cap \mathbf{\Phi}^{x_c^j}$ ensures that change in $\overline{m}$ has no impact on x^i, as it only increases firm i's costs without affecting the price equilibrium..

Under asymmetric supply shortages, $(N^i, N^j) = (S, L)$ and $\bar{t}^\alpha < \bar{t} < \bar{t}^c$, absent binding harvesting constraints the equilibrium price lies at the intersection between

$\rho^i(p^j, x^i_c)$ and $\rho^j(p^i, x^j_\alpha)$[30] along $r^i(p^j, c+\bar{t})$. It is straightforward to see that tighter harvesting constraints imply a further reduction in the available forest stock in country 1. This shifts the intersection between $\rho^i(p^j, x^i)$ and $r^i(p^j, c+\bar{t})$ toward firm j's most preferred point, which is the intersection between $\Psi^j(p^i, \bar{t})$ and $r^i(p^j, c+\bar{t})$. That is, firm j expands its output to implement a price-pair that lies closer to $\Psi^j(p^i, \bar{t})$ shifting the market share away from firm i. Therefore, we conclude that

$$\Delta^i = -(p^i - c - \bar{t})\frac{\partial Q^i(p^i, p^j)}{\partial p^j}\frac{\partial p^j}{\partial x^j}\frac{\partial x^j}{\partial \overline{m}} > 0 \qquad for \quad \bar{t}^\alpha < \bar{t} < \bar{t}^c;\ (N^i, N^j) = (S, L).$$

(**c**) Using Lemma 1, we obtain

$$\frac{\partial \pi^i(p^i_c, p^j_c)}{\partial \overline{m}} = \left[\frac{\partial \pi^i(p^i_c, p^j_c)}{\partial x^j}\frac{\partial x^j}{\partial t^i_s} - x^i\right]\frac{\partial t^i_s}{\partial \overline{m}}.$$

Keeping in mind that $x^i\dfrac{\partial t^i}{\partial \overline{m}} = \overline{n}^i x^* \dfrac{\partial t^i}{\partial \overline{m}}$ this indicates that

$$\Delta^i = -\frac{\partial \pi^i(p^i_c, p^j_c)}{\partial x^j}\frac{\partial x^j}{\partial t^i_s}\frac{\partial t^i_s}{\partial \overline{m}} > 0 \qquad for \quad \bar{t} > \bar{t}^c.$$

■

References

Barrett, S.: 1994, Strategic environmental policy and international trade, *Journal of Public Economics* **54**.

Bergman, M. and Brannlund, R.: 1995, Measuring oligopsony power, *Review of Industrial Organization* **10**, 307–321.

Bourke, I. and Leitch, J.: 2000, Trade restrictions and their impact on international trade of forest products, *Food and Agriculture Organization of the United Nations* .

[30]Note that $x^j_\alpha = Q^j(p^i_\rho, p^j_\alpha) > x^i_c$.

Brander, J. and Spencer, B.: 1985, Export subsidies and international market share rivalry, *Journal of International Economics* **18**.

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**, 361–368.

Hamilton, S. F. and Requate, T.: 2004, Vertical structure and strategic trade policy, *Journal of Environmental Economics and Management* **47**(2).

Hartman, R.: 1976, The harvesting decision when a standing forest has value, *Economic Inquiry* **14**, 52–58.

Johansson, P.-O. and Löfgren, K.-G.: 1985, *The Economics of Forestry and Natural Resources*, Basil Blackwell, Oxford, U.K.

Koskela, E. and Ollikainen, M.: 1998, A game-theoretic model of timber prices with capital stock: An empirical application to finnish pulp and paper industry, *Canadian Journal of Forest Resources* **28**, 1481–1493.

Koskela, E. and Ollikainen, M.: 2001, Optimal forest conservation: Competitiveness versus green image effects, *Forest Science* **47**, 178–187.

Kreps, D. and Scheinkman, J.: 1983, Quantity precommitment and bertrand competition yield cournot outcomes, *Bell Journal of Economics* **14**, 326–337.

Kuhn, K.-U.: 1997, Nonlinear pricing in vertically related duopolies, *RAND Journal of Economics* **28**(1), 37–62.

Maggi, G.: 1996, Strategic trade policies with endogenous mode of competition, *American Economic Review* **86**, 237–258.

Nash, J.: 1950, The bargaining problem, *Econometrica* **28**, 155–162.

Rauscher, M.: 1994, On ecological dumping, *Oxford Economic Papers* **46**, 822–840.

Sedjo, R. A.: 2001, Changing demands on the world's forests: Meeting environmental and institutional challenges, *S.J. Hall Lecture delivered September 28, 2001 College of Natural Resources, University of California, Berkeley, California.* .

Ulph, A.: 1996, Environmental policy and international trade when governments and producers act strategically, *Journal of Environmental Economics and Management* **30**, 265–281.

Ulph, A.: 1997, International trade and the environment: A survey of recent economic analysis., *in* H. Folmer and T. Tietenberg (eds), *The International Yearbook of Environmental and Resource Economics 1997/1998*, Cheltenham, Edward Elgar.

Essay III: Harmonization Versus Mutual Recognition of National Eco-labels

Abstract

This paper formalizes a welfare-comparison between two international eco-labeling schemes: harmonization and mutual recognition. The model involves two countries. In each country there are two incumbent firms and a number of potential entrants producing for domestic and export markets. In an asymmetric information-environment, where the goods' environmental attributes are unobservable, firms with different labeling standards cannot implement a separating equilibrium through price signaling. The difference between the standards generates an information-rent in the export market increasing the number of active firms with a labeling program applying lower standards to producers. Intensified price competition improves the aggregate product quality in the markets and this pro-competitive spillover of lower market transparency thus implies that mutual recognition is welfare superior to harmonization, insofar as the difference between the standards is relatively low.

Keywords: Labeling, Environmental-quality uncertainty, duopoly signaling
JEL Classification: C72, L15, F18

1 Introduction

Eco-labeling has become a standard practice in most countries (Vossenaar 1997). These programs are designed by an independent intermediary, which imposes and monitors certain criteria that producers must meet in order to receive a certification for their environmental performance.[1] A market-based reason for the existence of eco-labels is

[1] Economic studies argue that third-party labeling performs better than industry-led programs in correcting for the problem of asymmetric information between producers and consumers. See, e.g.

their role as a signal of higher environmental quality which might not be fully assessed on behalf of the customers with a willingness to pay for the products' environmental attributes. In theory, labeling therefore constitutes an efficient, non-mandatory, instrument of environmental policy. However, while the positive environmental benefits of credible eco-labeling are clear, some argue that these programs have become an important factor in market access generating pressures for the producers to apply for a label. This has contributed to a several trade-disputes as national eco-labeling schemes are often perceived to discriminate against outside producers generating distortional effects on trade, and fueled public debate about an appropriate level of differentiation between regional labeling standards in the global markets.[2]

There are two suggested remedies for the problem of multiple country-specific labels. *Harmonization* of labeling standards has certain benefits as it helps the exporters sell their products without having to comply with different regulations in each country. Harmonization also increases market transparency by ensuring the consumers that imported goods comply with the same standards. The second remedy is the *mutual recognition* of existing labeling schemes. This means that if a product is eligible for a label granted by a national labeling program, it would automatically receive an equal treatment with any other label in the importing countries. Mutual recognition is arguably more flexible from the viewpoint of the producing countries for it allows them for more leverage to consider the national characteristics in the design of labeling standards.[3]

The economic trade-off between these policy schemes is linked to an old issue in competition policy debate; namely, market transparency. Less transparency on the consumer side, so consumers are uninformed about the product characteristics, usually diminishes the producers' incentives for product differentiation (see e.g. Bester 1998

Kirchhoff (2000) and Cason and Gangadharan (2002).

[2]For example, Germany requires companies not participating in its Green Dot scheme to take back their packaging and bear the cost of recycling themselves. The cost is naturally greater for foreign companies, which therefore have claimed that the for Green Dot label places imported goods at a market disadvantage.

[3]It is implausible to presume that countries have identical environmental characteristics or social preferences on which the labeling standards should be based. For instance, Scandinavian countries and Canada are by far more sensitive to acid rain generated by the release of oxides of nitrogen (NOx) and sulphur dioxide (SO2) than countries in Central Europe and US.

and Akerlof 1970). The transparency problem arises under mutual recognition as goods with higher environmental standards might not survive the competition in the markets.[4] To prevent the collapse of markets for goods with high environmental quality, it seems therefore plausible to think that the optimal coordination of ecolabeling schemes calls for harmonization.

This paper presents the idea that despite the potential lack of market transparency, the mutual recognition of labeling standards in the international markets could be welfare superior to harmonized labeling standards. In a specific example involving vertically differentiated industry and an economy in which consumers cannot fully observe the environmental quality of the products, this means that a small market failure generated by the lack of market transparency induces more producers to apply for a label. The positive welfare effect of mutual recognition is that tougher competition between producers makes the labeled goods more affordable to consumers which improves the quality allocation in the market.

Essentially, the model combines several features in the literature on industrial organization, signaling games and international trade. The analysis derives the main contributions of this paper in three steps. The first step derives a benchmark involving closed markets and full information. The market is segmented by consumer types with different willingness to pay for the products' environmental quality and a price competition between firms induces a market outcome involving different qualities.[5] The second step introduces asymmetric information to the model. This reflects the usual property that sellers are often better informed about the production related environ-

[4]A dispute, which is at least partly driven by this trade-off, is between the dominant forest certificates in Europe, Pan European Forest Certificate (PEFC) and Forest Stewardship Council (FSC). Each side has a strong nationally divided group of representatives. For instance, most Finnish forest owners are certified by PEFC while the Swedish forests belong dominantly to FSC program. The representatives of PEFC argue that FSC requirements do not consider the regional differences between forests' ecological characteristics and the ownership structure. PEFC thus claims that both certificates should be treated equally as there is only minor differences between the actual requirements. However, FSC and some environmental organizations argue that any labeling program, which does not meet FSC standards, is insufficient to guarantee environmentally sound forest management and consumers should question the environmental attributes of PEFC-labeled products. See, e.g. "Anything Goes" (2001) by Greenpeace and The Finnish Nature League.

[5]See e.g. Arora and Gangopadhyay (1995). More recently, Cremer and Thisse (1999) employed a similar vertical product differentiation framework and show that environmental quality competition improves the overall quality on the market, but in the absence of government intervention the equilibrium fails to satisfy the criteria for Pareto-efficiency.

mental attributes of the goods than consumers; hence, the extent to which they can capitalize on the consumers' willingness to pay depends on their ability to signal the improvements in their environmental performance to consumers.[6]

The examination of the signaling game shows that they cannot implement a separating equilibrium, in which consumers observe the differences between the environmental qualities in the market. This results in a collapse of markets for goods with high environmental quality, unless there is a labeling program monitored by an independent third party.[7] Labeling enhances the quality distribution in the market, but the market outcome fails to implement a Pareto efficient allocation of environmental quality. This is because in a closed economy a labeling program does not provide incentives for new producers to enter the market, leaving the incumbent firms with market power which they can employ to price discriminate the consumers.

The analysis of the signaling game in a single market serves as building block for the third step of the analysis which considers two countries with two firms producing for the domestic and a third country export market. Within this framework the analysis shows that under mutual recognition between country specific labels, the signaling problem carries over to the export market: When the export market consists of producers with different labeling standards, the ones with higher standards cannot implement a separating equilibrium. This generates an information rent for the producers with lower labeling standards which, in turn, induces more producers to apply for this label. Tougher competition in the market for labeled goods depresses prices and thereby increases the market efficiency making the higher environmental quality more affordable to consumers. By comparing the equilibrium outcomes between harmonized labels and mutually recognized labels, the analysis shows that a market failure in the form of lower market transparency might have a pro-competitive spillover, implementing an equilibrium which Pareto dominates harmonization.

[6]In a seminal article Akerlof (1970) established that under asymmetric information markets are ineffective in providing quality and only goods with lowest quality are sold to the market.

[7]There is a number of studies on asymmetric information and quality-signaling, but the most severe problem, namely, the case of goods' credence attributes has deserved less attention (see e.g. Shapiro 1982). This problem is particularly relevant for most internationally traded goods with production related environmental externalities, since the consumers may have diminished ability to learn the goods' environmental quality, because of the physical distance between the production and consumption sites.

Market transparency, product differentiation, eco-labeling and the signaling problem have been touched upon before in the economic literature. However, the analysis of the international dimensions of labeling and transparency in the presence of credence attributes has not been conclusive. Most of the literature on quality signaling examines the interaction between one firm and consumers, abstracting from signaling between competing senders.[8] The literature on oligopoly-signaling focuses on cost-signaling between competing firms and, as in the present study, quality-signaling between firms and consumers.[9] Included among these are Herzendorf and Overgaard (2000); Herzendorf and Overgaard (2001) and Fluet and Garella (2002), which examine price signaling behavior when the firms do not have an established reputation.[10]

Kirchhoff (2000) examines the role of third-party labels in producers' environmental quality decision, when monopolist can build reputations and the qualities are revealed with a certain probability. The results establish that third-party labeling increases the likelihood that compliance to voluntary environmental standards is profitable for a monopolist. For the general case of labeling standards and trade, Jansen and Lincé de Faria (2002) compared mutual recognition and harmonization for two countries with different consumer preferences and cost differences. The study showed that harmonization, in most cases, leads to a better welfare outcome than mutual recognition.

The remainder of the paper is organized as follows. Next section describes the assumptions of the model. Section three establishes the criteria for welfare optimal distribution of environmental quality, and examines firms' quality decisions under full information and autarky. Section four analyzes the signaling game under asymmetric information, and compares the results with full information and Pareto efficient benchmarks. Section five analyzes how third-party labeling influences the industry-equilibrium in domestic and foreign markets. Conclusions follow.

[8] For instance Milgrom and Roberts (1986) examine the price and advertising signaling in monopoly.
[9] For information on signaling as a mechanism to deter entry, see, e.g. Bagwell and Ramey (1991).
[10] Herzendorf and Overgaard (2001) and Fluet and Garella (2002) also allow for advertising signals.

2 The Model

We consider a partial equilibrium model, in which good x is produced in two countries, domestic and foreign. When needed, subscripts, d and f, are used as a mnemonic for domestic and foreign country. In each country there are two incumbent firms and n potential entrants. The incumbent firms are denoted by superscripts 1 and 2; and the entrants are denoted by superscript $N = (3, 4, ..., n)$. The firms produce good x for domestic and world market. The remaining assumptions of the model are comparable to the ones used in the literature on vertical product differentiation:

1. **Abatement**: Production of x generates an environmental externality (emissions), $e = (\underline{e} - a)$, where $\underline{e}$ denotes *laizzes faire* emission level, and $a \in (\underline{a}, \bar{a})$ denotes the abatement level, where $\underline{a} > 0$ is the minimum abatement requirement for an active firm. Abatement level $\bar{a}$ denotes the most efficient, technically feasible, abatement level.

2. **Production costs**: For each active firm, a short-term cost function takes the form $C(a) > 0 \; \forall a > \underline{a}$ and $C(a) = 0$ otherwise. The cost is constant in quantity, but convex in abatement: $C'(a) > 0$ and $C''(a) > 0$. In addition, each firm which upgrades its technology from, say a^i to a^j, and wishes to inform the consumers about it, incurs a fixed set-up and advertisement cost, $\eta^j(a^j) = \eta$, before the production stage. The cost satisfies,

$$C(a^j) - C(a^i) \geq \eta^j(a^j) \quad for\ any \quad a^j > a^i \geq \underline{a} \tag{1}$$

   reflecting that the marginal cost of producing higher quality is higher than the set-up and advertisement cost per unit of production. The incumbent firms have an initial abatement technology $\underline{a}$. Hence, they may produce with minimum quality level without an additional cost. A representative entrant has an initial abatement level $a^N = 0$. Entry thus requires an upgrade to $\underline{a}$ and a cost equal to $\eta^N(\underline{a}) = \eta$.[11]

[11] Condition (1) thus states that η is small enough to ensure non-negative payoff for the entrant that chooses quality a^i, provided that the rival firms' quality is higher and there is positive demand for the product variety.

3. **Preferences and asymmetric information**: The description of consumer preferences is a version of Mussa and Rosen (1978). In each country there is a continuum of consumers uniformly distributed and ranked in the same interval in *decreasing order* of their intensity of preferences for goods' environmental quality $\theta \in [\overline{\theta}, \underline{\theta}] \equiv [0, 1]$. The density is given by $M > n + 2$, i.e. in each country there is less potential producers than consumers. When the quality of the goods is perfectly observable, the indirect utility of purchasing one unit of good x is conditional on consumer's type θ and can be formalized as

$$U(p; \theta) = [R + (\alpha - \theta)a - p(a)] \tag{2}$$

where R denotes the reservation value, which represents common willingness to pay for the good's basic physical characteristics with any given quality. Parameter $\alpha > 1$ expresses the common component in consumers preferences for environmental quality.[12] In a full information environment parameter a denotes the environmental attribute of the good determined by the seller's abatement technology, and $p(a)$ is the price of the good. Thus, $(\alpha - \theta)a$ determines consumer-specific marginal willingness to pay for the good's environmental quality.

The environmental quality is considered a credence attribute, which cannot be observed even after the purchase.[13] Consumers have, however, a prior idea about the initial distribution of qualities in the market and observe the cost-structure described in assumption (2). This gives a raise to a signaling game in which the firms can use prices to affect the consumers' beliefs about their environmental quality.

The signaling game has two stages. The consumers enter the market with a prior distribution of qualities in their minds. The firms set prices and the consumers update their beliefs about the goods' environmental qualities on the basis of

[12] The role of parameter α is treated in more detail in assumption 5.

[13] This is a plausible assumption, especially in the case of internationally traded goods with long geographical distance between production and consumption locations. Firms cannot build reputations, as the quality is unobservable. For more information on reputation-building and product quality, see Shapiro (1982). For more information on credence attributes and signaling through labeling see Auriol and Schilizzi (2003).

their information on the cost-structure.[14] When a price-signal $p^*(a)$ is perceived credible by the consumer θ, her utility of the purchase coincides with (2), i.e. $U = U[p^*(a);\theta]$. However, in a market with different qualities and no credible price-signal linking the qualities and goods, the consumer-specific marginal willingness to pay for the good's environmental quality is the same for any good in the market. Hence, the indirect utility in a pooling equilibrium can be described by the following von Neuman-Morgenstern utility function

$$U^e[p(\Delta^c);\theta)] = [R + (\alpha - \theta)\Delta^c - p(\Delta^c)],$$

where $\Delta^c = \sum_{i=1}^{N} \frac{a^i}{N}$ and N denotes the number of active firms.[15] This indicates that the perceived environmental quality in a pooling equilibrium is determined by the average quality in the market. From the specification of the utility function it follows immediately that although the consumers willingness to pay increases when a producer chooses to increase his quality, only the goods with the lowest price survive in the market. Hence, the market for high qualities will collapse, unless the producers can credibly signal their qualities through labeling or price-signaling.

4. **Market coverage:** The preferences and the cost function satisfy the following properties:

$$C(\bar{a}) \leq R \quad and \quad C'(\bar{a}) \leq (\alpha - \underline{\theta}), \tag{3}$$

Expression (3) states that if goods are priced at marginal cost, then all consumers buy the highest quality.[16] Furthermore, when the lowest quality in the market is priced at $C(\bar{a})$, all consumers buy a good regardless of the quality-distribution.

5. **Quality decision and asymmetric information**: The quality game between the firms is sequential: Nature the incumbent that gets to choose its quality first. After the incumbents' quality decision, the entrants choose quality levels.[17]

[14] A more detailed description of the consumers' belief system is in subsection 2.1.
[15] See also Jansen and Lincé de Faria (2002).
[16] This assumption ensures that so-called finiteness property holds, hence, the market is a natural oligopoly under full information. See Anderson et al. (1992).
[17] For a similar treatment of firms' entry decisions in a vertically differentiated oligopoly, see e.g.

The quality levels are observable, but non-verifiable. Specifically, the existing qualities are observed by each agent, but they cannot be linked to a particular firm.[18]

6. **Labeling and mutual recognition:** Under third-party labeling, an independent intermediary monitors firms' performance and grants a label for a firm that meets the given labeling requirement. Consumers perceive the label as a credible signal of the goods' environmental quality. Mutual-recognition of labels implies that when the market consists of multiple labels, consumers observe the existing quality-requirements, but without further information they cannot ascertain the potential differences between environmental qualities indicated by the labels.

7. **The structure of the full game:** The structure of the game is depicted in Figure 1. First, the firms choose qualities as described above. This involves a decision about participation to the national labeling program and, by entrants' quality decisions, the number of active firms at the production stage of the game.[19] Second, the consumers and the firms form their prior beliefs about qualities in the market. Third, the firms set prices, on the basis which the consumers update their beliefs. Firms can set a single price within each country, but can use price

Peitz (2002).

[18] For instance, when firm 2 is the first-mover and incumbent 1 is the follower, firm 1 observes that quality distribution on the market is $\Delta^1(a^2) = a^2$. After the quality decision of firm 1, the first entrant N observes the existing qualities and based on a^2 and a^1, its assessment of overall quality on the market is $\Delta^N(a^2, a^1) = (a^2 + a^1)/2$.

[19] That is, each entrant that chooses a quality $a^N > 0$ is considered an active firm.

discrimination across markets.

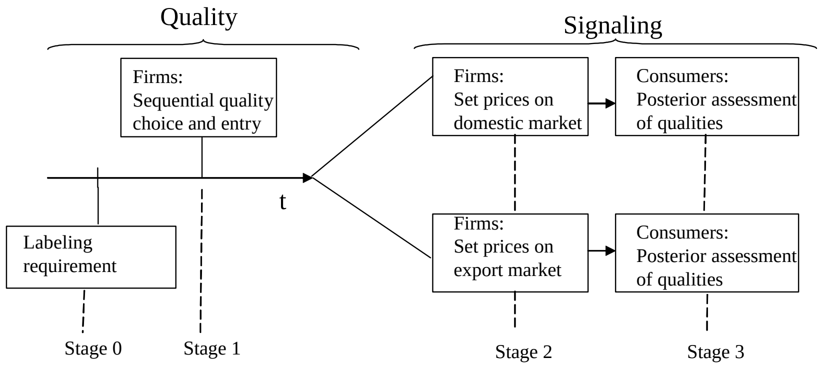

Figure 1: Timing of the game

3 Pareto-Efficiency and Full-Information Benchmark

This section characterizes market behavior under full information and imperfect competition, and derives the circumstances under which the market exhibits a Pareto-efficient quality allocation. We use Pareto efficiency as a benchmark to illustrate the welfare loss associated with the market imperfections. Full information benchmark comes in useful as a starting point for the analysis of the quality competition under asymmetric information and welfare comparisons under different labeling schemes.

Letting $p(a)$ denote the market price of the good with quality a, a necessary requirement for Pareto-efficiency is given by

$$p(\bar{a}) - p(a) \leq (\alpha - \theta)(\bar{a} - a) \quad for\ all\ \theta \in [\bar{\theta}, \underline{\theta}] \quad and \quad a \in [\underline{a}, \bar{a}]. \tag{4}$$

Pareto-efficiency thus requires that quality $\bar{a}$ is produced and each consumer buys this quality at a price that yields her a nonnegative surplus in comparison to competing varieties in the market. For future reference it is worth noting that this allocation obtains when $p(\bar{a}) = C(\bar{a})$.

3.1 Full-Information Benchmark

Suppose that the market consists of firms 1 and 2.[20] The firms produce goods x^1 and x^2 with environmental qualities a^1 and a^2, respectively. We assume that the qualities satisfy $a^1 < a^2$. For the ease of exposition we assume that in full-information equilibrium, the market is fully covered.

Denote the customer who is indifferent between buying x^1 and x^2 at prices p^1 and p^2, as $\widehat{\theta}$. Since the ranking of preferences is inverse, each consumer with $\theta < \hat{\theta}$ buys the higher quality, and consumers $\theta > \hat{\theta}$ buy the lower quality. The demand for x^2 and x^1 can thus be formalized as $D^2 = M\widehat{\theta}$ and $D^1 = M(1 - \widehat{\theta})$, respectively. Using consumers' utility function we obtain $\widehat{\theta} = \alpha - (p^2 - p^1)/(a^2 - a^1)$; hence, the profits can be written as

$$\pi^2(p^2, p_l^1) = M\widehat{\theta}[p^2 - C(a^2)] - \eta^2(a^2),$$
$$\pi^1(p^2, p^1) = M(1 - \widehat{\theta})[p^1 - C(a^1)] - \eta^1(a^1),$$

where $\eta^2(a^2) = \eta$; and $\eta^1(a^1) = \eta$ for $a^1 > \underline{a}$ and $\eta^1(\underline{a}) = 0$. The firms choose prices taking the quality decisions and the associated sunk costs as given. The first-order conditions yield the following equilibrium price levels:

$$\hat{p}^2 = 1/3[(\alpha + 1)(a^2 - a^1) + 2C(a^2) + C(a^1)] \quad (5)$$
$$\hat{p}^1 = 1/3[(2 - \alpha)(a^2 - a^1) + 2C(a^1) + C(a^2)]. \quad (6)$$

It is easy to verify that (5) and (6) express the equilibrium prices.[21] Hence, we infer that

Lemma 1 *In a full-information equilibrium, qualities are such that* $\underline{a} \leq a^1 < a^2 \leq \bar{a}$ *and* $\widehat{\theta} < \underline{\theta}$. *The quality distribution in the market falls short of the Pareto-efficient allocation*

Proof. The first part of the proof is by contradiction. Assume $\underline{a} < a^1 = a^2 \leq \bar{a}$,

[20] Although the model allows for entry, we assume only two firms. This is for expositional purposes to illustrate the perfect information benchmark. A condition which determines the upper bound for active firms can be found in Cremer and Thisse (1999).

[21] For a similar analysis of the price game, see e.g. Cremer and Thisse (1999).

by Bertrand argument the long-term profit is $\pi^i = -\eta < 0$; $i = 1, 2$. Hence, the equilibrium is strictly dominated by any quality distribution that involves $\underline{a} \leq a^1 < a^2 \leq \bar{a}$. Assume then that $\underline{a} = a^1 = a^2$. (1) together with (5) and (6) imply that for given $\underline{a} = a^1$, an increase in a^2 yields a positive mark-up for each firm. Quality distribution $\underline{a} = a^1 = a^2$, in turn entails $\pi^i = 0$; $i = 1, 2$, hence, this distribution is strictly dominated by $\underline{a} \leq a^1 < a^2 \leq \bar{a}$.

The proof of the second part is a straightforward consequence of (4) and the first-part of Lemma 1. Since both firms are active in equilibrium, at least one consumer buys the good with quality $a^1 < \bar{a}$. Hence, the equilibrium does not satisfy the requirement for Pareto-efficiency (4). ■

This result establishes that both incumbent firms are active and produce differentiated goods with prices strictly above their marginal cost. The quality difference depends on the parameters of the model, therefore, little can be said about the relation between quality extremes and equilibrium qualities. However, Lemma 1 unambiguously establishes the quality allocation is not welfare-optimal. The reason is that the firm producing higher quality can price-discriminate consumers with a lower willingness contributing to a inefficient market outcome as some consumers do not buy quality $\bar{a}$.[22]

4 Asymmetric-Information Benchmark in Autarky

When environmental quality of the goods is a credence attribute, the consumers know the distribution of qualities in the market, but the quality-differences cannot be verified without further information.[23] This gives raise to the signaling game which is the focus of the analysis in this section. For the reasons of tractability we consider first the case of single a market. The results will then be used as a stepping stone in the analysis of third-party labeling and international trade.

[22] This result coincides with previous studies on vertical product differentiation. For example, Crampes and Hollander (1995) show that although high-quality producer could capture the entire market, it is more profitable to allow lower qualities exist on the market.

[23] This is arguably a rather extreme assumption, but it is widely used in models of oligopoly signaling. See e.g. Herzendorf and Overgaard (2000); Herzendorf and Overgaard (2001); and Fluet and Garella (2002).

4.1 Consumer Beliefs and Demand

Suppose that the market consist of two active firms.[24] The firms first set prices and consumers then draw inferences about the actual qualities of goods in the market. The equilibrium of the signaling game is thus a pair of prices and a system of posterior beliefs about product qualities. The solution mechanism of the game is the following. Starting from the last stage, we determine the set of price-pairs that implement a belief system consistent with the definition of the separating equilibrium. This involves the analysis of the evolution of consumers' belief system and corresponding demand functions. Given the consumers' belief system, the second step is to investigate firms' signaling strategies, which determines the equilibrium outcome of the signaling game for any given quality distribution. Finally, we examine the firms' quality and entry decisions.

Let $\mu^p = \mu(\check{p}^1, \check{p}^2, a^1, a^2)$ and $\mu^s = \mu(p^1, p^2, a^1, a^2)$ denote the beliefs when qualities are verifiable and unverifiable by consumers, respectively. Furthermore, given prices p^1 and p^2, let $\beta^1(p^1, p^2)$ denote the consumer's assessment that firm 1's quality is a^2. This belief system satisfies $\beta^1(p^1, p^2) = 1 - \beta^2(p^1, p^2)$, where $\beta^2(p^1, p^2)$ is the consumer's assessment that firm 2's quality is a^2.[25]

Consumers know the cost functions of the firms and a rational consumer infers that the price of a variety a^2 must yield a non-negative mark-up for the producer, i.e. $p^2 \geq C(a^2)$. Hence, the belief system exhibits the following properties.

Lemma 2 *Suppose that* $a^2 > a^1$. *Given qualities* (a^1, a^2), *prices* (p^1, p^2) *and costs* $[C(a^1), C(a^2)]$; *system* $\mu(p^1, p^2, a^1, a^2)$ *is such that*

(i) $\mu = \mu^p$, *i.e.* $\beta^1(p^1, p^2) = 1/2 \quad iff \quad p^1, p^2 \in [C(a^2), \overline{p}]$,

(ii) $\mu = \mu^s$, *i.e.* $\beta^1(p^1, p^2) = 0 \quad iff \quad p^1 \in [C(a^1), C(a^2))$, *where* $\overline{p} = R + \alpha a^2$.

Proof. Lemma 2 requires that all observed prices must be admissible. Hence,

(**i**) For prices $p^1, p^2 \in [C(a^2), \overline{p}]$, where $\overline{p} = R + \alpha a^2$ is the choke-off price, consumers infer that *any* firm charging $p \geq C(a^2)$ could be selling quality a^2. Hence, a consumer expects that any good in the market is of the higher quality with probability 1/2.

[24] It will be shown that in equilibrium only two firms are active.

[25] Since the market consists of two product varieties, the beliefs are such that $\beta^1(p^1, p^2) + \beta^2(p^1, p^2) = 1$.

(**ii**) Admissibility ensures that no firm will set prices below their marginal-cost. Thus, if a price $p^1 < C(a^2)$ is observed, it implies that the quality of the good is a^1, and consumers update their beliefs accordingly. ■

Lemma 2 establishes that the consumers' beliefs are determined through the low-quality firm's pricing decision. Consequently, implementation of separating beliefs requires that firm 1 has an incentive reveal its true type. Otherwise, no separating equilibrium exists.[26]

Using Lemma 2, the demand system, $\mathbf{D} \equiv (\widehat{D}^2, \widehat{D}^1)$, can be written as

$$\mathbf{D} \equiv \begin{cases} (M\widehat{\theta}, M(1-\widehat{\theta})) & for \quad \mu = \mu^s \\ (M/2, M/2) & for \quad \mu = \mu^p : p^1 = p^2 < R + (\alpha - 1)\Delta^c(a^1, a^2) \\ (0, M) & for \quad \mu = \mu^p : p^1 < p^2 \leq R + (\alpha - 1)\Delta^c(a^1, a^2) \end{cases}$$

where $\Delta^c(a^1, a^2) = (a^1 + a^2)/2$ denotes the expected quality in the market. The system is derived using the consumers' assessments about qualities and responses to the observed price-differential. First, when consumers observe the actual qualities, the demand system coincides with the one under full information. Second, in a pooling equilibrium, the firms split the market with equal prices. Finally, when the consumer cannot link the firms and qualities, a firm with lower price captures the entire market, because consumers are willing to pay a single price for any good in the market.

4.2 Price Signaling

Having analyzed how consumers update their beliefs after realizing the prices in the market, we move on to the analysis of firms' pricing strategies. The analysis is in three steps. First, we show that full-information prices do not constitute an equilibrium under asymmetric information. Then we investigate the existence of price-pairs, which constitute separating equilibria. Finally, after the determination of the set of potential equilibrium price-pairs, we solve for an equilibrium that cannot be destabilized by one-stage deviations.

[26]It is important to note that Lemma 2 describes the basic belief system, which abstracts from refinements that rely on out-of-equilibrium prices. Out-of-equilibrium beliefs will be treated in more detail below.

Consider firm 1's price decision when it conjectures that firm 2 has set its price equal to full-information level. Lemma 2 establishes that a separating equilibrium requires the firm with lower quality to reveal its type. In Appendix A we show that given the full-information price level $\hat{p}^2$, firm 1's optimal price-response is

$$\begin{aligned} p^1 &= \hat{p}^2 \qquad for \qquad \hat{p}^2 \leq R + (\alpha - 1)\Delta^c(a^1, a^2) \\ p^1 &\leq \hat{p}^2 \qquad for \qquad \hat{p}^2 > R + (\alpha - 1)\Delta^c(a^1, a^2), \end{aligned} \tag{7}$$

where $\hat{p}^1$ and $\hat{p}^2$ denote full-information price levels. Hence, full-information prices do not constitute an equilibrium under asymmetric information. This is because firm 1 observes that for given $\hat{p}^2$, it can split the entire market for the goods by imitating firm 2. If $\hat{p}^2$ is high enough, so that pooling induces partial market-coverage, firm 1 captures the entire market and increases its profit by setting $p^1 = R + (\alpha - 1)\Delta^c(a^1, a^2)$, i.e. just the price for which it captures the entire market for the expected quality $\Delta^c(a^1, a^2)$.

In order to determine whether there is a price pair that constitutes a separating equilibrium, we need to consider firm 1's best-response to all admissible prices $p^2 \in [C(a^2), R + \alpha]$. To this end, consider firm 1's best-response correspondence, $p^1(p^2)$. A price p^2 that implements a separating equilibrium is such that firm 1 rather reveals its type by setting $p^1 < C(a^2)$ than imitates firm 2. In Appendix A we show that the best-response of firm 1 is always (weakly) higher than the marginal cost of the firm with higher quality:

Proposition 1 *Regardless of the differences between the firms' environmental quality, the firm producing higher environmental quality cannot induce the low-quality firm to reveal its actual quality to consumers. Hence, no separating equilibria exist.*

Proof. See Appendix A. ■

This proposition states that firm 2 cannot implement a separating equilibrium. The reason is that for $p^2 > C(a^2)$, by setting $p^1 = p^2 - \varepsilon$, firm 1 captures the entire market for expected quality $\Delta^c(a^1, a^2) \geq a^1$. For $p^2 = C(a^2)$, firm 1, in turn, imitates firm 2 and charges $p^1 = C(a^2)$ rather than reveals its type.

We have now determined the set of potential equilibria in the signaling game. To establish the strategically stable equilibrium, however, requires a brief look at how the consumers update their beliefs on the basis of observed out-of-equilibrium prices. Consider a candidate equilibrium: $\tilde{p}^1 = \tilde{p}^2 > C(a^2)$. The strict inequality implies that each firm can increase its profit by slightly cutting the price-level. A price-cut could be inferred as a defection by the low quality firm, but the consumer has no reason to rule out the possibility that the lower price is set by the one with quality a^2. Hence, when consumer observes prices $p^1 < p^2$, she updates her beliefs to $\beta^1(\cdot) = 0$, if and only if $p^1 < C(a^2)$.[27] This result gives raise to the following proposition:

Proposition 2 *Equilibrium prices equal the marginal cost of the high-quality firm $C(a^2)$. Although firm 2 makes zero short-term profit, it will not be driven out of the market. Firm 1's mark-up equals the difference between the firms' marginal costs, i.e.*

$$\begin{aligned} \pi_h^1(a^1, a^2) &= (M/2)[C(a^2) - C(a^1)] > 0 \\ \pi_h^2(a^1, a^2) &= (M/2)[C(a^2) - C(a^2)] = 0. \end{aligned}$$

Proof. See Appendix A. ■

The result can be understood intuitively as follows. A candidate pooling equilibrium-candidate with a prior belief-system $\Delta^c(a^2, a^1) > a^1$ and prices $p^1 = p^2 > C(a^2)$, does not constitute an equilibrium. This is because the equilibrium is destabilized by a price-cut on behalf any of the two firms, insofar as consumers' beliefs about product quality are unaffected by such defection. For $p^1 = p^2 = C(a^2)$, a price-cut results in an update of consumer beliefs, so that a firm with price $p' < C(a^2)$ is producing lower quality with certainty.

Although the equilibrium outcome is driven by Bertrand-type argument, the characterization of the equilibrium is quite different. From the consumers' viewpoint, each good in the market has the same expected quality and the evolution of the belief system allows the firms to cut prices similarly as in a standard Bertrand game. However, as opposed to the Bertrand-outcome with heterogeneous costs, in equilibrium both firms are active since no firm can feasibly set its price below $C(a^2)$. This is because by setting

[27] It is important to note that we abstract from equilibrium refinements that are consistent with another equilibrium. Mailath, Okuno-Fujiwara and Postlewaite (1993) argue that no defection should be considered in isolation. Their idea is that an equilibrium can be destabilized only by another equilibrium, not by an isolated defection.

$p^1 < C(a^2)$, the firm 1 would induce a shift in consumer beliefs, which by condition (3) results in zero demand for its product.

4.3 Quality Game

The quality subgame is a sequential decision process in three stages.[28] First, the incumbent 2 chooses its quality. Second, incumbent 1 observes that market consists of quality a^2 and chooses a^1. Finally, the entrants observe the quality distribution in the market and choose to enter or remain passive.

The incumbents anticipate the potential entrants' quality decisions and observe that the price-premium generated by choosing higher abatement level will be fully appropriated by one of the rivals. This implies negative payoff in the long-term, and thus, the optimal strategy for each incumbent is quality $\underline{a}$:

Proposition 3 *Under asymmetric information without labeling, the market consist of two incumbent firms producing at the minimum quality level,* $\underline{a}$.

Proof. Consider the incumbent 2's quality decision. Letting $a^N(a^2, a^1)$ denote the entrants' quality decision given the incumbents' qualities, the incumbent firm 2's program is given by

$$\begin{aligned}
\max_{a^2} \pi^2[a^2, a^1, a^N(a^2, a^1)] &= (M/n)[p^2(a^2, a^1, a^N) - C(a^i)] - \eta^2(a^2), \\
&\quad s.t. \\
p^2(a^2, a^1, a^N) &= C(a^2) \qquad for \qquad a^2 \geq \underline{a}
\end{aligned}$$

where $a^N(a^2, a^1)$ is the entrant's best response function to incumbents' quality decisions and $\nu = n + 2$ for $a^N(a^2, a^1) \geq \underline{a}$; and $\nu = 2$ for $a^N(a^2, a^1) = \underline{a}$. It is sufficient to show that firm 2 always chooses $a^2 = \underline{a}$, for this induces $a^1 = \underline{a}$ and $a^N(a^2, a^1) = \underline{a}$. Suppose firm 2 chooses $a^2 > \underline{a}$. By Proposition 2, this implies that the firm 1 with lower quality can capture positive rent by choosing $a^1 = \underline{a}$. This yields a negative long-term profit for firm 2. Hence, an optimal strategy for firm 2 involves $a^2 = \underline{a}$, which implements $a^1 = \underline{a}$ and $a^N(a^1, a^2) = \underline{a}$. ■

[28] For a similar treatment of firms' quality decision under threat of entry, see e.g. Peitz (2002).

A firm that chooses to abate more than the minimal requirement $\underline{a}$, raises the overall quality and the price level in the market. This generates an information rent for the firms producing lower quality. Anticipating this, the firms have diminished incentives to improve their quality for it yields a negative long-term profit. Hence, only the incumbent firms can feasibly produce for the market, but the quality level will be inefficiently low.[29] This result is typical in models with asymmetric information, like those in Akerlof (1970) and Leland (1979). However, unlike these papers, the present model allows for endogenous quality choice. The welfare implication of the result is nevertheless that provision of quality is minimal and therefore lower than under full information with two active firms.

5 Third-Party Labeling and Trade

This section examines the influence of third-party labeling-programs in the domestic and export markets. Since we assume that the firms set a single price within each market, but can price discriminate between markets, it is convenient to analyze the market outcomes separately. In what follows, the first subsection introduces national labeling requirements and examines firms' quality decisions in autarky. The second subsection examines the industry equilibrium in the export market under mutual recognition of labels. Finally, we analyze whether the equilibrium properties in the export-market influence the domestic market, and compare the welfare implications under different presumptions about the labeling requirements.

5.1 Labeling in Autarky

Suppose that a domestic labeling intermediary imposes a requirement $a_d : \bar{a} \geq a_d > \underline{a}$, which the local firms must meet to be eligible for quality-certification, L_d. Consumers observe that any firm i with a label L_d is producing with quality $a^i \geq a_d$. The label L_d indicates thus that the good meets the standard a_d, but if the market consists of two labeled goods with qualities $a^j > a^i \geq a_d$, the label does not provide ranking between

[29]It is worth noting that raising the minimum quality standard would imply negative long-term profit as the competition would drive the price premium to zero for each active firm.

the goods in terms of their quality. Hence, the problem of asymmetric information is present in each sub-market with more than one product variety.

A feasible standard a_d must satisfy the following participation constraint for firm 2:

$$\pi^2[a^1(a^2), a^2, \mathbf{a}^N(a^1, a^2)] \geq 0 \quad for \quad a^2 \geq a_d, \tag{8}$$

where $\mathbf{a}^N(a^1, a^2) = [a^3(a^1, a^2), a^4(\cdot), ..., a^n(\cdot)]$ denotes the quality response of the entrants and $a^1(a^2)$ that of the incumbent 1. The constraint simply states that a successful program yields a non-negative long-term profit.

Consider then the firms' quality decisions under a given standard a_d. Starting from the last stage of the quality game, the entrant takes the existing qualities in the market as given and chooses whether to enter the market. The optimal quality choice is the following:

$$a^N(a^1, a^2) \begin{cases} = a_d & for \quad a^i > a_d \quad and \quad a^j = \underline{a} \\ = \underline{a} & for \quad a^i = a_d \quad and \quad a^j > \underline{a} \\ = 0 & for \quad a^i = a_d \quad and \quad a^j = \underline{a}, \end{cases}$$

where $i, j = 1, 2$ denote the existing qualities in the market and $a^N = 0$ refers to the case of no entry. The characterization of this quality decision implies that entrant N chooses to enter, when it observes quality levels higher than a_d or $\underline{a}$. The decision is driven by the observed information rent in each sub-market which can be fully appropriated by an entrant that has a lower quality-level than the incumbent firm. However, when incumbents choose qualities a_d and $\underline{a}$, entry yields negative long-term profit for the entrant. As a result, such initial quality distribution discourages entry and leads to a duopoly outcome in the market.

Firm 1 anticipates the entrant's response to incumbents' quality-decisions. Hence, given incumbent 2's quality level a_d or $\underline{a}$, firm 1's quality-response becomes

$$a^1(a^2) \begin{cases} = a_d & for \quad a^2 = \underline{a} \\ = \underline{a} & for \quad a^2 = a_d. \end{cases}$$

The reason why firm 1's choice is a binary one between a_d and $\underline{a}$, is that for any other quality level, either firm 2 or the entrants appropriate the information rent associated with increase in firm 1's quality.

Given the followers' responses, a similar reasoning applies for firm 2 and its decision boils down to choosing between quality levels a_d and $\underline{a}$. Thus, when requirement is such that

$$\pi^2(a^2, a^1) = \pi^2[\hat{p}^2(a_d), \hat{p}^1(\underline{a})] > \pi^2[\hat{p}^2(\underline{a}), \hat{p}^1(a_d)], \tag{9}$$

where $\hat{p}^2(\cdot)$ and $\hat{p}^1(\cdot)$ denote the full information prices, firm 2 chooses $a^2 = a_d$. If the inequality is reversed, firm 2 chooses $a^2 = \underline{a}$ and firm 1's response is $a^1 = a_d$. In both cases, entry is deterred by the incumbents, because the entrants observe that entry with a higher quality level leads to a signaling game which yields negative long-term profit.

The analysis implies that the equilibrium in autarky involves two active firms with qualities a_d and $\underline{a}$. Hence, resulting equilibrium can be characterized as follows:

Lemma 3 *In autarky, a labeling program implements an equilibrium that coincides with the full information equilibrium with qualities $a^1 = \underline{a}$ and $a^2 = a_d$. Regardless of the standard a_d, the market equilibrium does not satisfy the criteria for Pareto-efficiency.*

Proof. The proof follows immediately from the analysis and the proof of Proposition 3. Lemma 1 ensures that the outcome is not welfare optimal. ■

Lemma 3 implies that only qualities a_d and $\underline{a}$ survive the competition in the domestic market and entry is not profitable. Since only the incumbent firms are active, the price competition is less intense and the high-quality producer can price discriminate the consumers with lower willingness to pay. This means that the equilibrium does not satisfy the criteria for Pareto efficiency as there is segment of consumers not buying the high quality good.

5.2 Equilibrium Pricing in the Export-Market

The importing country has no domestic production of x and it has not designed a label for the imported goods. Under mutual recognition of labels, the consumers observe that the labeled sub-market involves two qualities, a_d and a_f, but the difference between the qualities indicated by the labels cannot be verified. The consumer's prior belief about the quality of a good with a label is therefore $\Delta^c(a_d, a_f) > a_d$, when $a_d < a_f$. When the labels are harmonized, there is a full information in the labeled sub-market, i.e. $\Delta^c(a_d, a_f) = a_d$.

Since the consumers cannot observe the quality difference, the equilibrium in the export market has the following properties:

Lemma 4 *Suppose that each producing country has a labeling program that allows firms with quality a_d (a_f) carry a label L_d (L_f). IN equilibrium:*

(**i**) *Under harmonized requirements, (i.e. $a_f = a_d$), only labeled goods are exported and sold at marginal cost.*

(**ii**) *Under mutual recognition of country-specific labels with qualities $a_f > a_d > \underline{a}$, there is a pooling equilibrium in the export market. The consumers' beliefs about the quality of the labeled goods are given by $\Delta^c(a_f, a_d) > a_d$ and prices equal the marginal cost of the firm with higher quality, i.e. $p_d^2 = p_f^2 = C(a_f)$. Each firm with a label survives in the export market.*

(**iii**) *When the quality difference is small, each consumer rather buys a labeled good than an unlabeled one. Hence, the unlabeled goods will be driven out of the export market if*

$$(\alpha - \underline{\theta})[\Delta^c(a_f, a_d) - \underline{a}] \geq C(a_f) \qquad for \qquad a_f - a_d > \delta, \tag{10}$$

where δ is a critical parameter that determines the quality difference under which the consumers are just indifferent between buying a good with expected quality $\Delta^c(a_f, a_d)$ and a good with a certain quality $\underline{a}$ for a marginal cost prices $C(\underline{a})$ and $C(a_f)$.

Proof. Result (**i**) follows immediately from Bertrand argument and condition (1). Part (**ii**) is a direct consequence of Lemma 3: When $a_d < a_f$ the labeled firms from country d prefer to pool rather than set their prices below $C(a_f)$, indicating that the optimal pricing strategy for the firms with a label L_d is $p_d^2 = p_f^2 = C(a_f)$. Part (**iii**) follows directly from a consumers' payoff comparison: Under marginal cost pricing, the expected quality of a labeled good $\Delta^c(a_f, a_d)$ yields a higher surplus than the unlabeled variety, insofar as the quality difference is small enough. For instance, when $a_d \to a_f$, no consumer is willing to purchase an unlabeled good, and the market for $\underline{a}$ does not exist. ■

The first part of the result is straightforward. In equilibrium, firms with identical costs and qualities end up setting marginal-cost prices. By condition (3) this drives the unlabeled variety out of the market, thus all active firms have zero profit in the export market. The second part argues that the labeled sub-market exhibits pooling. The reasoning is similar to that of Proposition 2: For any given price p_f^2, a labeled firm of country d will not reveal its true type, and consequently, the labeled producer set their prices equal to marginal cost of the high-quality producer. These prices are just high enough to keep all labeled firms active in the export market and sustain pooling beliefs.

The third part argues that the quality distribution in the export market depends on the steepness of the consumers' utility function and that of the cost function. When the consumers have strong preferences for environmental quality, they rather buy any good with a label than a good without one. This property holds locally when the quality-difference is small, i.e. $\Delta^c(a_f, a_d) \to a_f$, and globally when $a_d \to \underline{a}$, provided that the cost function is sufficiently flat.

Figure 3a describes a polar case which illustrates the third part of Lemma 4. In this case the cost function is relatively flat and $a_d \to \underline{a}$. Consumer $\underline{\theta}$ observes that the expected quality of labeled goods is lower than the highest quality available, but for a price equal to $C(a_f)$, she rather buys a labeled good than an unlabeled one, the low-quality firms split the unlabeled sub-market and make zero profit.[30] This is illustrated in Figure 3b, where consumers $\theta = \underline{\theta}$ purchase the unlabeled variety.

[30] In Figures 3a and 3b, $CS[\Delta^c(a_f, a_d)]$ denotes the difference between consumer surplus when buying labeled goods instead of unlabeled ones for marginal cost prices, $C(a_f)$ and $C(\underline{a})$, respectively.

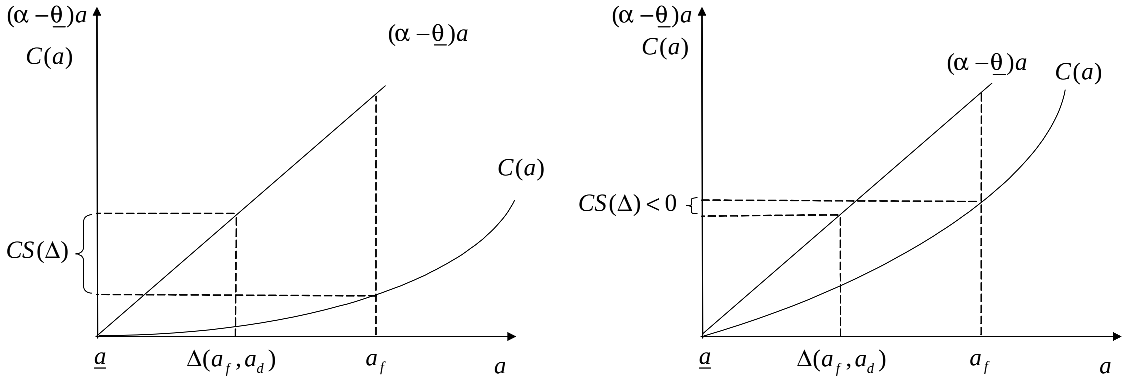

Figure 3a:
$(\alpha - \underline{\theta})[\Delta^c(a_f, a_d) - \underline{a}] > C(a_f)$

Figure 3b:
$(\alpha - \underline{\theta})[\Delta^c(a_f, a_d) - \underline{a}] < C(a_f)$

5.3 Welfare Analysis

This section derives the links between the outcomes in the different markets of the model. In particular, we examine whether the information rent in the export market is sufficiently high to induce entry in the producing countries, and thereby influence the quality distribution and pricing in the markets of the producing countries.

The entry decision is driven by two effects. First, Lemma 3 implies that in autarky, entry induces zero short-term profit in the domestic market, regardless of the labeling requirements of the foreign country. Second, a difference between the labeling requirements generates a rent in the export market. When this rent is high enough, it outweighs the fixed cost of entry, and therefore, increases the number of labeled producers. The market implications of these effects are described in more detail in the following lemma:

Lemma 5 *Suppose that (10) holds. If $a_f > a_d$ the industry-equilibrium is such that*

(**i**) *Each domestic firm chooses quality a_d and makes positive profits in the export market:*

$$\pi_d^2(a_d, a_f) = [M/(n+3)][C(a_f) - C(a_d)] > 0.$$

Marginal-cost pricing implies zero-profit for the foreign firm.

(**ii**) *Domestic market consists of $n+2$ labeled firms producing quality a_d, and charging prices equal to $C(a_d)$.*

Under harmonized labeling requirements $a_f = a_d$, the market outcome in the producing countries coincides with the full information benchmark with qualities $\underline{a}$ and a_d. Only labeled firms produce for the export market, in which prices equal marginal cost.

Proof. See Appendix B. ■

Lemma 5 establishes that a difference between labeling requirements increases the number of firms with label L_d. In domestic market this induces tougher competition, and consequently, increases the market share of the labeled variety. Under harmonized labeling requirements, firms' profits in the export market are zero. Since the incumbent can deter entry in the domestic country, the lack of competition in the producing countries implies that the quality distribution coincides with the one under autarky.

The following result illustrates the welfare implications of this pro-competitive effect of mutual recognition of national eco-labels.

Proposition 4 *For any given a_f, a labeling schedule with requirement $a_d^* = a_f - \varepsilon$, where $\varepsilon \to 0$, is welfare-superior to harmonized labels, $a_d = a_f$. In particular, when $a_f = \bar{a}$, the property $a_d^* = \bar{a} - \varepsilon$ implements a Pareto-efficient allocation of quality in country d and export market.*

Under harmonized standards the export market exhibits marginal-cost pricing, but in each producing country there is only one labeled producer which can employ its market power to gain positive mark-up for its product and price-discriminate consumers with lower willingness to pay. This is because entry is unprofitable and the lack of competition in labeled sub-market implies that the outcome does not satisfy the criteria for Pareto-efficiency.

Proposition 4 states that there is a positive spillover associated with mutual recognition which can correct for inefficiently low provision of quality in domestic market. To further emphasize this effect, suppose that $a_f = \bar{a}$. A small difference between the labeling requirements changes the industry-structure through the information rent in the export-market, generating an incentive for new producers to apply for domestic label. An increase in the number labeled firms intensifies the price-competition in domestic market, and consequently, drives the prices down toward marginal-costs. Lower prices allow *all* domestic consumers to purchase the labeled variety and unlabeled goods will be driven out of the market. It then follows that when labeling requirement of the foreign country is $\bar{a}$ and the difference between requirements is small, the outcome in the domestic market satisfies the criteria for Pareto-efficiency.

While this result provides a stylized argument for mutual recognition of labels, it should be noted that Pareto-efficient outcome in all markets is unfeasible. This is because it requires that only quality $\bar{a}$ is produced and purchased by each individual in all countries. Based in the above considerations this cannot be implemented through labeling or by imposing minimum quality standards.

6 Conclusion

This paper examined the structure of an international vertically differentiated industry, and the welfare implications of harmonization and mutual recognition of national eco-labels. The analysis shows that a difference between labeling requirements induces a positive spillover in a country which applies lower standards to its producers. The effect is generated through an information rent in the export-market which increases the number of labeled producers, and thereby improves the aggregate environmental quality of goods.

More specifically, the paper showed first that under full information, the overall quality in the market falls short of Pareto-efficiency. Second, asymmetric information drives all goods produced with higher abatement level out of the market, and consequently, only goods with minimal environmental quality will be produced. The problem of asymmetric information can be mitigated by establishing a third-party labeling program. In autarky, the program improves quality provision, but yet the allocation of environmental quality is inefficient. This is because incumbent firms can deter entry in the labeled sub-market and then price-discriminate consumers with a lower willingness to pay for the goods' environmental quality.

Mutual recognition of labels with different labeling standards generates an information rent in the export market for the firms with lower standards. The rent also yields positive profit for the entrants and thereby intensifies price-competition in domestic market as the number of the labeled firms increases. In other words, a small imperfection in the form of lower market transparency in the export market intensifies competition, and makes the high quality goods more affordable to consumers in the producing countries. This increases the consumers' surplus and diminishes the production related environmental externalities. Under harmonized labeling requirements the incumbent firms can deter entry, which diminishes the share of high quality products in domestic market. A welfare comparison between mutual recognition and harmonization thus reveals that under mutual recognition a small difference between labeling standards Pareto-dominates the full information outcome with harmonized labels.

Appendix A

Proof of (7). The proof consists of two cases: (**a**) fully covered markets $\hat{p}^2 < R + (\alpha - 1)\Delta^c(a^1, a^2)$ and (**b**) partial market-coverage $\hat{p}^2 > R + (\alpha - 1)\Delta^c(a^1, a^2)$. Uncovered market refers to the case in which the full information price $\hat{p}^2$ is high enough so that when both firms set their price equal to $\hat{p}^2$ then some consumers do not buy the good.

(**a**) Full market coverage implies that when firm 1 sets $p^1 = \hat{p}^2$ each consumer buys the good and firms split the demand. The condition $\pi^1[p^1, \hat{p}^2; \mu^p] \geq \pi^1(\hat{p}^1, \hat{p}^2; \mu^s)$ thus becomes

$$\frac{1}{2}\left[\hat{p}^2 - C(a^1)\right] \geq \left[1 - \alpha + \frac{(\hat{p}^2 - p_l^1)}{(a^2 - a^1)}\right][\hat{p}^1 - C(a^1)].$$

By substituting the closed form expression for $\hat{p}^2$ the condition can be rewritten as

$$(\alpha + 1)(a^2 - a^1) + 2C(a^2) \geq 2(1 - \hat{\theta})\left[(\alpha - 1)(a^2 - a^1) + C(a^1) + C(a^2)\right].$$

Since $\alpha + 1 > 2(1 - \hat{\theta})(\alpha - 1)$ and $2C(a^2) > C(a^1) + C(a^2)$, we conclude that full information prices do not constitute an equilibrium.

(**b**) Partial market coverage implies that some consumers refuse to buy the good at price $\hat{p}^2$. However, for any price below the critical level each consumer would buy the good with expected quality $\Delta^c(a^1, a^2)$. Hence, it is sufficient to show that by setting $p^1 = R + (\alpha - 1)\Delta^c(a^1, a^2)$, firm 1's payoff is higher than under full information prices, and thereby the condition can be written as

$$R + (\alpha - 1)\Delta^c(a^1, a^2) - C(a^1) > (1 - \hat{\theta})[\hat{p}^1 - C(a^1)].$$

The properties $1 - \hat{\theta} < 1$ and $R + (\alpha - 1)\Delta^c(a^1, a^2) > \hat{p}^1$ readily show that pooling is indeed optimal for firm 1. ■

Proof of Proposition 1. To show that firm 2 cannot induce firm 1 to reveal its true type we must prove that under no circumstances firm 1 sets its price below $C(a^2)$. Existence of separating equilibrium thus requires that there is p^2 that induces a response $p^1 < C(a^2)$. Formally, this requires

$$\tilde{p}^1 = \arg\max_{p^1} \pi^1(p^1, p^2, \mu^s) \tag{11}$$

$$\pi^1(\tilde{p}^1, p^2; \mu^s) \geq \pi^1(p^2, p^2; \mu^p) : \quad \tilde{p}^1 < C(a^2) \tag{12}$$

Expression (11) states that $\tilde{p}^1$ must be a profit maximizer for firm 1 given beliefs μ^s; (12) sates that in an equilibrium, firm 1 has no incentives to pool.

In the proof of (7) we showed that for $p^2 > C(a^2)$ firm 1 can capture the entire market by setting $p^1 = p^2 - \varepsilon$. Plugging this into (12) and evaluating at $\varepsilon \to 0$, the condition becomes:

$$(1 - \hat{\theta})[p^1 - C(a^1)] \geq \left[p^2 - C(a^1)\right].$$

This is obviously a contradiction since $(1 - \hat{\theta}) < 1$. For $p^2 = C(a^2)$, condition (3) implies that firm 1 reveals its type iff

$$0 \geq \frac{1}{2}\left[C(a^2) - C(a^1)\right].$$

This is a contradiction. Hence, no separating equilibrium exists. ■

Proof of Proposition 2. The proof follows the same lines of reasoning as the proof of Proposition 1. Consider an equilibrium candidate $(\tilde{p}^1, \tilde{p}^2) : \tilde{p}^1 = \tilde{p}^2 > C(a^2)$. By Bertrand-argument we infer that each firm can destabilize the equilibrium by setting its price marginally lower than that of the rival: e.g. $p^1 = \tilde{p}^2 - \varepsilon$ and capture the entire market.

Price-cutting is (weakly) beneficial for both firms insofar as the strategy profiles satisfy $\tilde{p}^2 - \varepsilon = C(a^2)$. Letting $\varepsilon \to 0$, the equilibrium price-pair thus becomes $(\tilde{p}^1, \tilde{p}^2) = [C(a^2), C(a^2)]$ with payoffs $\pi^1(a^1, a^2) = (M/2)\,[C(a^2) - C(a^1)] > 0$ and $\pi^2(a^1, a^2) = (M/2)\,[C(a^2) - C(a^2)] = 0$.

This equilibrium is strategically stable for the following reasons: (**a**) Since the firm with lower price captures the entire market, neither firm can increase its payoff by upward price-deviation. (**b**) Price-cutting implies negative profit for firm 2. In terms of price-cost margin per unit of output, firm 1 would make positive profit by cutting its price. However, since firm 1's conjectures that the rival will keep its price fixed $p^2 = C(a^2)$, it also infers that when beliefs are updated according to the observed signal $p^1 < C(a^2)$, each consumer would buy the good with quality a^2 implying zero demand. ■

Appendix B

Proof of Lemma 5. The first part states that (**a**) all domestic firms produce with quality a_d and (**b**) the foreign firm is active in the export market.

(**a**) Lemma 4 readily shows that export market exhibits pooling and the cost advantage for domestic firms is $C(a_f) - C(a_d)$ per unit of output. For the domestic entrants this implies positive payoff from entry. Hence, each entrant enters with quality a_d. Condition (3) and a standard Bertrand argument ensures that domestic market with multiple firms with quality a_d induces marginal cost pricing in the labeled sub-market and thus zero demand for the unlabeled variety. Thus, all domestic firms choose quality a_d.

(**b**) Follows immediately from that foreign country has positive mark-up in the local market which provides an incentive to participate the labeling program.

The second part argues that under identical labeling requirements, domestic market equilibrium coincides with the full information outcome with qualities a_d and $\underline{a}$. Bertrand argument ensures that market outcome in the export market involves marginal-cost pricing, and consequently, zero profit for all labeled firms. Thus, Lemma 4 ensures that entry yields negative profit in both in domestic and in the export market, indicating that the market in the producing countries involves only 2 firms producing qualities $\underline{a}$ and a_d. ■

References

Akerlof, G.: 1970, The market for lemons, *Quarterly Journal of Economics* **LXXXIV**, 488–500.

Albano, G. L. and Lizzeri, A.: 2001, Strategic certification and provision of quality, *International Economic Review* **42**(1), 267–283.

Anderson, S. P., Palma, A. D. and Thisse, J. F.: 1992, *Discrete Choice Theory of Product Differentiation*, MIT Press, Cambridge, MA.

Arora, S. and Gangopadhyay, S.: 1995, Toward a theoretical model of voluntary over-compliance, *Journal of Economic Behavior and Organization* **28**.

Auriol, E. and Schilizzi, S. G.: 2003, Quality signaling through certification. theory and an application to agricultural seed market, *IDEI Working Paper 2003* .

Bagwell, K. and Ramey, G.: 1991, Oligopoly limit pricing, *Rand Journal of Economics* **22**(2), 155–172.

Bansal, S. and Gangopadhyay, S.: 2003, Tax/subsidy policies in the presence of environmentally aware consumers, *Journal of Environmental Economics and Management* **45**(2), 333–355.

Bester, H.: 1998, Quality uncertainty mitigates product differentiation, *RAND Journal of Economics* **29**(4), 828–844.

Cason, T. N. and Gangadharan, L.: 2002, Environmental labeling and incomplete consumer information in laboratory markets, *Journal of Environmental Economics and Management* **43**(1), 113–134.

Cho, I.-K. and Kreps, D. M.: 1987, Signaling games and stable equilibria, *Quarterly Journal of Economics* **102**(2), 179–221.

Crampes, C. and Hollander, A.: 1995, Duopoly and quality standards, *European Economic Review* **39**(1), 71–82.

Cremer, H. and Thisse, J.-F.: 1999, On the taxation of polluting products in a differentiated industry, *European Economic Review* **43**(3), 575–594.

Fluet, C. and Garella, P. G.: 2002, Advertising and prices as signals of quality in a regime of price rivalry, *International Journal of Industrial Organization* **20**(7), 907–930.

Gabszewicz, J. J. and Turrini, A.: 2000, WorkersŠ skills, product quality and industry equilibrium, *International Journal of Industrial Organization* **18**, 575–593.

Greenpeace and The Finnish Nature League: 2001, Anything goes? Available at: http://www.pefcwatch.org/anything.html.

Hertzendorf, M. N. and Overgaard, P. B.: 2000, Will the high-quality producer please stand up? - a model of duopoly signaling, *Mimeo* .

Hertzendorf, M. N. and Overgaard, P. B.: 2001, Price competition and advertising signals - signaling by competing senders, *Journal of Economics and Management Strategy* **10**, 621–662.

Jansen, M. and Lincé de Faria, A.: 2002, Product labeling, quality and international trade, *CEPR Discussion Paper* (3552).

Kirchhoff, S.: 2000, Green business and blue angels, *Environmental and Resource Economics* **15**, 403–420.

Leland, H. E.: 1979, Quacks, lemons and licensing: A model of minimum quality standards, *Journal of Political Economy* **87**(61), 1328–1346.

Lizzeri, A.: 1999, Information revelation and certification intermediaries, *Rand Journal of Economics* **30**(2).

Mailath, G. J., Okuno-Fujiwara, M. and Postlewaite, A.: 1993, Belief-based refinements in signalling games, *Journal of Economic Theory* **100**(6), 241–76.

Milgrom, P. and Roberts, J.: 1986, Price and advertising signals of product quality, *Journal of Political Economy* **94**(4), 796–821.

Moeltner, K. and Van Kooten, G. C.: 2003, Voluntary environmental action and export destinations: The case of fores certification, *Journal of Agricultural and Resource Economics* **28**(2), 302–315.

Mussa, M. and Rosen, S.: 1978, Monopoly and product quality, *Journal of Economic Theory* **18**(2), 301–17.

Peitz, M.: 2002, The pro-competitive effect of higher entry costs, *International Journal of Industrial Organization* **20**, 353–364.

Shapiro, C.: 1982, Consumer information, product quality, and seller reputation, *The Bell Journal of Economics* **13**(1), 20–35.

Vossenaar, R.: 1997, Eco-labelling and international trade, *in* S. Zarilli, V. Jha and R. Vossenaar (eds), *Eco-Labelling and International Trade*, NY: Macmillan Press, New York.